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International Centre for Science and High Technology

GOVERNMENT OF THE GAMBIA
Department of State for Trade, Industry and Employment

FINAL REPORT

for

ICS Training Course

on

"Balance of System and PV Application Technologies"

21-24 May 2001
Banjul, The Gambia

Sponsored by:
ICS-UNIDO and The Gambia Government

Hosted by:
The Department of State for Trade, Industry and Employment

ACKNOWLEDGEMENTS

This report was prepared by the Energy Division of the Department of State for Trade, Industry and Employment (DOSTIE) of the Republic of The Gambia as part of the training course on "Balance of System and Solar PV Application Technology" hosted by DOSTIE in The Gambia from the 21 – 24 May 2001 at the Tafbel Masionettes.

The Department of State for Trade, Industry and Employment (DOSTIE) wishes to extend its thanks and appreciation to the United Nations Industrial Development Organisation (UNIDO) for providing the funds for the training course, and the International Centre for Science and High Technology (ICS) for selecting the Department of State for Trade, Industry and Employment (DOSTIE) to host this training course.

The Department of State also recognises the efforts of Mr. Anthony Bromley of UNIDO, Mr. Kenichi Ushiki of ICS, Mr. Umberto Moschella – ICS Consultant, Vivian Zaccaria - ICS Secretary, the Acting Director of Energy and all the staff of the Department of State for Trade, Industry and Employment towards the successful realization of the of the training course. Special thanks go to the Organising Committee on the training course at DOSTIE comprising Ms Amie Nyan – Principal Assistant Secretary, Mr. Lamin A M Njie – Acting Principal Energy Officer, Mr. Fansu Nyassi – Assistant Commissioner of Petroleum and Mr. Bah F M Saho – Acting Director of Energy.

Finally, the Department of State extends its appreciation to all the facilitators: Prof R I Salawu of the University of Lagos, Prof Guilliano Martinelli of the Universita di Ferrara, Italy, Prof Paolo Pinceti of the University of Genoa, Italy, and Dr. Mahmadou Lamin Toure of CRES, Mali, and all the participants who were able to honour the invitation of DOSTIE to attend this training course both within and outside the country.

ABOUT THE SUB-CONTRACTOR
(DEPARTMENT OF STATE FOR TRADE, INDUSTRY AND EMPLOYMENT)

The Department of State for Trade, Industry and Employment is the arm of government responsible for policy formulation, advice and implementation with regards to:

- Energy matters including petroleum and mineral resources
- Trade and consumer protection
- Industrial and investment promotion including small and medium enterprises
- Human resources and employment issues including labour matters.

MISSION STATEMENT

The Department of State for Trade, Industry and Employment accords top priority to evolving the appropriate economic, political and legal environment and to build a sound, reliable and sustainable infrastructure with a view to increasing the attractiveness of The Gambia as an investment destination by:

- Encouraging a liberalized system of trade characterized by fair competition with as little intervention from Government as possible;
- Ensuring the availability of affordable, reliable and efficient energy with little or no damage to the environment;
- Developing the human resource base needed by both the public and private sectors;
- Facilitate rapid socio-economic transformation and modernization through accelerated industrial development.

To achieve the stated overall objectives, the Department of State has the following mandates:

- Formulate and implement national trade policies to ensure the maintenance of liberalized trade policy regimes;
- Formulate and implement national industrial policies to facilitate the orderly socio-economic transaction and modernization process;
- Formulate and implement national energy policies to ensure the availability of reliable and efficient energy supply at affordable prices;
- Formulate and implement the national human resource and employment policies to ensure the building, strengthening and effective utilization of human capacities of the country for sustained development;
- Formulate and implement the national policies for the effective and efficient exploitation of the country's mineral resources for the diversification of the economy into processing and manufacturing enterprises consistent with the preservation of a sound and healthy environment;
- To generate and maintain a continually reviewed National Trade Promotion Strategies that succeeds through time in achieving positive commitments from The Gambia's targeted foreign investors;
- Provide general management services that ensure the effective functioning of the policies and for investment promotion.

The Department of State is headed by the Secretary of State, assisted by the Permanent Secretary, two (2) Deputy Permanent Secretaries, heads of Divisions/Units and support staff.

The Department of State is organised into five divisions as follows:

(i) Energy Division

The overall objective of the Energy Division is the formulation and implementation of policies and programs in the energy sector for provision of a reliable, affordable and efficient energy services to the population. The energy resource-base of the country is limited. The Gambia relies almost entirely on biomass fuels and imported petroleum products to meet her energy requirements. The main energy resources in the country comprise Fuelwood, Petroleum Products, Electricity, Liquefied Petroleum Gas (LPG), and Renewable Energy.

(ii) Trade Division

The main function of the Trade Division is the formulation, planning and management of trade policy. The Division is the arm of the Department of State responsible for trade and trade-related investments.

(iii) Industry and Investment Division

The Division is responsible for the formulation of industrial and investment policies to ensure that a conducive and challenging environment is in place for investment and the manufacturing sector in order to enhance its contribution to the economic growth and development.

(iv) Human Resources Development and Employment Division

The overall objective of the Human Resources Development and Employment Division is to develop policies, programmes and projects, analysis and evaluation in Human Resources Development (HRD), employment, social sector including health, and education, population, informal sector and medium and small enterprises (MSE), labour, and private sector capacity building.

(v) Petroleum Exploration and Production Division

The main objective of this Division is the administration of the Petroleum Act and Regulations in accordance with the provision of the Act. The Division is responsible for the development and formulation of policies and strategies for the exploration and production of the country's petroleum resources and the promotion of The Gambia's hydrocarbon acreage.

In addition to these Divisions mentioned above, the following units, housed outside the Department of State's building, also fall under the purview of the Department of State:

Geological Unit
Standards and Consumer Protection Bureau
Labour Department
Indigenous Business Advisory Service, and
Gambia Renewable Energy Centre (GREC).

ICS/UNIDO GOVERNMENT TRAINING COURSE ON 'BALANCE OF SYSTEM AND PV APPLICATION TECHNOLOGIES' BANJUL 21 – 24 MAY 2001

INTRODUCTION

The International Centre for Science and High Technology (ICS)/UNIDO in collaboration with the Government of The Gambia conducted a training course on 'Balance of System and Solar PV Application Technologies' hosted by the Department of State for Trade, Industry and Employment at the Tafbel Masionettes, The Gambia 21 – 24 May 2001.

The training drew lecturers and participants from ICS, UNIDO, The Gambia, Italy, Senegal, Guinea Bissau, Guinea Conakry, Mali, Sierra Leone, Ghana, Benin, Niger and Nigeria. Overall, 4 international Lecturers from Italy (2), Mali (1) and Nigeria (1), 2 Gambia lecturers and representatives of UNIDO, ICS and ICS Consultant attended. 11 international participants were drawn from the ECOWAS member countries mentioned above and 11 Gambian participants also attended.

The training course took the form of lectures, discussions, and country presentations on the solar/renewable energy situation in their respective countries. In addition to the lectures, there was a solar energy show organised by the Department of State for Trade, Industry and Employment at the Gambia Renewable Energy Centre (GREC) on Thursday 24th May 2001 and a field trip organised on Thursday afternoon, 24th May 2001, to visit a solar water pumping station at Tanji, near the beach.

ABSTRACT

The following lectures/presentations were made during the training workshop:

- 'Solar Radiation and Energy' was presented by Mr. Bah F M Saho. This paper presented the basic concept on solar radiation, the earth's energy budget, geometry and components of radiation, the effect on the earth's atmosphere, and the measurement and estimation of solar radiation.
- 'PV Cell, modules and array' and 'Grid connected, stand alone and hybrid systems' were presented by Dr. Mahmadou Lamin Toure.
- Prof. Giuliano Martinelli presented lectures on 'PV modules: Description of the main technological processes', 'How to perform an easy characterization of cells and modules', 'Examples of sizing PV systems' and 'advanced cells and hybrid-themic systems'.
- 'Power needs in an African family/community' and 'PV design and application' were presented by Prof. R. I. Salawu.
- Mr. Lamin A. M. Njie presented a paper on the 'Energy situation in The Gambia and solar PV application'. The presentation covered various forms of energy consumed in The Gambia, the country's energy balance and the utilization of Solar energy.
- Prof. Paolo Pinceti delivered lectures on 'PV integration in small utility grid – general aspects, applications and integrations by PV and batteries' and 'Experimental results of a test site'.

Finally, Mr. Anthony Bromley of UNIDO gave a presentation on 'the proposed solar activity project in The Gambia'.

In addition to the lectures, there were also country presentations on the energy/solar energy utilization in the respective countries of the participants. These include:

- Utilization of Solar Energy in Ghana
- Renewable Energy Situation in Sierra Leone
- Senegalese Experience on Solar Rural Electrification
- The Energy Sector in Senegal (Time was not available to present)
- Country report on renewable Energy Situation in Niger
- Renewable Energy in the Decentralised Rural Electrification Programmes in Guinea
- The Use of PV-Based Systems in Guinea Bissau
- Solar Energy for Remote Areas in Benin and
- Experience of Mali in the Field of Solar Photovoltaic

In addition to the presentations, documents were forwarded by John Ngundam of Cameroun and Nelson Obyo Obyo of Nigeria, both of whom could not attend the training workshop due to non-receiving of their tickets. Their presentations were:

- PV Power System Applications by John Ngundam and
- Strategic Developments in The Nigerian Energy Sector

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International Centre for Science and High Technology

GOVERNMENT OF THE GAMBIA
Department of State for Trade, Industry and Employment

Training Course
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Programme

Monday, 21 May 2001

08.00 – 09.00	Registration
09.00 – 11.00	Opening Ceremony – Chaired by Acting Director of Energy, DOSTIE Statement by Mr. Kenichi Ushiki, Area Director of ICS High Technology and New Materials Statement by Mr. Umberto Moschella, Consultant for ICS Photovoltaic Solar Energy Subprogramme Statement by Mr. Musa H Sillah, the Honourable Secretary of State for Trade, Industry and Employment
11.00 – 11.30	Coffee Break
11.30 – 12.00	Self Presentations by Participants
12.00 – 13.00	'Solar energy and radiation' by Mr. Bah F M Saho, The Gambia
13.00 – 14.00	Lunch
14.00 – 14.45	'PV cells, modules and array' by Mr. Mahmadou Lamin Toure, Mali
14.45 – 15.30	'PV modules: Description of the main technological processes' by Mr. Giuliano Martinelli, Italy
15.30 – 15.45	Coffee Break
15.45 – 16.45	'How to perform an easy characterization of cells and modules' by Mr. Giuliano Martinelli, Italy
16.45 – 17.35	'Examples of sizing PV systems' by Mr. Giuliano Martinelli, Italy
17.40 – 18.10	Utilization of Solar Energy in Ghana by Benjamin Agyare and Mahama Kappiah
18.10 – 18.25	Renewable Energy Situation in Sierra Leone by Dr. David L B Kamara

Tuesday, 22 May 2001

09.00 – 09.30	'Advanced cells and hybrid PV-thermic systems' by Mr. Giuliano Martinelli, Italy
09.30 – 10.30	'Power need in an African family/community' by Mr. R.I. Salawu, Nigeria
10.30 – 11.00	Coffee Break
11.00 – 12.00	'Grid connected, stand alone, hybrid systems' by Mr. Mahmadou Lamin Toure, Mali
12.00 – 13.00	Senegalese Experience on Solar Rural Electrification by Ibrahima Dabo and Mamadou Kanoute
13.00 – 14.00	Lunch
14.00 – 16.00	'PV integration in small utility grids – general aspects, applications and integrations by PV and batteries' by Mr. Paolo Pinceti, Italy
16.00 – 16.15	Coffee Break
16.15 – 17.00	'Experimental results of a test site' by Mr. Paolo Pinceti, Italy
17.00 – 17.25	Experience of Mali in the Field of Solar Photovoltaic by Alhouseini Issa Maiga
17.25 – 17.45	Country Report on renewable Energy Situation in Niger by Nassourou Bello

Wednesday, 23 May 2001

09.00 – 10.30	'PV design and application' by Mr. R.I. Salawu, Nigeria
10.30 – 11.00	Coffee Break
11.00 – 12.45	'Energy situation in the Gambia and solar PV application' by Mr. Lamin A.M. Njie, The Gambia
12.45 – 14.00	Lunch
14.00 – 15.30	'The proposed solar activity project in the Gambia' by Mr. Anthony Bromley, Austria
15.30 – 16.00	Renewable Energy in the Decentralised Rural Electricity Programmes in Guinea by Alkhaly Mohammed Tahey Conde
16.00 – 16.30	Coffee Break
16.30 – 17.00	The Use of PV-Based Systems in Guinea-Bissau by Raimundo Lopes Joao
17.00 – 17.35	Solar Energy for Remote Areas in Benin by Daniel Assogba

Thursday, 24 May 2001

09.00	Depart the hotel for the Gambia Renewable Energy Centre (GREC)
09.30 – 11.30	Opening of the 'Solar Energy Show'
11.30 – 12.30	Return trip to the Tafbel Masionettes
13.00 – 14.15	Lunch
14.15 – 15.30	Conclusion by Mr. Umberto Moschella
15.30 – 17.00	Visit to Solar PV Water Pumping Installation at Tanji

NOTES:

1. Each item includes time for discussions.
2. The questionnaires were compiled during the conclusion remarks by Mr. Moschella.

OPENING SESSION

OPENING STATEMENT BY THE HONOURABLE SECRETARY OF STATE FOR TRADE, INDUSTRY AND EMPLOYMENT AT THE ICS/UNIDO & GAMBIA GOVERNMENT TRAINING WORKSHOP ON BALANCE OF SYSTEM AND SOLAR PV APPLICATION TECHNOLOGY

Mr. Chairman,
Distinguished Resource Persons from UNIDO and ICS,
ICS Consultant,
Distinguished Facilitators and Participants,

It gives me great pleasure to welcome you all to The Gambia and to this very important training workshop, the first of its kind to be held in The Gambia. For those of you visiting The Gambia for the first time, I urge you to take some time off your busy schedule to explore some of the attractions that The Gambia offers.

On behalf of the Government and people of The Gambia, I wish to express our appreciation to the United Nations Industrial Development Organisation (UNIDO) for organising this very important training course for participants from Africa and in particular, for holding it in The Gambia. I also wish to take this opportunity to thank the International Centre for Science and High Technology (ICS) for choosing my Department of State to host this training course. I am aware of the series of correspondence between ICS, UNIDO and my Department of State to ensure the success of this training workshop. I wish to recognise the noble efforts of Mr. Anthony Bromley of UNIDO, Mr. Ushika of ICS and Mr. Moschella - ICS consultant.

The workshop is very timely, coming at a time when the demand for alternative sources of energy such as solar, wind and biomas is on the increase globally. However, Africa, which has an abundance of these types of energy, make minimum use of it. The continuing lack of access to sustainable energy sources in many countries is causing serious, often life-threatening, economic, social and ecological problems. Therefore, the need for greater sensitization and training cannot be over-emphasised.

Mr. Chairman, The Gambia like many African countries depends entirely on imported petroleum products for its modern energy requirements for electricity generation and transportation. This heavy dependence on hydrocarbons is resulting in serious balance of payments problem, and constitutes a drain on our limited foreign exchange earnings and a threat to security of supply and the environment.

This situation is undoubtedly not sustainable. Rapid population growth and uneven and faster growing demand for resources, coupled with the threat of limited resources and the growing awareness of the negative impact of their use, require us to plan and rethink our energy economic system.

Cognizant of these problems, the Government of The Gambia has shifted its policy to diversify its energy resource base by putting emphasis on alternative and sustainable forms of energy such as the sun, the wind and other renewables like biomas. This shift in government policy is manifested in:

1. the establishment of the Gambia Renewable Energy Center (GREC)
2. the removal of customs duty on imported solar panels and
3. the encouragement of private sector participation in the renewable energy sector.

My Department of State will continue to support and develop appropriate policies in the solar energy sector for the improvement and expansion of this vital energy resource for socio-economic development. I am pleased to say that in The Gambia, solar PV technology have been applied in the areas of space lighting, powering of televisions and videos, water pumps, refrigeration, and telecommunication repeater station especially in the remote parts of the country.

Mr. Chairman, please allow me to throw some lights on the significance of this training course. We are all aware of the potentials of solar PV equipment in Africa and that Africa has a vast experience with excellent solar regimes. However, to make good use of these solar energy resources, the solar equipment must be available, the people sensitized and the equipment installed. Today many solar energy companies and institutions have been established on the African continent. However, for effective utilization of the equipment, proper installation of these solar devices has to be done otherwise it defeats the gains already made in the solar PV industry. The significance of this training workshop is to provide the required knowledge and skills to do that. It also provides a forum for the exchange of experiences in the use of solar PV technology. This is undoubtedly beneficial to our countries.

In The Gambia, while my Department of State is continuing to encourage the establishment of private solar energy companies for the provision of solar energy systems, we are mindful of the importance of standard practices and procedures for solar PV installation that needs to be observed by all private operators and their technicians. The good image of the solar PV industry can only be preserved where the technicians, engineers, lecturers and vendors have the required skills and competence to (1) advise properly, (2) size the systems accurately and (3) install the devices professionally. My department of state is hoping to come-up with a training package soon for training and certificating all technicians in the country so that they could provide the desired services to their customers.

In conclusion, Mr. Chairman, while Africa has vast experience in renewable energy technologies, Africa still suffers from acute lack of access to and comparatively high cost of solar PV technologies. I therefore challenge participants to this workshop to prepare a catalogue of solar PV technologies with application in Africa and to find innovative ways to finance renewable energy applications at the initial phase of their dissemination.

Finally, I take this opportunity to wish all of you a fruitful training session. To the participants, I admonish you to make maximum advantage of this opportunity provided to acquire the skills and to transfer the knowledge to others in your respective countries.

It is my pleasure to declare open this workshop on Balance of System and Solar PV Application technology.

I thank you for your kind attention.

May 21, 2001

SOLAR ENERGY AND RADIATION

By Bah F. M. Saho
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1. Introduction

The Sun has provided all the energy that we utilize known as SOLAR ENERGY. It drives the weather system by causing heating of the atmosphere leading to atmospheric pressure differences, wind, rain, waves, etc. All plants and trees absorb solar energy through photosynthesis while they are growing and it is that energy which is released when they are burned as fuels.

These fuels (coal, oil, and gas) were formed by plant matter decaying over millions of years, so in fact that energy originally came from the sun. That solar energy was collected over millions of years by plants and processed in the ground over millions of years. We are now using that stored fossil fuel energy very quickly.

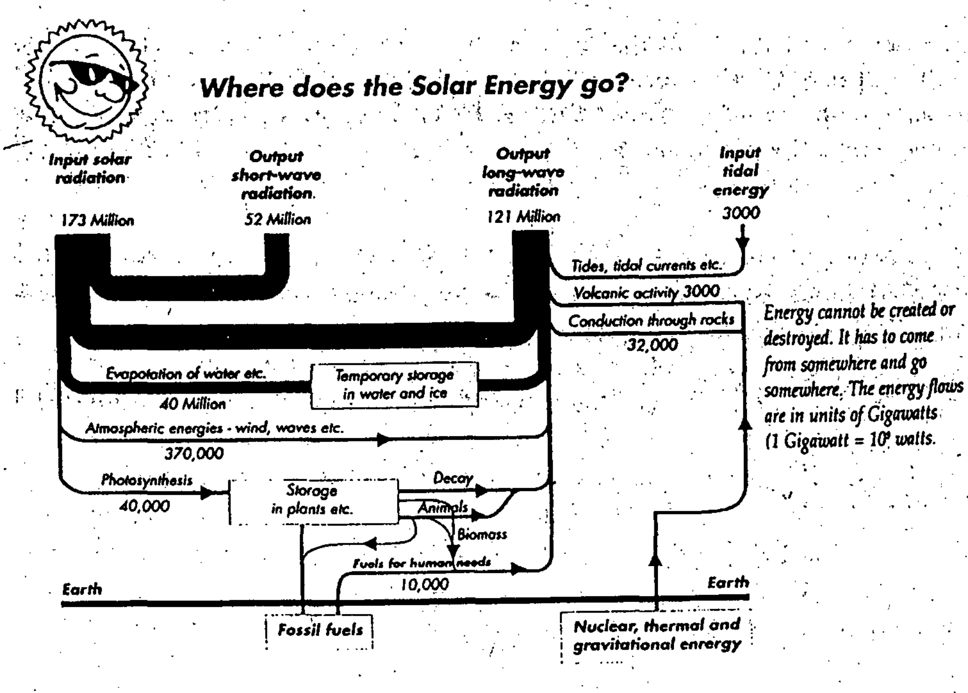


Figure 1 - Solar energy flow

2. The Earth's Energy Budget

The earth is in an energy equilibrium with respect to radiant energy received from the sun and its own emitted radiant energy. Both the earth and the sun can be regarded as full or black body. The Solar-surface-atmosphere energy flow as shown in figure 1 above, is a simplified version. As indicated in the figure, energy cannot be created or destroyed. It has to come from somewhere and go somewhere.

3. Solar Radiation

Solar radiation arrives on the earth at a minimum flux density of about 1KWm-2 in a wavelength band between 0.3 and 2.5 micrometers (μm). This is called short wave radiation and includes the visible spectrum. For habited areas, received fluxes vary widely from about 3 to 30 MJm–2day–1, depending on place, time and weather. The quality of the radiation is characterized by the photon energy of around 2 eV as determined by the 6000 K surface temperature of the sun. This is an energy flux of very high thermodynamic quality, from an accessible source at a temperature very much greater than those of conventional engineering sources. This flux can be used thermally with devices relating to conventional engineering (e.g. steam turbines), and more importantly with methods developed from photochemical and photophysical interactions.

Radiant energy fluxes relating to the earths atmospheric and surface temperature are also of the order of 1 KWm-2, but occur in a wavelength band between about 5 and 25 μm, called long wave radiation, peaking at about 10 μm.

The short and long wave radiation regions can be treated as quite distinct from each other. The proportion of solar radiation that reaches our device depends on geometric factors such as latitude and on atmospheric factors such as absorption by water vapor.

4. Extraterrestrial solar radiation

Nuclear fusion reactions in the active core of the sun produce inner temperatures of about 107K and an inner radiation flux of uneven spectral distribution. This internal radiation is absorbed in the outer passive layers which are heated to about 5800K and so become a source of radiation with a relatively continuous form of spectral distribution.

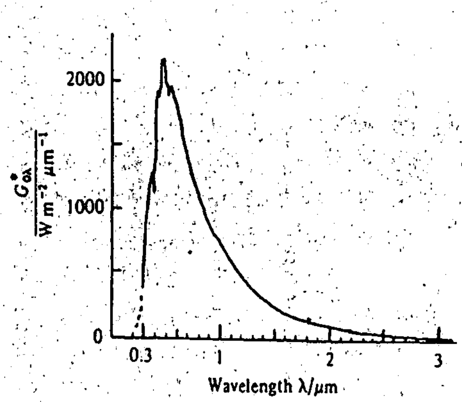


Figure 2 - Spectral distribution of extraterrestrial solar irradiance, G*o^ (NASA standard curve, NASA, 1971)

Figure 2 shows the spectral distribution of the solar irradiance at the earths mean distance, uninfluenced by any atmosphere. Note how his distribution is like that from a black body at 5800

K in shape, peak wavelength and total power emitted. The area beneath this curve is the solar constant G*o = 1367Wm–2. This is the radiant flux density (RFD) incident on a plane directly facing the suns rays, above the atmosphere at a distance of 1.496 x 10^6km from the sun (i.e. at the earths mean distance from the sun). The RFD actually received by the top of the atmosphere differs from the solar constant by less than ±1.5% because of fluctuation is the suns radiant output, and by ±4% through the year because of the predictable changes in the sun-earth distance arising from the earths slightly elliptic path.

The solar spectrum can be divided into three main regions:
(1) Ultraviolet region ($\lambda < 0.4$ µm): 9% of the irradiance
(2) Visible region (0.4 µm< λ <0.7µm): 45% of the irradiance
(3) Infrared region (λ >0.7µm): 46% of the irradiance

The contribution to the solar radiation flux from wavelengths greater than 2.5µm is negligible, and all three regions are classed as solar short wave radiation.

5. Components of radiation

Solar radiation incident on the atmosphere from the direction of the sun is the solar extraterrestrial beam radiation. Beneath the atmosphere at the earth's surface, the radiation will be observable from the direction of the suns disk in the direct beam, and also from other directions as diffuse radiation. Figure 3 is a sketch of how this happens.

The practical distinction between the two components is that only the beam component can be focused. Even on a clear day there is some diffuse radiation. The ratio between the beam irradiance and the total irradiance thus varies from about 0.9 on a clear day to zero on a completely overcast day.

It is important to distinguish the various components of solar radiation and to distinguish the plane on which the irradiance is being measured.

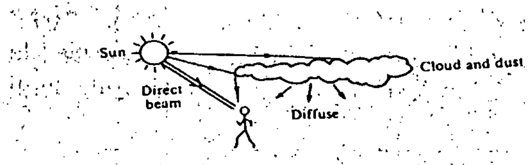


Fig.3 Origin of direct beam and diffuse radiation

6. Geometry of the earth and sun
6.1 Definitions

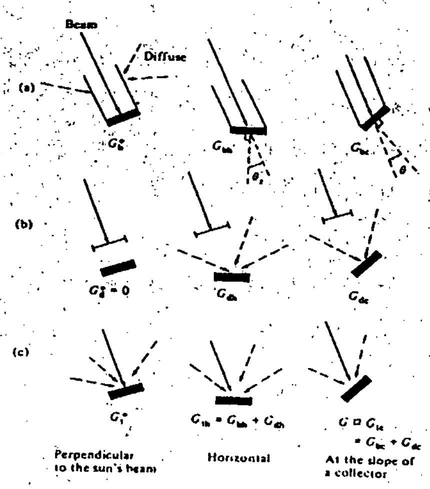


Fig. 4 (opposite) Techniques to measure various components of solar radiation. The detector is assumed to be a black surface of unit area with a filter to exclude long wave radiation.
(a) Diffuse blocked.
(b) (b) Beam blocked. (c) Total

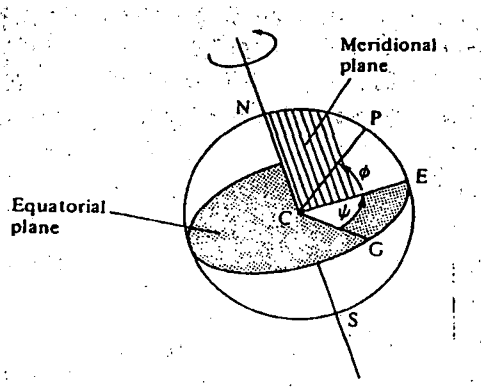


Figure 5 - Definition sketch for latitude Φ and longitude ψ (see text for detail).

Figure 5 shows the earth. It rotates in 24 hours about it own axis, which defines the points of the north and south poles N and S. The axis of the poles normal to the earth's equatorial plan. In figure 5, C is the center of the earth. The point p on the earth's surface is determined by its latitude Φ and longitude ψ. Φ is positive for points north of the equator, negative south of the equator. ψ is measured positive eastwards from Greenwich, England. The vertical north-south plane through P is the local meridional plane. E and G in figure 5 are the points on the equator having the same longitude as P and Greenwich, respectively.

Once every 24 hours the meriodional plane CEP includes the sun. This is noon on solar time for all points having that longitude. Clocks do not necessarily read 12.00 at solar noon, mainly because civil time, on which they are set, is defined so that large parts of a country, covering up to 15° of longitude, share the same civil time, i.e. those places are all in the same time Zone. Resetting the clocks for 'summer time' means that solar time and civil time may differ by over one hour. Moreover, the ellipticity of the earth's orbit around the sun means that it is not exactly 24 hours between successive solar noons, although the average interval is 24.000 hours.

The earth revolves around the sun once per year. The direction of the earth's axis remains fixed in space, at an angle $\delta = 23.5°$ away from the normal to the plane of revolution (figure 6). The angle between the sun's direction and the equatorial plan is called the declination δ, and provides a convenient measure of seasonal changes.

6. Latitude, season and daily insolation

The daily insolation H is the total energy per unit area received in one day from the sun.

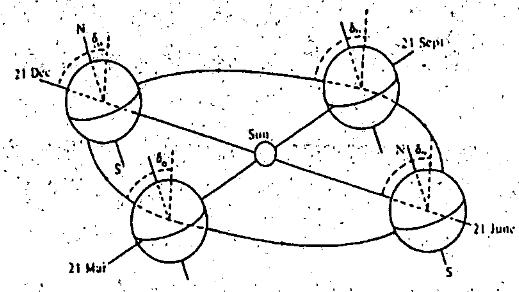


Fig. 6 The earth revolving around the sun, as viewed from a point obliquely above the orbit (not to scale!). The heavy line one the earth is the equator

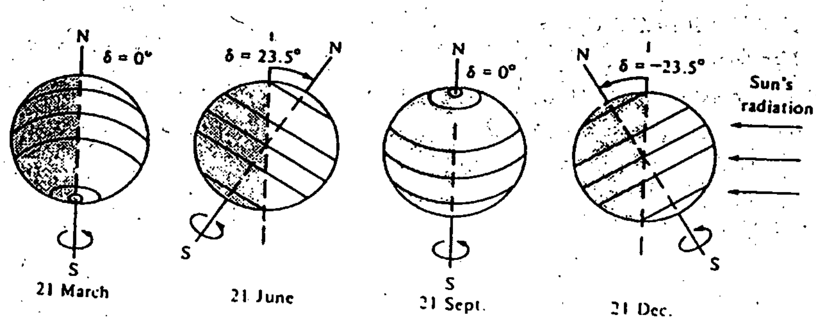


Figure 7 - The earth, as seen from a point further along its or orbit, at various times of the year. Circles of latitude 0°, ±23.5°, ±66.5° are shown. Note how the declination δ varies. (After Dickinson and Cheremisinoff, 1982)

Figure. 7 illustrates how the daily insolation varies with latitude and season. The seasonal variation at high latitudes is very great. The quantity arises from three main factors:

Variation in the length of the day shows that the number of hours between sunrise and sunset is:

N = (2/15) Cos–1(-tan Φ tan δ)

At latitude 48°, for example, N varies from 16h in midsummer to 8h in midwinter.

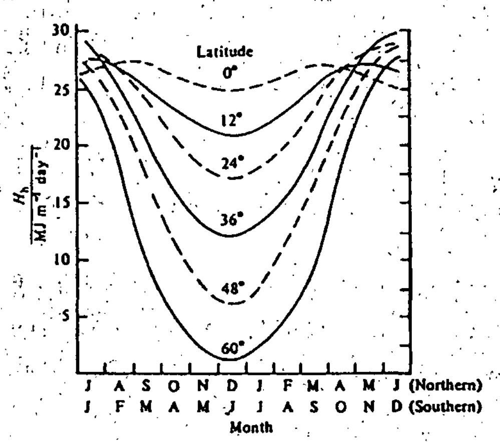


Figure 8 - Variation with season and latitude of Hh, the solar energy received on a horizontal plane on a clear day. In summer, Hh is about 25MJm–2day–1 at all latitudes. In winter, Hh is much less at high latitudes because of shorter day length, more oblique incidence and greater atmospheric attenuation.

(2) Orientation of receiving surface.

(3) Variation in atmospheric absorption. The clear sky radiation plotted in figure 8 is less than the extraterrestrial radiation because of atmospheric attention. This attenuation increases with θz, so that G*b is lower in winter, effects (1) and (2).

Although the clear sky radiation is a rather notional quantity, and actual weather conditions vary widely from those assumed in its calculation, figure 8 still gives a useful guide to the average isolation as a function of latitude and season.

7. Optimum orientation of a solar collector

A concentrating collector should always point towards the direction of the solar beam ($\theta = 0$). The optimum direction of a fixed flat plate collector is perhaps not obvious, however. The insolation Hc received is the sum of the beam and diffuse components.

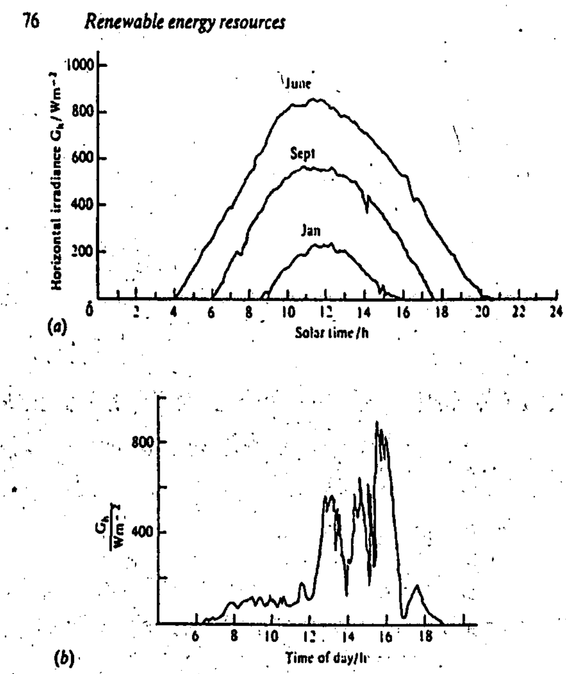


Figure 9
(a) Irradiance on a horizontal surface, measured on three different almost clear days at Rothamsted (52°N, 0°W). Note how both the maximum value of Gh and the length of the day are much less in winter than summer. After Monteith (1973).
(b) Typical variation of irradiance an a horizontal surface for a day of variable cloud. Note the low values during the overcast morning, and the large irregular variation in the afternoon due to scattered cloud

8. Effects of the earth's atmosphere

(a) Air mass ration

The distance traveled by the direct beam through the atmosphere depended on the angle of incidence to the atmosphere (the zenith angle) and the height above sea level of the observer (figure 10). We consider a clear sky with no cloud, dust or air pollution. Since the top of the atmosphere is not well defined, of more importance than the distance traveled is the mass of atmospheric gases and vapors encountered. For the direct beam at normal incidence passing through the atmosphere at normal pressure, standard mass of atmosphere will be encountered. If the beam is at zenith angle θz, the increased path length compared with the normal path is called the air mass ratio (or air mass), symbol m. the abbreviation AM is used for air mass ratio. AM1 refers to zero atmosphere, i.e. radiation in outer apace; AM1 Refers to m= 1, ie. Sun overhead; AM2 refers to m= 2; and son on. From figure 10, since no account is usually taken of the curvature of the earth, $M = \mathrm{Sec}\theta z$

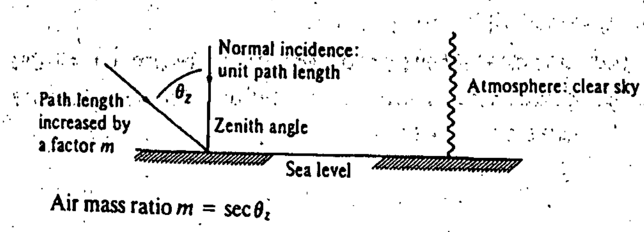


Figure 10 - Air mass ratio m = Secθz

(b) Atmospheric absorption and related processes

As the solar short wave radiation passes through the earth's atmosphere a complicated set of interactions occurs. The interactions include absorption, the conversion of radiant energy to heat and the subsequent re-emission as long wave radiation; scattering, the wavelength dependent change in direction so that usually no extra absorption occurs and the radiation continues at the same frequency; and reflection, which is independent of wavelength. These processes are outlined in figure 11.

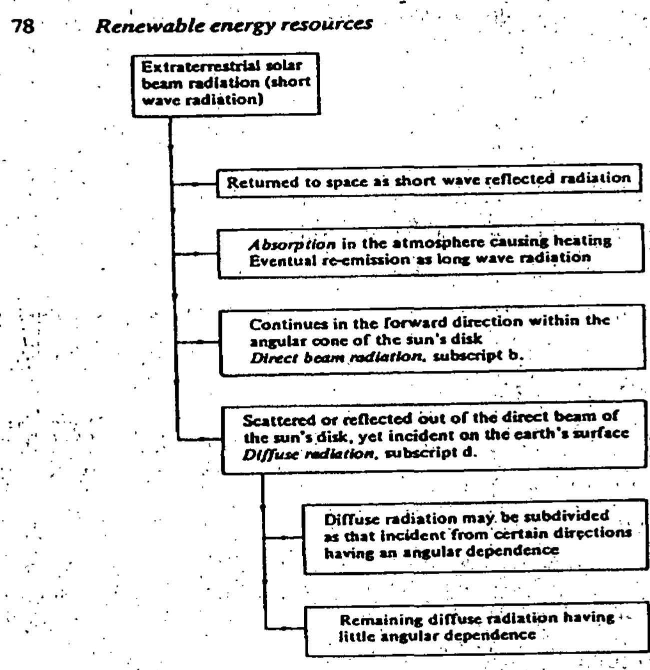


Figure 11 - Effect occurring as extraterrestrial solar radiation is incident upon the atmosphere.

The effects and interaction that occur may be summarized as follows:

Reflection
On average about 30% of the extraterrestrial solar intensity is reflected back into space. Most of the reflection occurs from clouds, with a small proportion from the earth's surface (especially snow and ice). The continuing short wave solar radiation has flux density approximately 1Kwm-2. This reflection is called the albedo.

Greenhouse effect and long wave radiation
In space, the long wave radiation from the earth has approximately the spectral distribution of a black body at 250K. The peak spectral distribution at this temperature occurs at 10pm, and the distribution does not overlap with the solar distribution.

A definite distinction can be made between the spectral distribution of the sun's radiation (short wave) and that from the thermal sources of the earth's atmosphere (long wave). The infrared long wave fluxes at the earth's surface are themselves complex and large. The atmosphere radiates down to this surface as well as up and out into space. When measuring radiation or when determining the energy balance of an area of ground or a device, it is extremely important to be aware of the invisible infrared fluxes in the environment which often reach intensities of 1KWm-2

The effective black body temperature of the earth's system is equivalent to that of the outer atmosphere and not of the earth's surface. The earth's average surface temperature of about 14°C is about 40°C above the temperature of the outer atmosphere which acts as an infrared "blanket". This increase in temperature is called the greenhouse effect, since the glass of a horticultural glasshouse (a greenhouse) likewise prevents the transmission of infrared radiation from inside to out, but does allow the short wave solar radiation to be transmitted.

(c) Absorption in the atmosphere

The solar short wave and the atmospheric long wave spectral distribution may be divided into regions to explain the important absorption processes.

9. Measurements of solar radiation

Instruments

The instruments are mostly variations on two basic types: a pyroheliometer, which measures the beam irradiance G*b, and a pyranometer or solarimeter, which measures total irradiance Gtc.

Only the active radiometer (ACR) gives an absolute reading. In this intrument, the solar beam falls on an absorbing surface of area A, whose temperature rise is measured and compared with the temperature rise in an identical (shaded) absorber heated electrically.

10. Estimation of solar radiation

(a) Need for estimation

Before installing a collector of solar energy, it is necessary to determine how much solar energy there will be to collect. Knowing this, and the projected pattern of energy usage from the device, it is possible to calculate the size of the collector.

Ideally, the data required would be several years of measurements of irradiance on the proposed collector plane. This is very rarely available, so the required (statistical) measures have to be estimated from meteorological data available (1) at the site or (2) (more likely) at some "nearby site, which appears to have similar irradiance.

(b) Statistical variation

In addition to the regular variations, there are also substantial irregular variations. Of these the most significant for engineering purposes are perhaps the day-to-day fluctuations (e.g figure 8(a) as they affect the amount of energy storage that a solar energy system will require.

Thus even a complete record of past irradiance can be used to predict future irradiance only in a statistical sense. Therefore design methods usually rely on approximate averages, such as monthly means of daily insolation. To estimate these cruder data from other measurements is easier than to predict the whole pattern of irradiance.

(c) Sunshine hours as a measure of insolation

All major meteorological stations measure daily the hours of bright sunshine, n. Records of this quantity are available for several decades. It is usually measured by a Campbell-Stokes recorder, which comprises a specially marked card placed behind a magnifying glass. When the sun is 'bright' a hole is burnt in the card. The observer measures n from the total burnt length on each day's card.

Many attempts have been made to correlate insolation with sunshine hours. Moreover, the correlation coefficient is usually only about 0.7, i.e. the data are widely scattered from those predicted from the equation.

Sunshine hour data give a useful guide to the variations in irradiance. For example, it is safe to say that a day with $n<1$ will contribute no appreciable energy to any solar energy system. The requirement for energy storage can therefore be assessed from the daily data. The records can also be used to assess whether, for instance, mornings are statistically sunnier than afternoons at the site.

Many other climatological correlations with insolation have been proposed, using such variables as latitude, ambient temperature, humidity and cloud cover. Most have a limited accuracy and range of applicability.

(d) Proportion of beam radiation

As noted in Section 5, the proportion of incoming radiation that is focusable (beam component) depends on the cloudiness and dustiness of the atmosphere.

These factors can be measured by the clearness index KT, which is the ratio of radiation received on a horizontal surface in a period (usually one day) to the radiation that would have been received on a parallel extraterrestrial surface in the same period.

The clearest days have air mass ratio $m = 1$ and therefore $KT = 0.8$. For these days the diffuse fraction is about 0.2; it rises to 1.0 on completely overcast days ($KT = 0$). On a sunny day with significant aerosol or with a little cloud, the diffuse fraction can be as high as 0.5.

(e) Effect of inclination

If all solar radiation came in the solar beam, it would be straightforward to convert irradiances measured on one plane to those on another plane. This is particularly important for transforming data from the horizontal plane.

PHOTOVOLTAIC EFFECT

If we illuminate the p-n junction, a volume generation of electron-hole pairs is formed.

To obtain a current it is necessary to separate the two different kind of carriers. This can be done by means of the inner field $\in$.

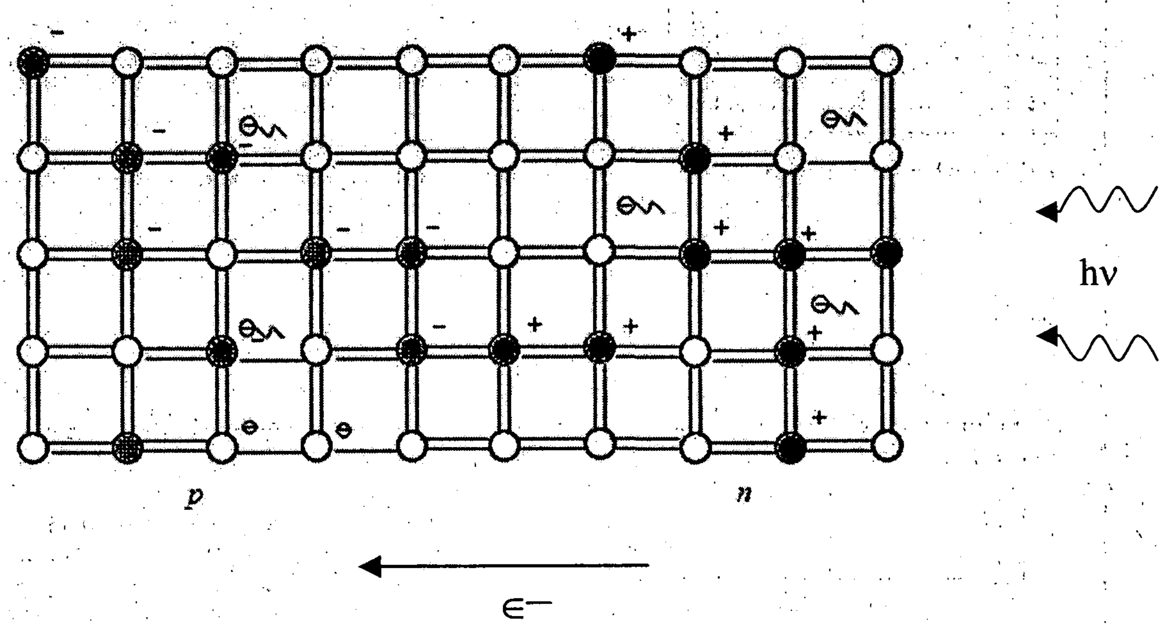


Figure 1 - The photons give rise to electron-hole pairs.

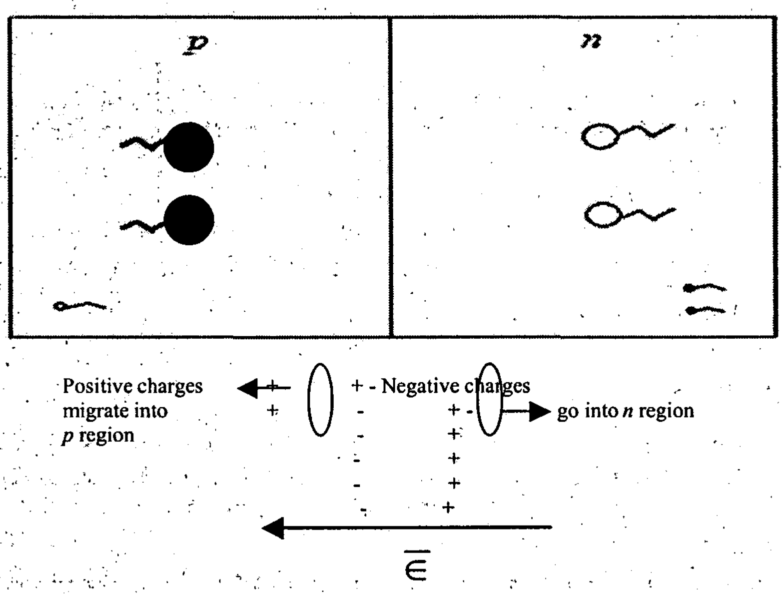
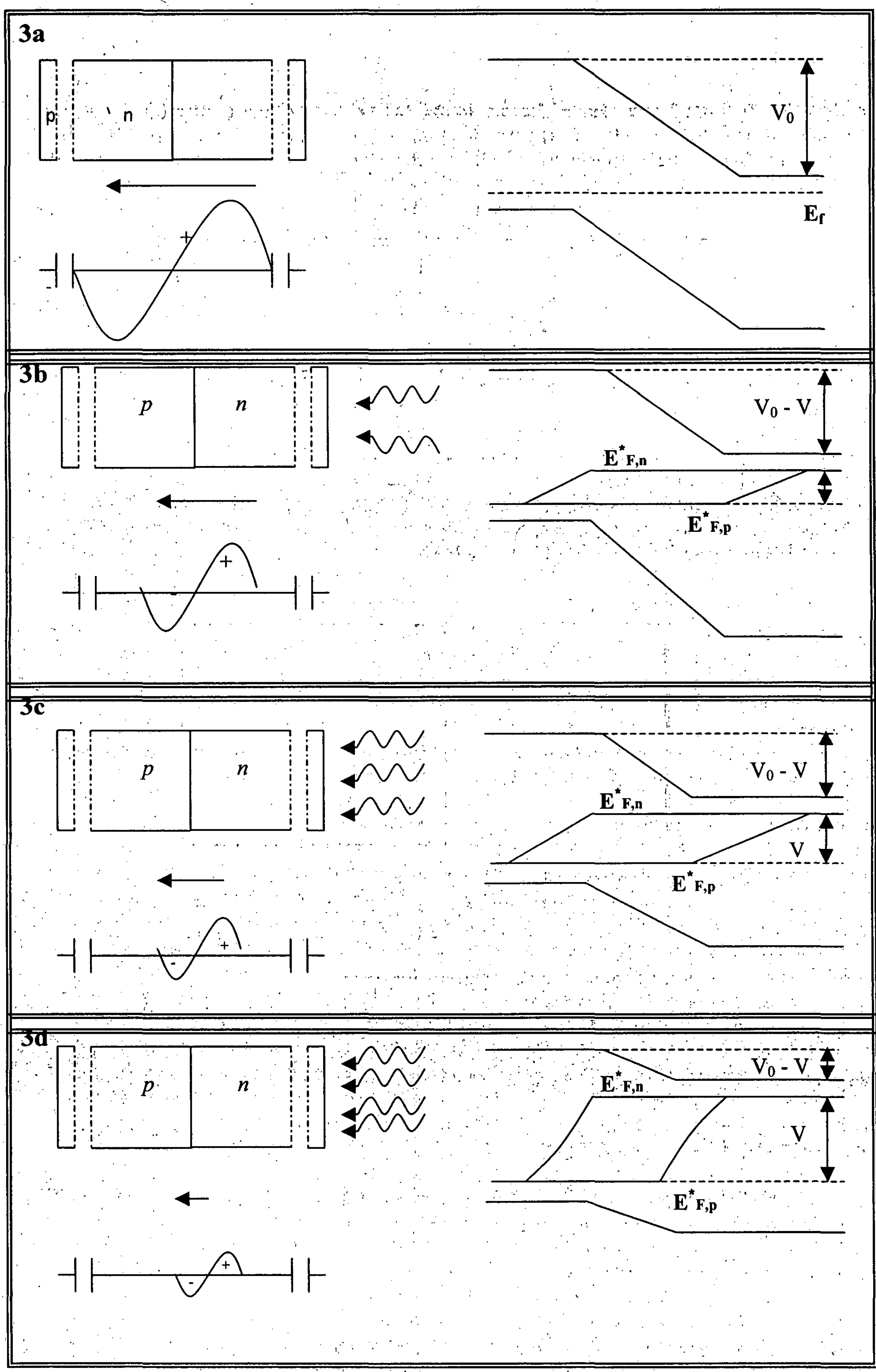


Figure 2

Therefore the equilibrium voltage V0 becomes V0 – V; V is called photovoltage.

The situation is similar to the direct bias one, but, under illumination, the charge density decrease is due to the minority carriers formed.



3a
p
n
+
V0
Ef
3b
p
n
+
V0 - V
E*F,n
E*F,p
3c
p
n
-
+
V0 - V
E*F,n
V
E*F,p
3d
p
n
-
+
V0 - V
E*F,n
V
E*F,p

The quasi Fermi levels E*F,n and E*F,p are introduced to describe the carrier density under illumination (figures 3b, 3c, 3d represent the effect of increasing illumination), that is off of the thermal equilibrium (figure 3a; the Fermi level is defined under thermal equilibrium).

To make clear this concept we can examine the reverse bias.

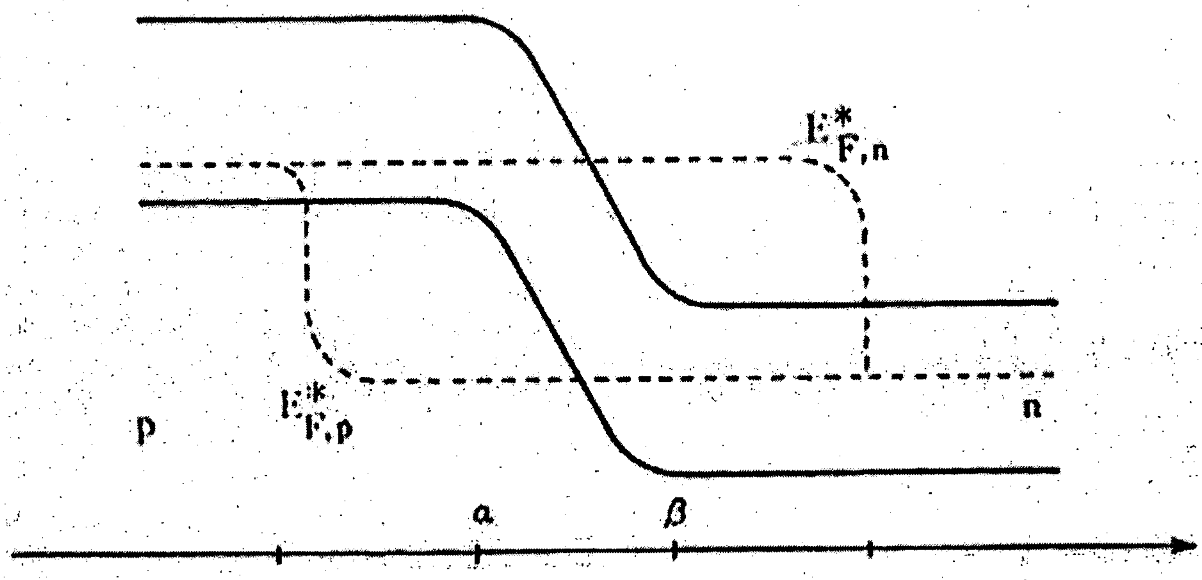


Figure 4

The flux of minority electrons from the p to n region causes a reduction of their density, described by E*F,p and the reduction of holes into n region causes a raising of the Fermi level until E*F,n.

The majority carriers density (that is larger) is not modified by this flux.

When there is a recombination process, it is possible to define a lifetime and a diffusion length L:

$$L = \sqrt{D\tau}$$

For solar cells, we are interested into minority carriers lifetime:

$$\tau_n = \frac{\Delta n}{U}$$

$$\tau_p = \frac{\Delta p}{U}$$

where U is the net recombination rate and Δn and Δp are variations as regards the equilibrium the equilibrium values n0 and p0.

By considering Δn instead of the direct bias V', we obtain:

$$n_{p\alpha} = n_{p0} e^{\frac{|e|V}{kT}}$$

$$p_{p\beta} = p_{n0} e^{\frac{|e|V}{kT}}$$

If Δnpα = npα - np0 represents the contribution of the minority carriers due to the illumination:

npα = Δnpα + np0

and

$$\Delta n_{p\alpha} + n_{p0} = n_{p0} e^{\frac{|e|V}{kT}}$$

Therefore

$$V = \frac{kT}{|e|} \ln\left[\frac{\Delta n_{p\alpha} - n_{p0}}{n_{p0}}\right]$$

Similarly for the holes:

$$V = \frac{kT}{|e|} \ln\left[\frac{\Delta p_{n\beta} - p_{n0}}{p_{n0}}\right]$$

The continuity equations can be written:

(1.1)
$$\frac{1}{|e|}\frac{\partial I_n}{\partial x} = \frac{\Delta n}{\tau_n}$$ minoritary electrons

$$\frac{1}{|e|}\frac{\partial I_p}{\partial x} = \frac{\Delta p}{\tau_p}$$ minoritary holes

By integrating (1.1) between 0 and Ln, we have:

$$I_n(\alpha) = |e|\Delta n_{p\alpha} \cdot \frac{D_n}{L_n} - |e|GL_n$$

(Ln is referred to the electrons into p region).
Similarly for the holes:

$$I_p(\beta) = |e|\Delta p_{n\beta} \cdot \frac{D_p}{L_p} - |e|GL_p$$

Since the total current with illumination is

I = In (□) + Ip (□)

we have:

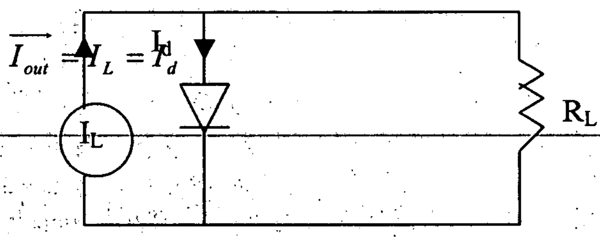
$$I = \left| -|e|G(L_p + L_n) + |e|\left(\frac{D_p p_{n0}}{L_p} + \frac{D_n n_{p0}}{L_n}\right)\left(e^{\frac{|e|V}{kT}} - 1\right)\right|$$

Therefore

$$I = \left| -|e|G(L_p + L_n) + |e|I_0\left(e^{\frac{|e|V}{kT}} - 1\right)\right|$$

The first term represents the illumination current:

$$I = \left| -|e|G(L_p + L_n)\right|$$



The second term is due to the polarization resulting from the illumination.
Therefore: I = Iout = | IL – Id |

From the equivalent circuit: Iout = IL – Id

$$I_{out} = I_L - I_0\left(e^{\frac{|e|V}{kT}} - 1\right)$$

If V = 0 ⇒ Isc = IL

If Iout = 0 ⇒ $V_{oc} = \frac{kT}{|e|}\ln\left(\frac{I_{sc}}{I_0} + 1\right)$

$$I_{sc} = I_0\left(e^{\frac{|e|V_{oc}}{kT}} - 1\right)$$

And

$$J_{sc} = J_0\left(e^{\frac{|e|V_{oc}}{kT}} - 1\right)$$

Temperature effect

By considering

$$J_0 = |e|\left(\frac{D_p p_{n0}}{L_p} + \frac{D_n n_{p0}}{L_n}\right)$$

and supposing D/□□temperature independent, we have:

$$J_0 = BT^{\beta} e^{-\frac{E_g}{kT}}$$

where B is T independent and □□□□3/2 + 3/2 = 3.

Therefore we have (-J0 is neglected):

$$J_{sc} = BT^{\beta} e^{-\frac{E_f}{kT}} e^{|e|\frac{V_{oc}}{kT}}$$

Deriving with respect to T and neglecting the Jsc variation we obtain a reduction of about 2 mV/°K.

THERMAL DIFFUSION OF PHOSPHOROUS INTO SILICON

1st Fick law $$J = -D\frac{\partial C}{\partial x}$$

The flux of the diffusing species is proportional to concentration gradient.
$D = D_0 e^{(-\Delta E/kT)}$ is the diffusion coefficient.

□E: height of the potential barrier from a) to b)

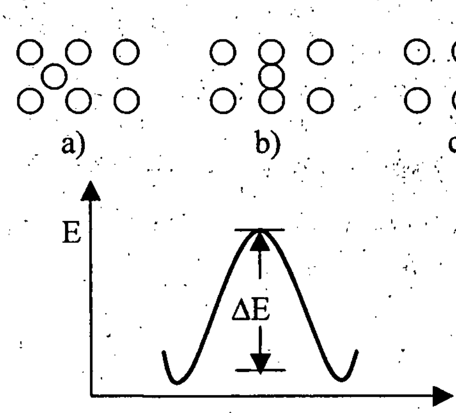
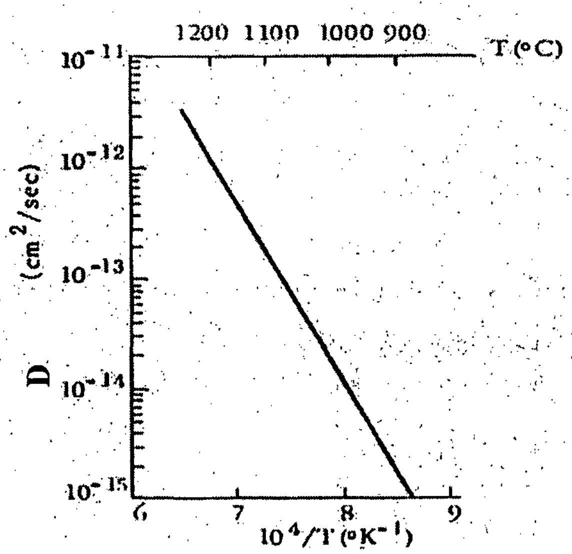


Figure 5



Diffusion coefficient D of phosphorous into silicon versus temperature

Figure 6

2nd Fick law

expresses C time dependence. $$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$$

2nd Fick law is obtained applying continuity equation $\frac{\partial C}{\partial t} = -\frac{\partial J}{\partial x}$ to the 1st Fick law.

The 2nd Fick law (written in this way) is true only if D is INDEPENDENT from C.

Front junction formation

Three different approaches to form front junction exist: diffusion from the vapour phase, diffusion out of a solid phase (source deposition techniques: CVD, spin-on or spray-on, screen printing) and ion implantation (excellent control of the impurity profile).

We consider the diffusion from the vapour phase: N2 carrier flows through a liquid POCl3 source and enters an open tube furnace where silicon wafers are stacked (figure 7).

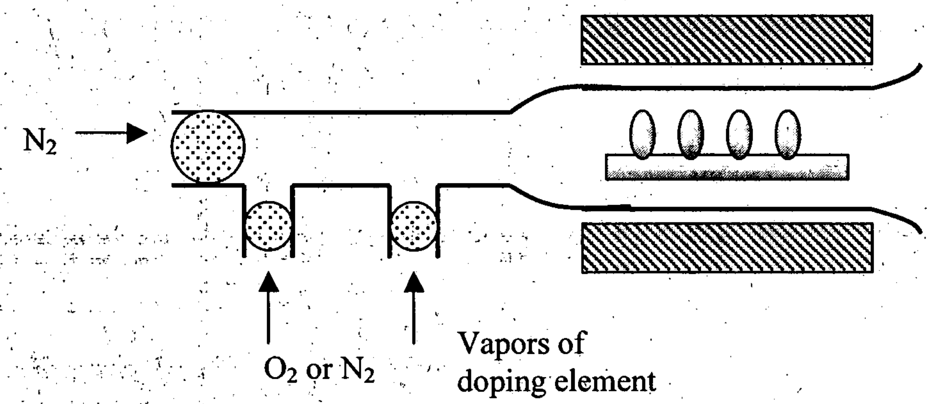


Figure 7 - An open tube diffusion furnace: diffusion from the vapour phase.

Steps of thermal diffusion process:
Phosphorous pre-deposition
Drive in (in O_2 or in N_2)
The chemical reactions are:
$2\ POCl_3 + 3/2\ O_2 \leftrightarrows P_2O_5 + 3\ Cl_2$
$Si + O_2 \leftrightarrows SiO_2$
$5\ Si + 2\ P_2O_5 \leftrightarrows 5\ SiO_2 + 4\ P$
Diffusion temperature: 900°C ÷ 1000°C
Diffusion time: from 20 to 60 minutes (depending from the requested profile).

Sheet resistance definition:

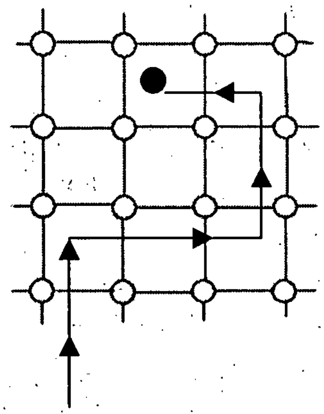
$$R\square = \frac{\rho_s \cdot l}{A}$$

$$R\square = \frac{\rho}{d}$$

Silicon diffusion mechanisms:

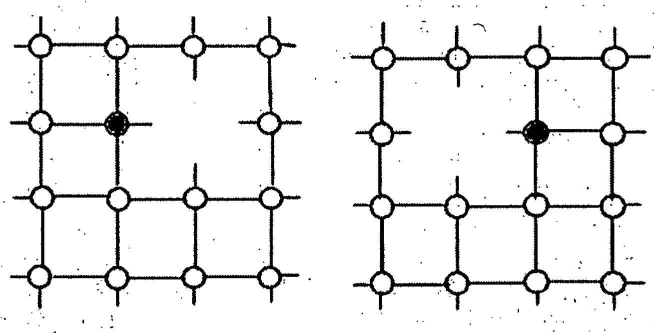
interstitial
by vacancy
"interstitialcy"

1) Interstitial



Interstitial diffusion is performed when the impurity atom moves jumping from an interstitial position to another one.

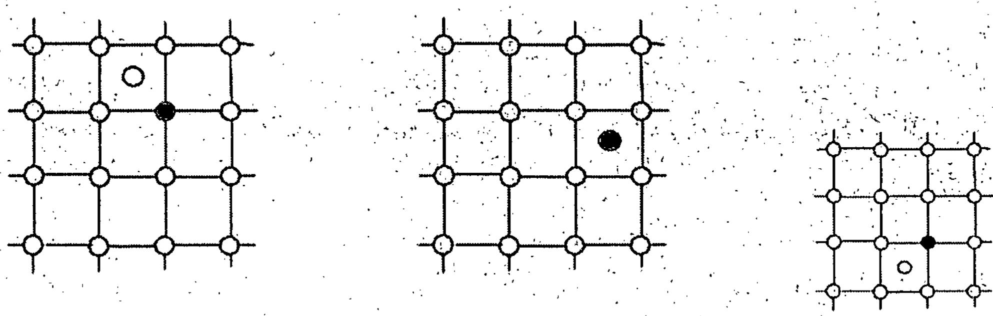
2. By vacancy



a) b)

The impurity advances filling in the near vacancy.

3) "Interstitialcy"



a) b) c)

The impurity atom moves filling alternatively in a vacancy or in an interstitial position

DIFFUSION EQUATIONS

The pre-deposition profile concentration is calculated solving equation: $\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$,
subjected to the initial condition:
C(x,0) = 0
and the two boundary conditions:

C(0,t) = CS
C(∞,t) = 0.

(The first boundary condition defines CS as the surface phosphorous concentration).

The solution is: $C(x,t) = C_S erfc\frac{x}{2\left(\sqrt{Dt}\right)_{predep}}$

where "erfc" function is defined:

$$erfc(y) = 1 - erf(y) = 1 - \frac{2}{\sqrt{Dt}}\int_0^y e^{-\xi}d\xi$$

and $\left(\sqrt{Dt}\right)_{predep}$ represents the thickness of the pre-deposited layer.
By integrating C(x,t), the total amount of dopant is obtained:

$$Q = \int_0^\infty C(x,t)dx$$

$$Q = \int_0^\infty C_S erfc\frac{x}{2\left(\sqrt{Dt}\right)_{predep}}dx$$

$$Q = \frac{2}{\sqrt{Dt}}C_S\left(\sqrt{Dt}\right)_{predep}$$

The pre-deposition stage is followed by the drive in. We consider only the inert atmosphere case. The concentration profile can be calculated imposing to the equation the two conditions:

$$\left(\frac{\partial C}{\partial x}\right)_{x=0} = 0$$

$$C(\infty,0) = 0$$

The initial condition becomes:

$$C(x,0) = C_S erfc\frac{x}{2\left(\sqrt{Dt}\right)_{predep}}$$

With such a a condition the problem is very complex. The difficulty can be reduced taking into account that:

$$\left(\sqrt{Dt}\right)_{predep} << \left(\sqrt{Dt}\right)_{drive-in}$$

Therefore the final profile (after drive-in) is not very influenced by pre-deposition profile supposing a δ function as initial profile C(x,0) = Qδ(x).

By taking the last one as initial condition, the solution is:

$$C(x,t) = \frac{Q}{\sqrt{\pi}\left(\sqrt{Dt}\right)_{drive-in}} \cdot e^{-\left[\frac{x}{2}\left(\sqrt{Dt}\right)_{drive-in}\right]^2}$$

that's a gaussian distribution.

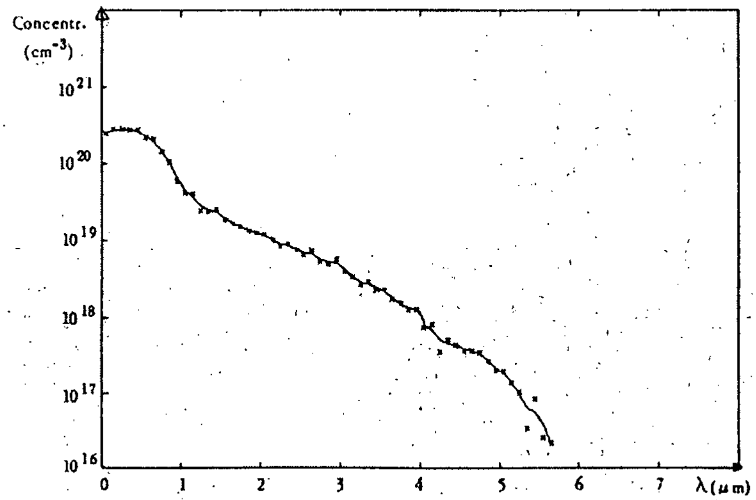


Figure 8 - Concentration profile of phosphorous in Si after thermal diffusion.

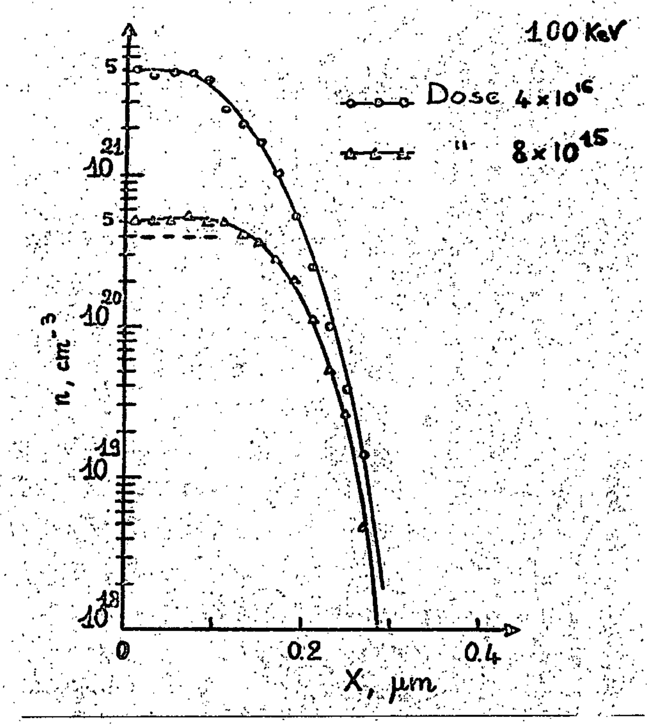


Figure 9
Concentration profile of phosphorous in Si after ion implantation.

ANTIREFLECTION TREATMENTS

By A.R. Coatings

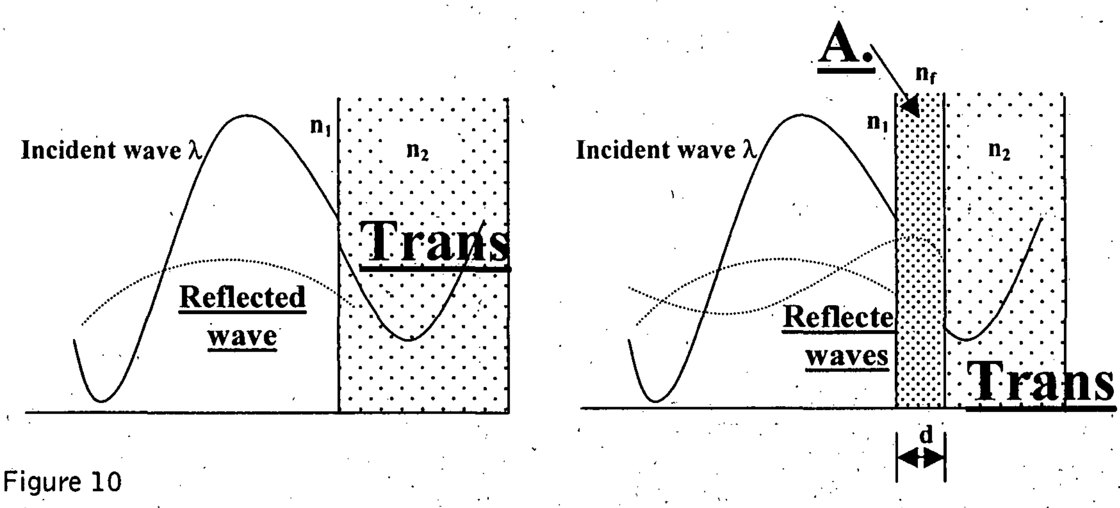


Figure 10

The bare silicon reflects partially the incident light (n2: refraction index of silicon). If an anti reflecting coating is interposed between silicon and medium, the reflectivity is reduced.

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)$$

Bare silicon reflectivity in a medium of refraction index n1. If a thin film of refraction index nf is interposed, the total reflectivity results:

$$R = \frac{r_1^2 + r_2^2 + 2r_1 r_2 \cos 2\delta}{1 + r_1^2 r_2^2 + r_1 r_2 \cos 2\delta}$$

where r1 and r2 are defined by:

$$r_1 = \frac{n_1 - n_f}{n_1 + n_f} \qquad r_2 = \frac{n_f - n_2}{n_f + n_2}$$

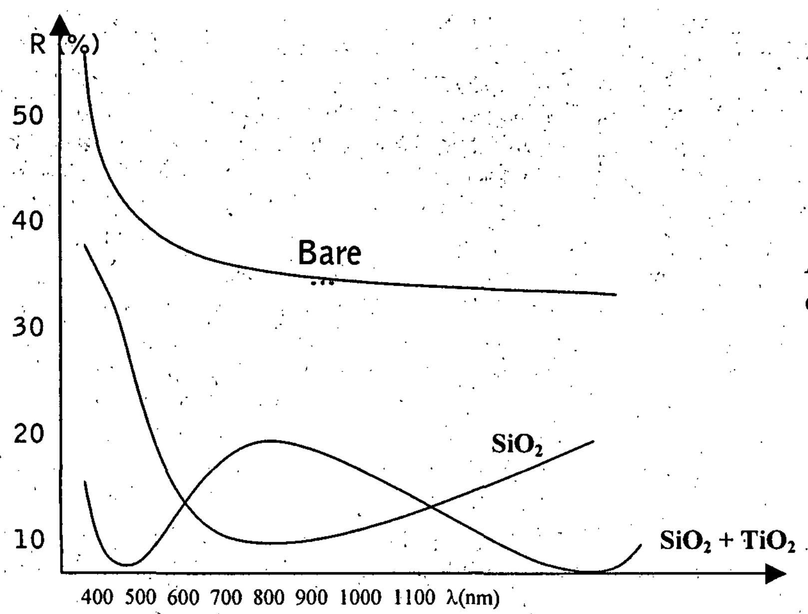


Figure 11 Si reflectivity for different ARC

δ is the phase displacement:

$$\delta = \frac{2Nn_f \cdot d}{\lambda}$$

The minimum of reflectivity is obtained if the conditions

$$d = -\frac{\lambda}{4n_f}$$ (for film thickness)

$$n_f = \sqrt{n_1 n_2}$$ (for film refraction index)

are contemporaneously verified.

Film	Refraction index
SiO	1.8 ÷ 1.9
SiO2	1.5
TiO2	2.2
Al2O3	1.9
Z/WS	2.25 ÷ 2.35
MgF2	1.35 ÷ 1.40
Ta2O5	2.25

2. Texturing

A significant innovation to silicon solar cell technology has been the use of orientation dependent etches to reduce reflection from the front surface of the cell. This process has been developed for (100) oriented silicon wafers but it is possible until ≅ ± 25° away from [100]. In figure 12 is shown the resulting pyramidal shape.

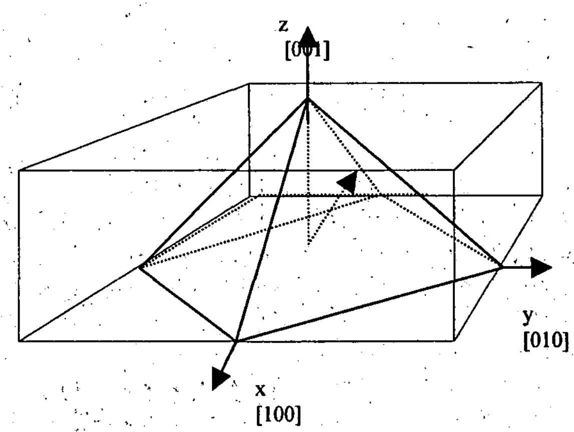


Figure 12 - (111) planes are perpendicular to ± i ± j ± k directions.

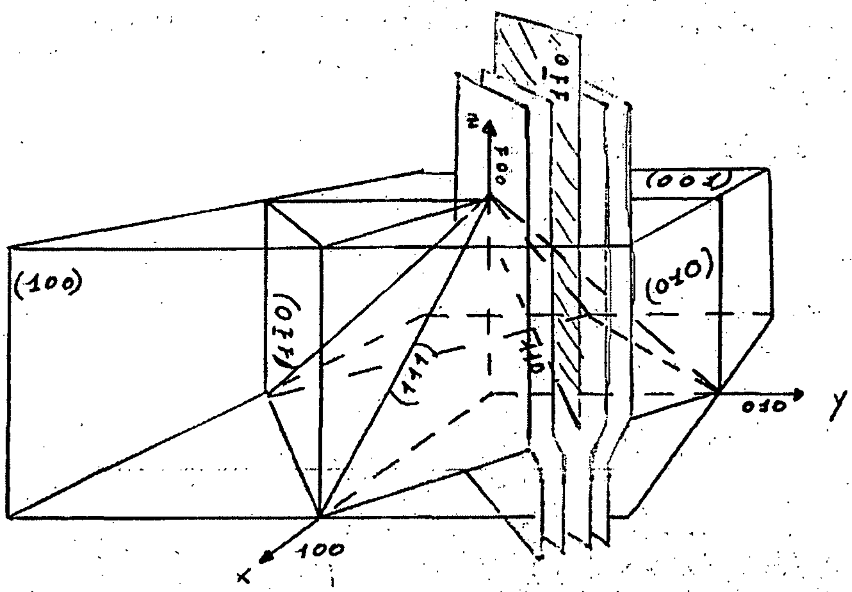


Figure 13

After texture-etching the surface area is 1.73 times the initial polished surface and it is independent from the pyramids dimensions.

A′ = total area obtained with small pyramids
A″ = total area obtained with large pyramids
A = area without pyramids

A′ = A″ = 1.73 A

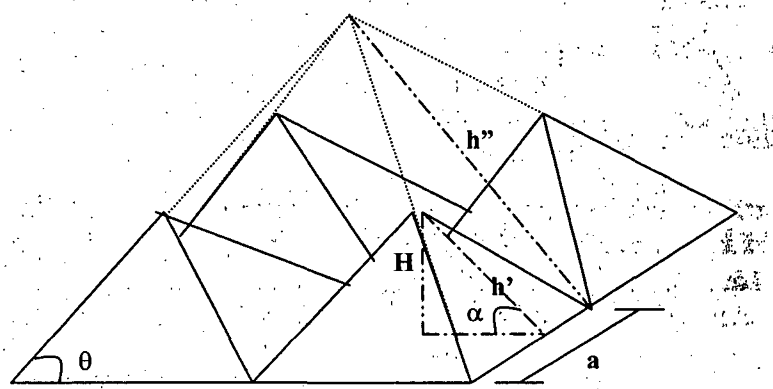


Figure 14

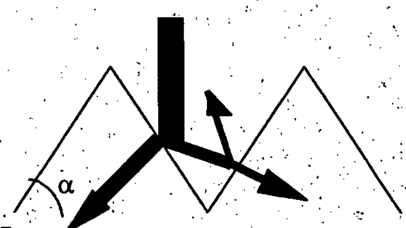


Figure 15

$\alpha = 54.73°$; $\theta = 60°$

Total reflection R = R1R2

θi1 = 54.7°

θi2 = 16.7°

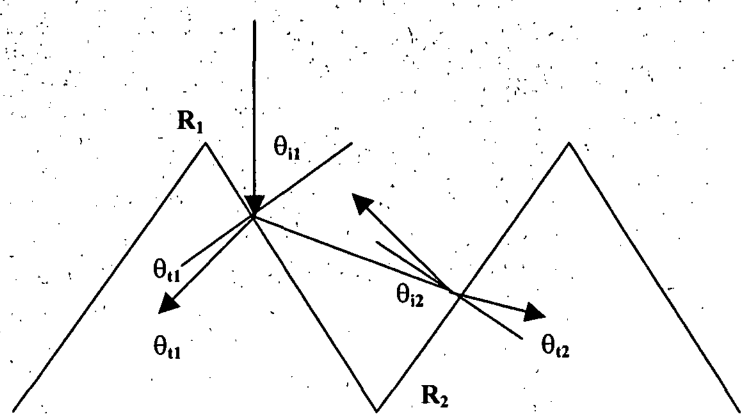


Figure 16

If Rp is the parallel component of light and Rn the transversal one, R can be expressed by:

$$R = \frac{R_p + R_n}{2} = \frac{R_{1p} R_{2p} + R_{1n} R_{2n}}{2}$$

with: $$R_{1p} = \frac{n_2 \cos\theta_{i2} - n_1 \cos\theta_{t1}}{n_2 \cos\theta_{i1} + n_2 \cos\theta_{t1}} \quad R_{2p} = \frac{n_2 \cos\theta_{i2} - n_1 \cos\theta_{t2}}{n_2 \cos\theta_{i2} + n_1 \cos\theta_{t2}}$$

$$R_{1n} = \frac{n_1 \cos\theta_{i1} - n_2 \cos\theta_{t1}}{n_1 \cos\theta_{i1} + n_2 \cos\theta_{t1}} \quad R_{2n} = \frac{n_1 \cos\theta_{i2} - n_2 \cos\theta_{t2}}{n_1 \cos\theta_{i2} + n_2 \cos\theta_{t2}}$$

where θt1 and θt2 are the refractive angles (Snellius law).

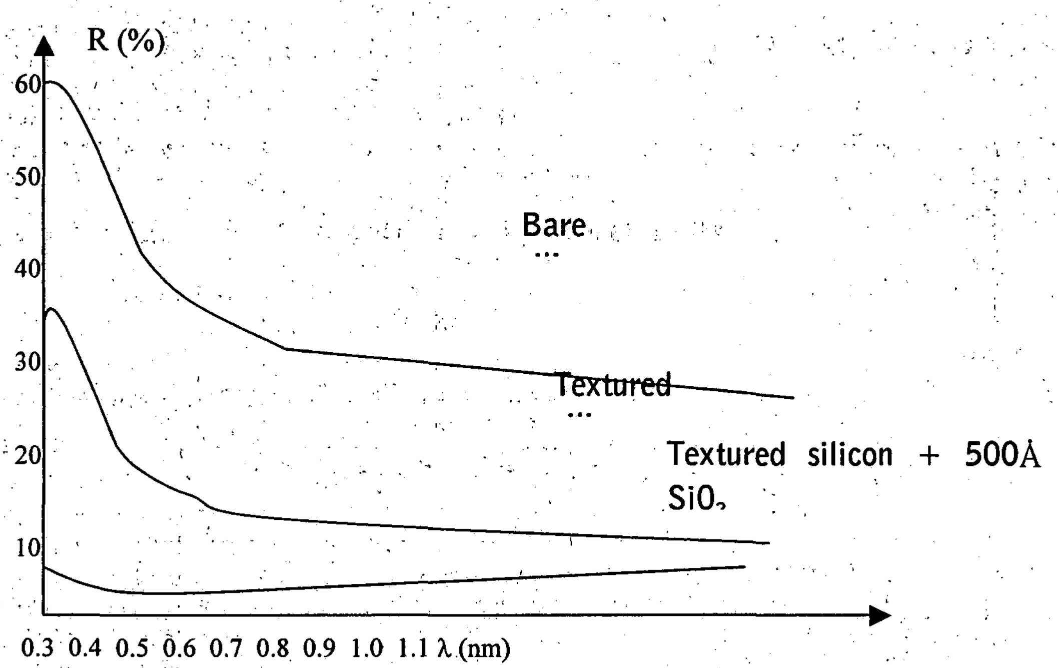


Figure 17 - Reflectivity of different Si surfaces.

METALLIC CONTACTS

Metallic contacts can be deposited on a Si wafer by vacuum evaporation, electroless chemical plating or screen printing. Screen printing method can be considered the most cost effective technology for production environment.

Screen printing technology

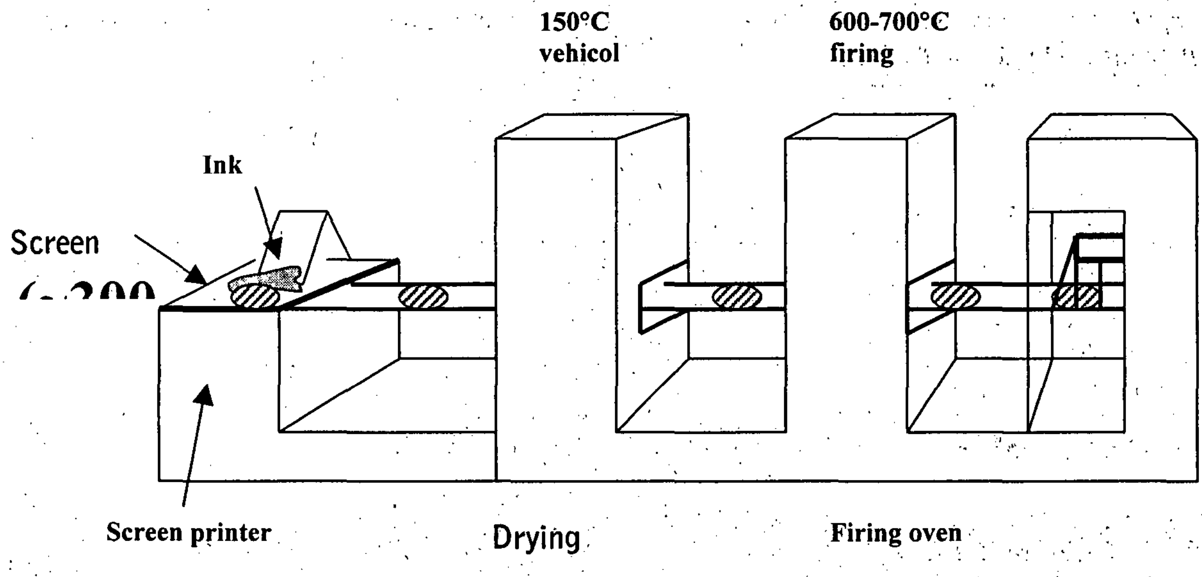


Figure 18 - Screen printing process

Screen printer provides contact pattern definition: a squeegee pushes the metallic ink[1] through the openings of a screen onto the silicon wafers. The printed paste is dried at about 150°C to allow the solvents to evaporate. A final thermal step, the firing, transform the metal powder (the main constituent of the ink) in a conductor and also occurs in a belt furnace.

Schematic picture of a PV cell

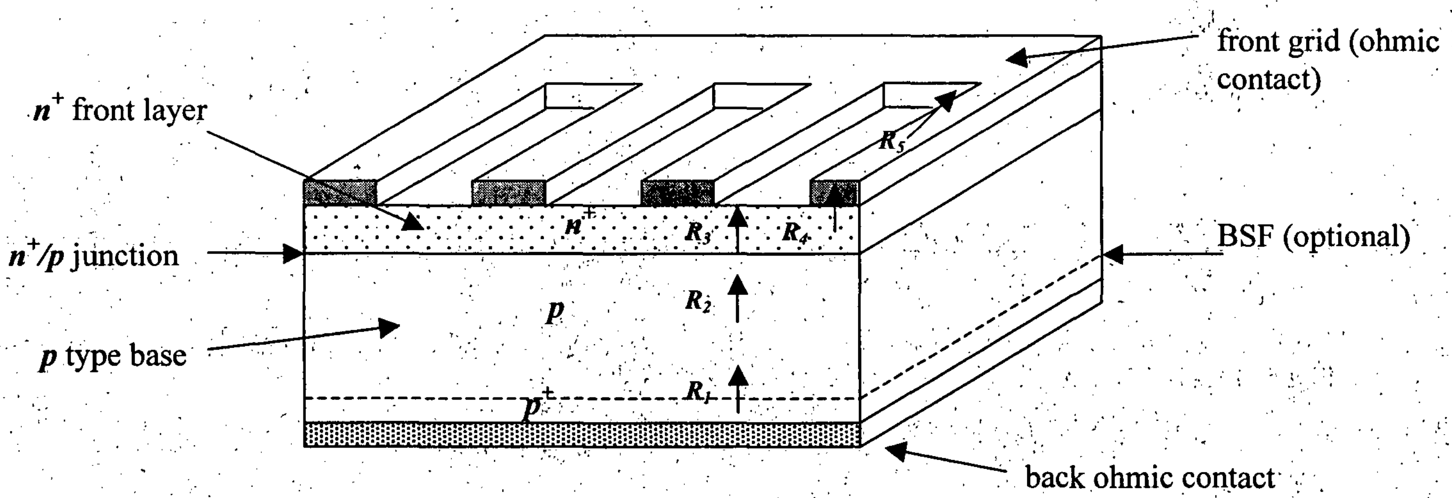


Figure 19 - Schematic picture of a standard PV cell

[1] A metallic paste for screen printing consists of a viscous part containing an active powder (Ag for front contacts, Al for back contacts, $\rho \approx 0.5\times10^{-6}\ \Omega$ cm), frit (Pb or B oxide), organic binders and solvents to obtain a viscosity of about 300 poise.

Back Surface Field (BSF)

The efficiency of a silicon solar cell can be improved by forming a p+ layer at the back surface (BSF): an electric field E' is added to junction field.

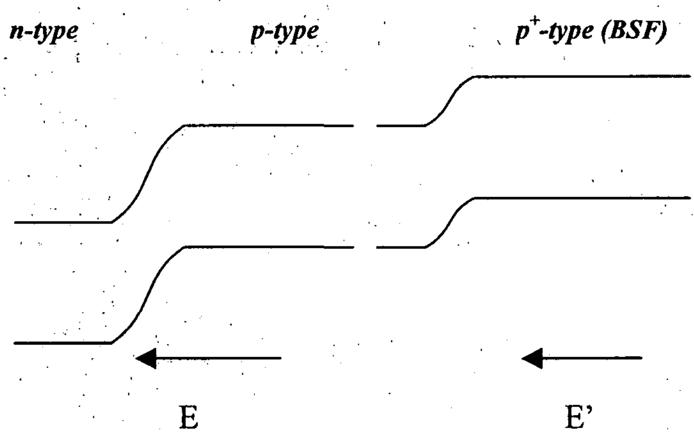


Figure 20 - Series resistance RS

RS = R1 + R2 + R3 + R4 + R5

R1	back contact resistance
R2	bulk resistance
R3	n layer resistance
R4	front contact resistance
R5	finger resistance

Shunt resistance Rsh

Material defects, junction holes (see figure 21)

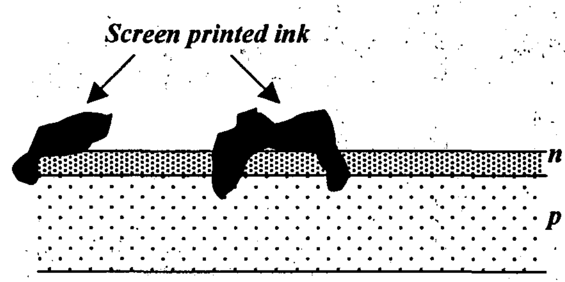


Figure 21

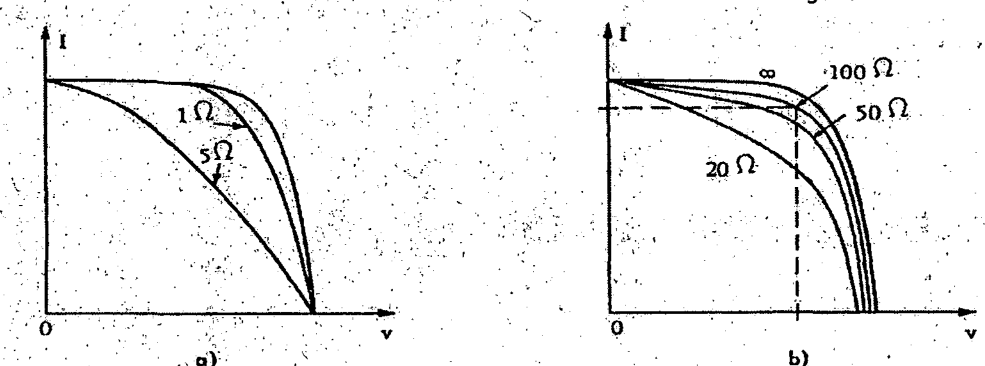
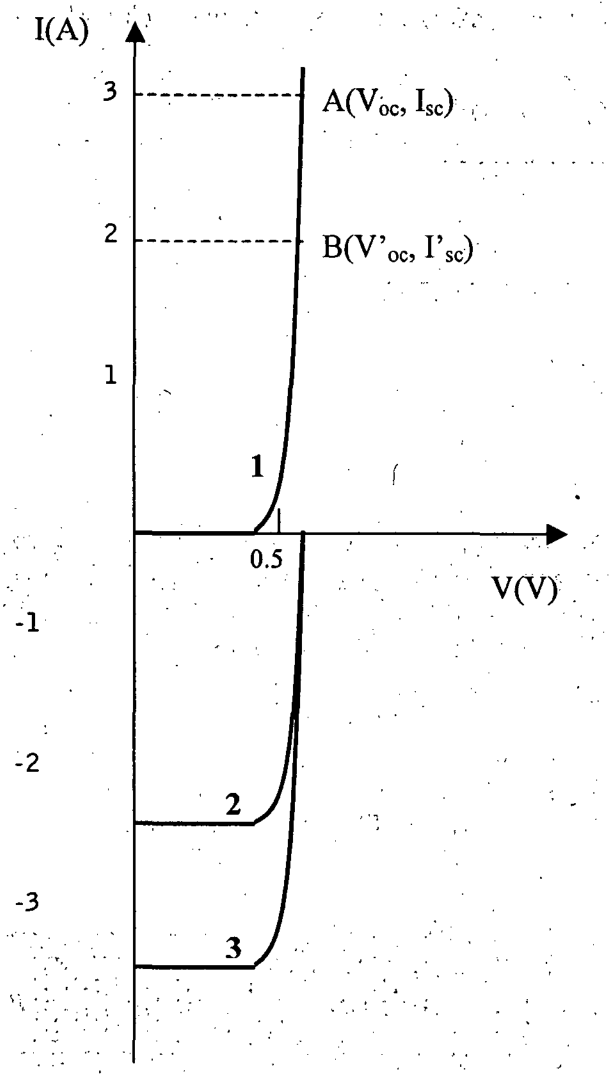


Figure 22

a) Series resistance effect (on a 4 cm2 solar cell)
b) Shunt resistance effect (on a 4 cm2 solar cell)

Both series resistance and shunt resistance cause a FF reduction.



Curves 2 and 3 represent I(V) for a cell with $I_0 = 9\times10^{-10}$ A, $I_{sc} = 3$ A, $V_{oc} = 0.570$ V, $R_S = 0$ and $R_{sh} = \infty$, calculated with different illumination; curve 1 represents the correspondent dark I(V).

Curve 1: $I_{out} = I_d$

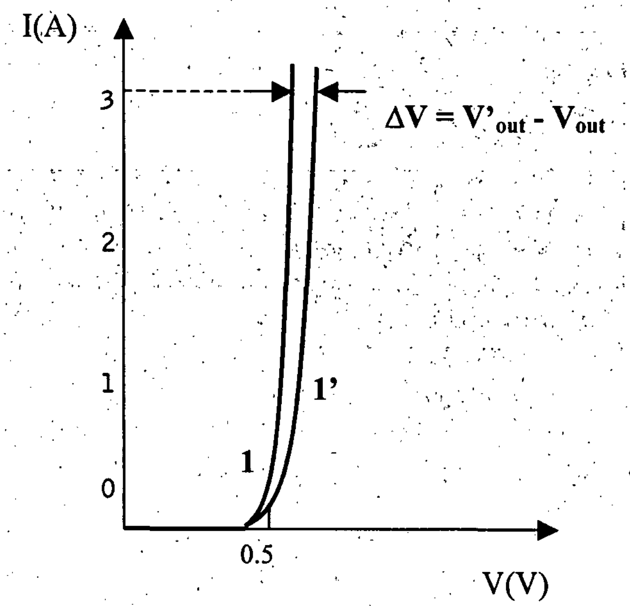
$$V_{out} = \frac{kT}{|e|}\ln\left(\frac{I_d}{I_0}+1\right)$$

Curve 2: $I_{out} = |2 - I_L|$

$$V_{out} = \frac{kT}{|e|}\ln\left(\frac{I_d}{I_0}+1\right)$$

Curve 3: $I_{out} = |3 - I_L|$

$$V_{out} = \frac{kT}{|e|}\ln\left(\frac{I_d}{I_0}+1\right)$$



Curve 1' represents dark I(V) with $R_S = 10^{-2}$
(and $R_{sh} = \infty$).

$V'_{out} = 0.6$ V
$V_{out} = V_{oc} = 0.57$ V
$I_{sc} = 3$ A

$$R_S = \frac{0.6 - 0.57}{3} = 10^{-2}\,\Omega$$

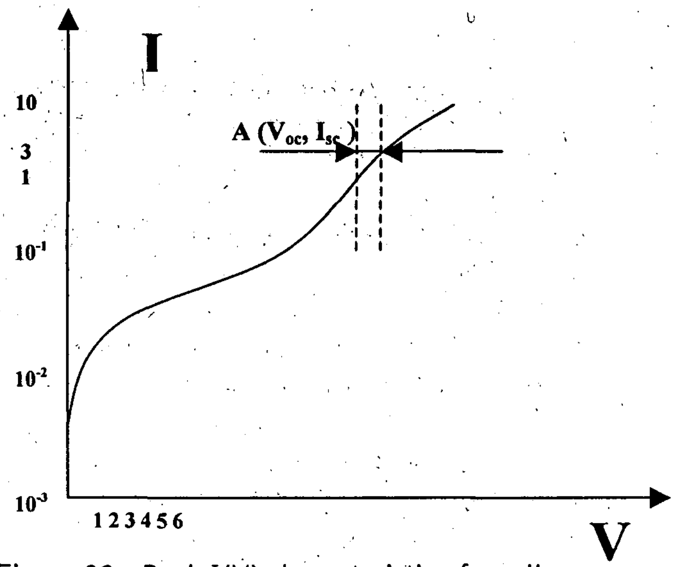


Figure 23 - Dark I(V) characteristic of a cell.

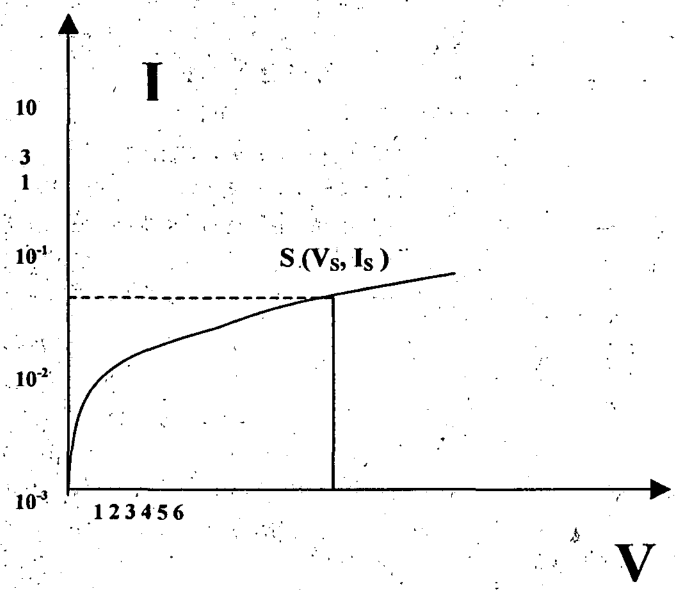
R_S measurement

Calculating the difference ΔV

$\Delta V = V'_{out} - V_{out}$

between the voltage measured under illumination (V_{oc}) and the value on the dark I(V) curve corresponding to I_{sc} *series resistance* can be calculated:

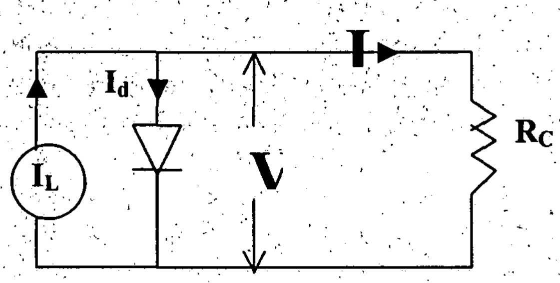
$R_S = \Delta V / I_{sc}$



R_{sh} measument

$R_{sh} = V_S / I_S$

Equivalent circuit (ideal):



$$I_L = A^* \int \Phi(\lambda) S(\lambda) d\lambda$$

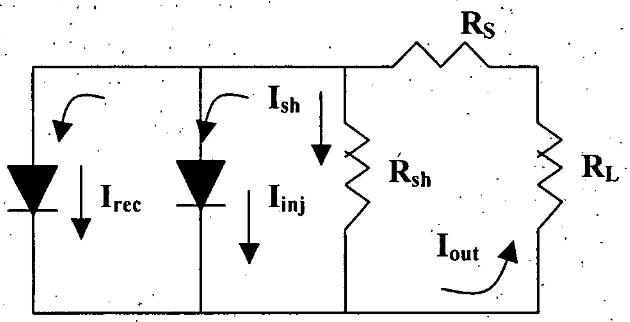
$$I_D = I_0\left(e^{qV/kT} - 1\right)$$

$$I = I_L - I_0\left(e^{qV/kT} - 1\right)$$

A^* = cell area – patterned area

Equivalent circuit (real cell):

Dark

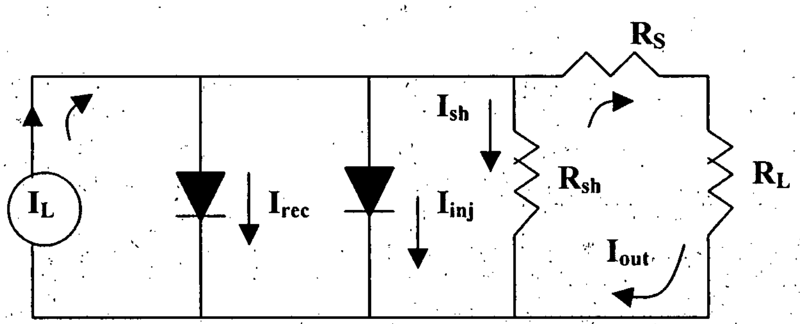


$$I_{sc} = \frac{V_{out} - I_{out} R_s}{R_{sh}}$$

Circuit equation:

$$I_{dark} = I_{out} = I_0\left(e^{\frac{|e|V_{out} - I_{out}R_S}{kT}} - 1\right) + I_W\left(e^{\frac{|e|V_{out} - I_{out}R_S}{2kT}} - 1\right) + \frac{V_{out} - I_{out}R_S}{R_{sh}}$$

Under illumination



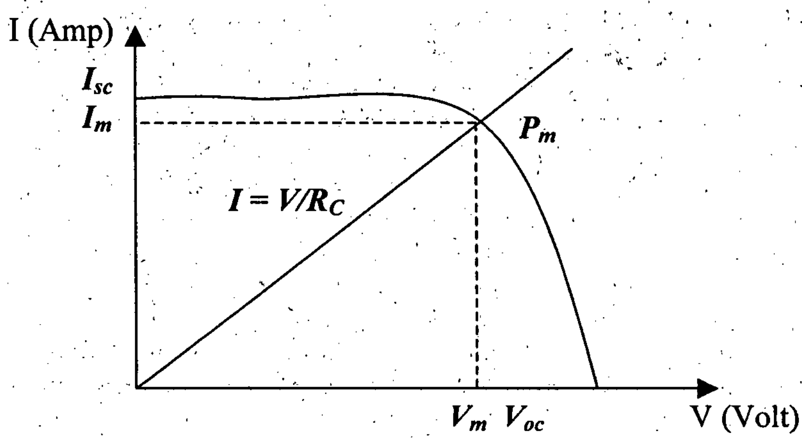
$$I_{dark} = I_{out} = I_0\left(e^{\frac{|e|V_{out} - I_{out}R_S}{kT}} - 1\right) + I_W\left(e^{\frac{|e|V_{out} - I_{out}R_S}{2kT}} - 1\right) + \frac{V_{out} - I_{out}R_S}{R_{sh}}$$

Parameters of performance:

$$I_{sc} = I_L$$

$$V_{oc} = \frac{kT}{q}\ln\frac{I_L - I_0}{I_0} \cong \frac{kT}{q}\ln\frac{I_L}{I_0}$$

$$VF = \frac{V_{oc}}{\left(E_a/q\right)}$$

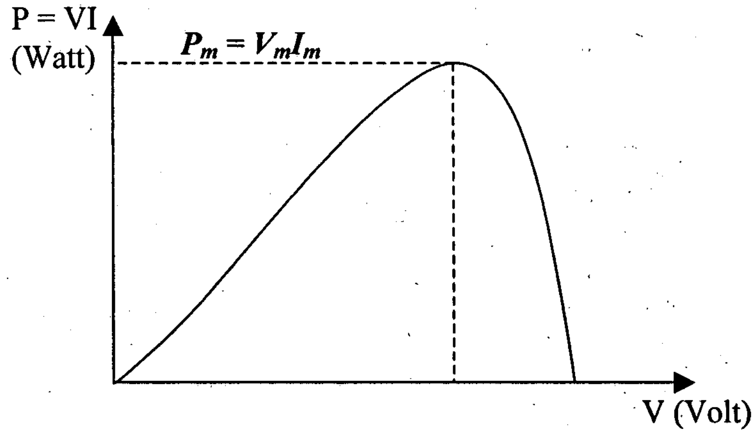


$$FF = \frac{I_m V_m}{I_{sc} V_{oc}}$$ (Fill Factor)

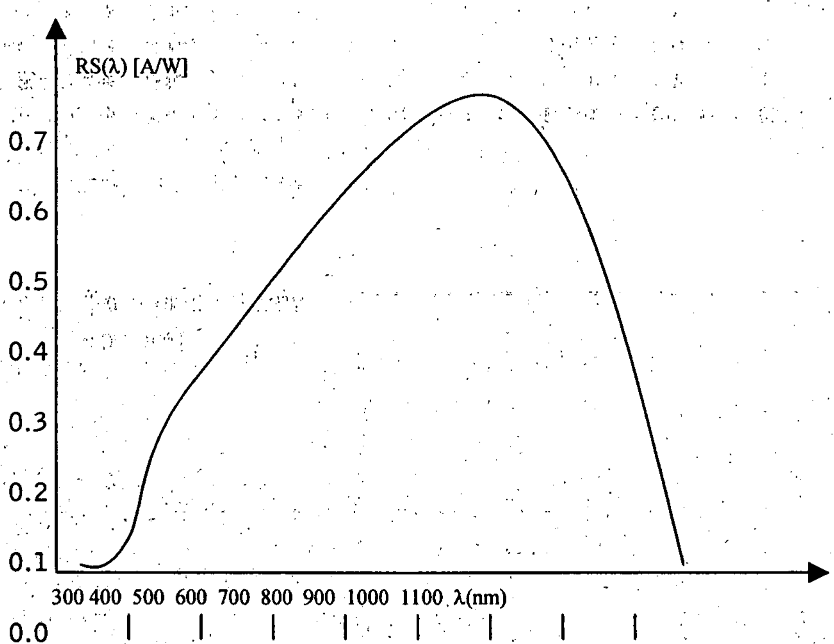
Photovoltaic conversion efficiency:

$$\eta = \frac{P_m}{P_{in}} = \frac{V_{oc} I_{sc} FF}{P_{in}}$$

$$P_{in} = A^{*} \int \Phi(\lambda) d\lambda$$



Absolute spectral response



$$RS(\lambda) = \frac{J_{sc}(\lambda)}{\Phi(\lambda)}$$

$RS(\lambda)$ is the absolute spectral response where $J_{sc}(\lambda)$ [A/m²] the short circuit current of the cell and $\Phi(\lambda)$ [W/m²] light spectral irradiance.

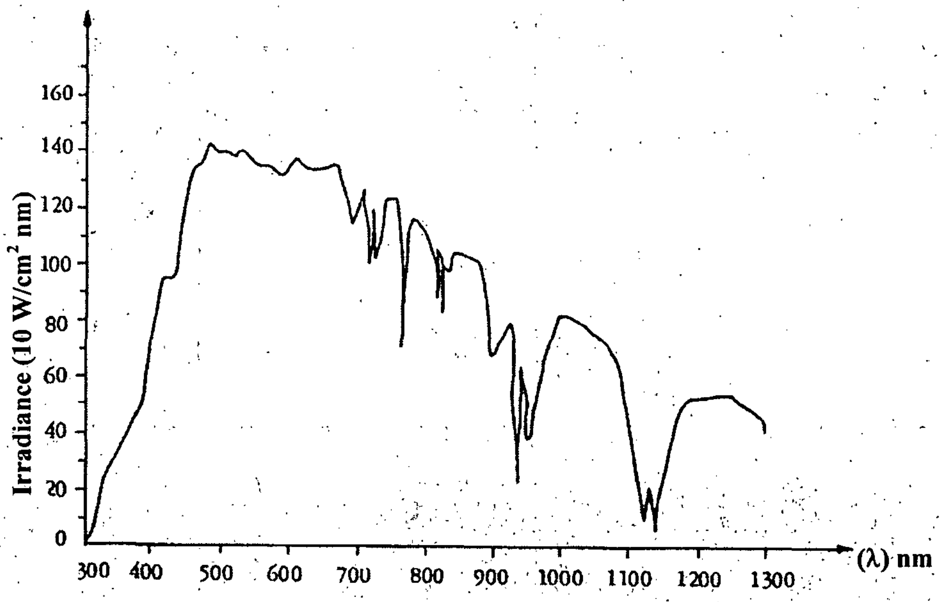
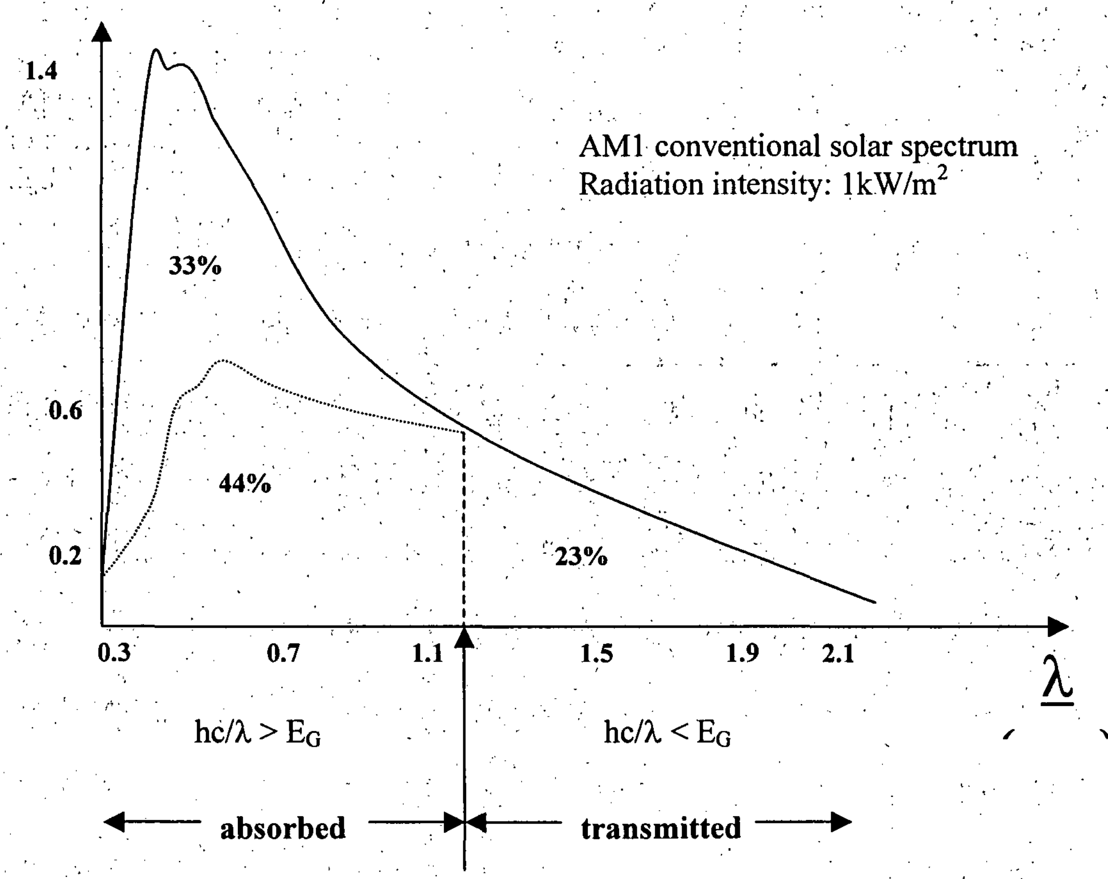
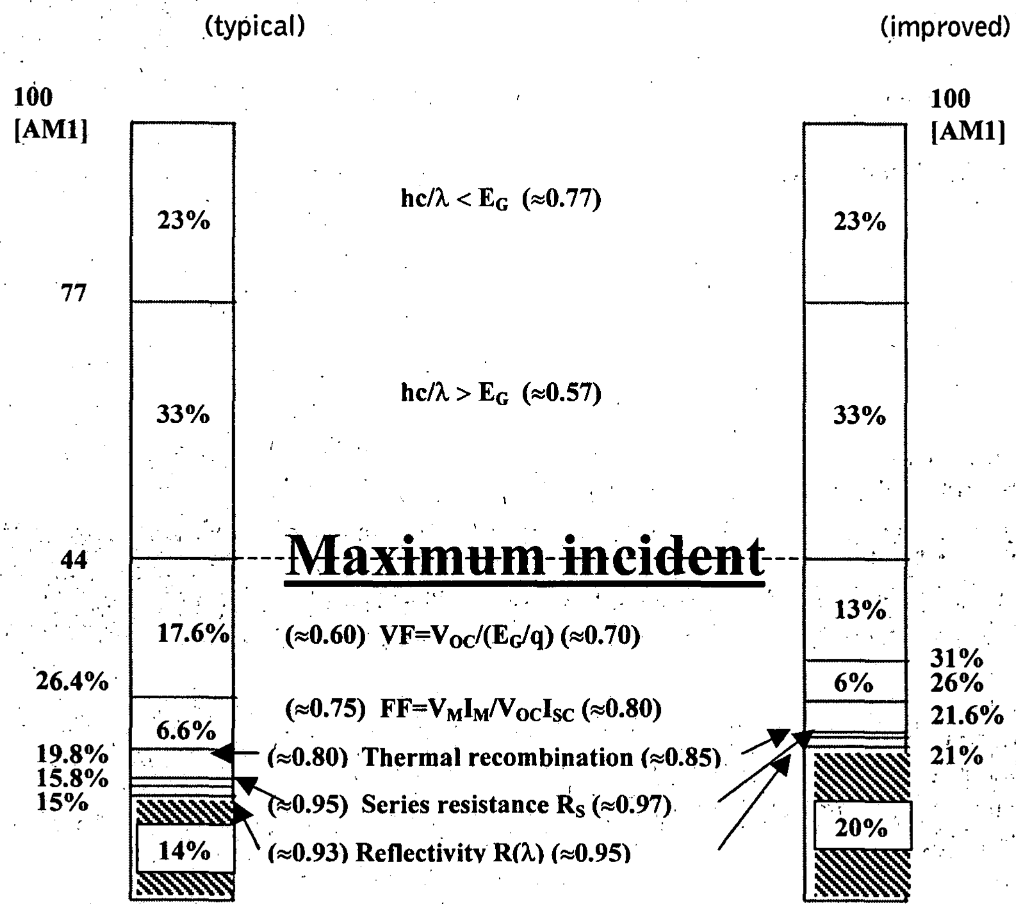


Figure 23
ASTM direct spectrum (AM 1.5).



Conventional Silicon solar cell



UTILISATION OF SOLAR ENERGY IN GHANA

CONTENTS

Introduction

Majority of the rural population, who are poor, are yet to see any real concrete effects of the Structural Adjustment Programme (SAP), whose implementation began in 1983. The following indicators of poverty are still observed in very large proportion among the rural people; contagious diseases, unemployment, underemployment, high infant mortality rate, illiteracy etc. This segment of the population, produces the bulk of the nation's agricultural products, the mainstay of the economy, using obsolete technology in the light of advances in modern technology.

About 70% of the rural areas in Ghana have no electricity, and other sources of energy are inadequately supplied.

The main problem of these rural areas not having electricity is that, most of them are in very remote parts of the country, where the existing hydropower grid cannot be extended to, due to the cost implications on the national budget. These areas, therefore, are not likely to benefit from the Government's programme of providing electricity to all communities in the country by the year 2020. Without access to energy supply as well as education and modern technology, the rural population will find it difficult to break the poverty cycle in which they find themselves and future programmes focused on poverty alleviation and wealth creation will still have no real impact towards the improvement of their life style. Thus, the option of the provision of alternative energy sources such as solar energy for such places will be most cost effective; nevertheless, solar energy technology is proven and can provide energy to meet individual and collective needs such as home lighting, communication, school lighting, refrigeration, water pumping for irrigation, water heating and crop drying to reduce post-harvest losses.

Fortunately, Ghana is situated between latitudes 50 and 110 N and receives solar radiation, ranging from 4.5 to 6.0 KWh/day, with corresponding annual sunshine duration of 1500 to 3000 hours and thus, has the necessary conditions for solar energy application and usage.

Already, over 700 solar energy systems for electricity and thermal applications have been installed in the country and are being used for lighting, communication, water heating, crop drying etc.

Country Background

The Republic of Ghana is located between latitudes 40 and 120 North, bordering the North Atlantic Ocean, between La Cote d'Ivoire to the West and Togo to the East. The climate is tropical and extremely sunny; warm and comparatively dry along the south-east coast; hot and humid in the south-west; and hot and dry in the north.

The country has about 18 million people with an average per capita income of approximately $400. In 1990, it was estimated that 70% of men and 51% of women aged 15 and over could read and write. Almost half the population (46%) is under the age of 15, 51% are between 15 and 64 years, and only 3% are 65 years and older. The population growth rate is estimated at 3.06% per year (mid-1995). Infant mortality rates are high: 81.7 deaths/1000 live births. At the current rate of population growth, the population will double by the year 2020.

General Overview of Energy, Supply, Demand and Pricing

Energy Supply Situation

The bulk of Ghana's energy requirements are met from biomass. In 1994, biomass mainly charcoal and firewood contributed 66% of the total energy consumed. Petroleum and electricity accounted for 21% and 31% respectively.

There are 1,122 MW of installed generating capacity in the public system in Ghana with 912 MW of hydro-power from the Akosombo Dam, 160 MW from the Kpong Dam and 30 MW of diesel power at Tema. Electrical load growth in recent years has consistently exceeded expectations. Between 1985 and 1992, domestic load growth averaged 9.6% per year. Between 1990 and 1992, despite tariff increases in both years, annual load growth exceeded 15%. Over 59% of the total domestic electricity consumption in 1990 was taken up by Volta Aluminium Company (VALCO). Industrial and the mining sector accounted for 21%, whilst the remaining 20% was consumed in the residential, commercial and the public sectors.

All the crude oil used in this country is imported. In 1994, a total of 1,073,670 TOE was consumed. The transport sector consumed the largest portion of about 59%, followed by residential and commercial sectors with 19%, whilst the industrial and agricultural sectors took 14% and 8% respectively. By 1989, only 12,000 metric tonnes of Liquified Petroleum Gas (LPG) out of the total production of 22,000 metric tonnes was consumed for cooking processes in households, commercial and industrial establishments. The rest was flared by Tema Oil Refinery causing severe pollution and a waste of our scarce foreign exchange. In this regard, the government launched the LPG Promotional Programme to create awareness on the the use of LPG. The programme has caught on well and presently demand has outstripped production.

Demand

The demand for energy is expected to increase rapidly in the future as the economy continues to expand and grow, with production and consumption forecast to grow at an average of 10% per annum until the year 2000, and thereafter at 2% per annum over the corresponding GDP growth rate.

Energy Pricing and Liberalisation of Markets

Measures have been taken to gear energy prices to realistic levels, based on the principles of full cost recovery of all investments made to secure, produce, process, transport and market energy services. Also, special levies and taxes have been incorporated into the price structures of petroleum products and electricity since 1988 to generate resources for current and future investments in the specific areas, as well as contribute to the annual national revenues for implementing the government's prioritised social and development programmes.

The marketing of petroleum products has been liberalised since 1 January, 1991. Under the new arrangements, the oil marketing companies set their own ex-pump prices for petroleum products which must not exceed maximum ceilings established by the Government. Also, it will be ensured that the ex-refinery price of petroleum products, all government taxes and duties, including provision of incentives for distribution of petroleum products in the rural and most inaccessible areas, are covered. Each company is required to sell its products at the same price throughout the country, and also make its own arrangements with dealers and transporters on margins and rates.

For the past electricity tariffs were based on the concept of Long Run Marginal Cost that is, the tariffs reflect the economic costs of supplying electricity so as to promote efficient resource allocation. In view of the Power Sector Reforms the following consideration having given:=====

Policy on Energy

Government Policy

The broad policy framework for energy sector programmes are focused around a strategy of which the principal aims are:

- to restore improved productivity and efficiency in the procurement, transformation, distribution and use of all energy resources;
- to reduce the country's vulnerability to short-term disruptions in energy resources and supply base;
- to ensure the availability and equitable distribution of energy to all socio-economic sectors and geographical regions;
- to consolidate and accelerate the development and use of the country's indigenous energy sources, especially woodfuels, hydro-power, petroleum and solar energy; and
- to secure future power supply through thermal complementation of the hydro-based electricity generation system.

1.3.3 Overview of Ghana Government's Policy on Renewable Energy vis-a-vis DANIDA Renewable Energy Policy

Government of Ghana Renewable Energy Policy

Currently, the Renewable Energy Development Programme developed and co-ordinated by the Ministry of Mines and Energy is focused on the following objectives:

- promotion and development of the renewable energy industries that have strong indigenisation prospects over the short and medium term;
- demonstration and evaluation of renewable energy technologies with the potential to meeting the needs of prioritised socio-economic welfare objectives;
- providing support for research, development and demonstration of renewable energy technologies with the greatest potential to increase and diversify the country's future energy base; and
- developing the relevant information base on the stock and status of renewable energy resources and suitable technologies and end-use patterns for the purpose of establishing a planning framework for the rationale use of the country's renewable energy resources.

Danida's Policy On Renewable Energy

It states that, Danida will:

- Support utilisation of proven renewable energy technologies within the field of biomass, wind, solar and small hydro;
- Support local organisations which have working foundation for skills development in renewable energy technologies;
- Support pilot projects aimed at adapting proven technologies to local conditions;
- Support information campaigns and other activities intended to create awareness of the potential of renewable energy sources;
- Support the drawing up of plans and policies in relation to the utilisation of renewable energy sources.

Danida will normally not support product development.

Assistance would be offered within the field of renewable sources of energy under the following conditions:

The country should have taken a political decision to support the use of the renewable source of energy in question.

Renewable energy projects will be subject to the same technical and economic evaluation as conventional energy sources; if, however major benefits and externalities cannot be quantified in a meaningful way, a lower, positive economic rate of return may be acceptable provided proper justification can be produced.

Private companies chosen for involvement in renewable energy projects should be able to provide credible spare part supply and after sales service similar to that demanded from conventional energy equipment.

Is the Government policy on renewable energy adequate for the effective implementation of Danida's policy on renewable energy in Ghana?

The government policy is quite adequate however, certain aspects of the policy should be revisited for further strengthening.

In reference to === of Danida's policy, the government policy has not created the enabling environment to stimulate private sector participation in the solar market due to the following reasons:

- import duty and sales tax imposition of solar products.
- non-availability of credit from the country's bank for solar business.

Thus government should create the conducive conditions to attract private investment in solar energy subsector.

The government's policy on solar energy could be strengthened by taking advantage of Danid's support in the drawing up of plans and policy by way of training and provision of funding for consultancy services.

Institutional and Regulatory Framework of the Solar Energy Sub-sector

Several institutional actors are play a roll in the effective and efficient use of the country's enormous solar energy potential. The government of Ghana plays a roll in terms of facilitator through legislation, awareness raising campaigns, customer and general promoter of the user of solar energy technologies.

Secondly private, non-governmental institutions are suppose to play an important role in stimulating the solar industry in Ghana. The involvement of these institutions in sale, marketing, installation and technical training have great prospects for the future.

Thirdly, specialised private and public organisations such as Danafco Engineering (DENG), ERGS Engineering, University of Science and Technology could be involved in the assemblying, training, maintenance and marketing of the solar energy technologies in the country.

A favourable investment code exists in Ghana which could provide incentives for local production and assembly of solar systems. In reference to Ghana Investment Promotion Act 478, 1994 Article 24 referring to exemption of non zero-rated items states that " Any enterprise which desires to avail itself of the incentives provided under section of this act, but whose plants, machinery, equipment or parts thereof are not zero-rate under the Customs Harmonised Commodity and Tariff Code schedule to the Customs Excise and Preventive Service Law, 1993 (PNDCL 330) may submit an application for exemption of import duties sales tax or excise duties on the plant, machinery, equipment or part thereof to the Centre". This means that any enterprise wishing to produce or assemble solar systems in the country will have all machinery and parts imported exempted from import duty and sales tax.

Currently apart from DENG which assembles solar water heaters all other dealers import solar systems into the country which attracts import duty and sales tax of 10% and 17.5% respectively. The corresponding figure for charge controllers and batteries are 10% and 7.5% respectively.

Codes and standards on solar energy technology do not exist, this is due to the fact that the technology is relatively new in the country.

Current Status of Solar Energy Utilisation

Literature Review

The Ministry of Mines and Energy carried out a survey between 1989 and 1992 to evaluate the performance of solar photovoltaic systems in Ghana with the following objectives:

- to compile an inventory of solar PV systems in Ghana and select some of them for in-depth study.
- to evaluate the performance of the selected systems and investigate major causes of system failure and identify solution for arresting them.
- to establish guidelines to improve design, installation and maintenance of solar PV system.

The findings of the survey on solar PV energy applications in Ghana indicated that about 700 solar PV stand alone systems have been installed in the country dating back from 1982 by public organisations, private individuals and religious institutions. Most of these installation were located in remote part of the country far from the national grid. These systems are used mostly for lighting, communication and refrigeration. In addition, the accomplish the other two objectives set forth.

A second study entitled Prospect for Solar Water Heating in Ghana was carried out by the Ministry of Mines and Energy between 1991 and 1993. The objectives of the study were:

- to identify major users of hot water in the various sectors of the economy;
- to assess the demand of hot water for the identified uses;
- to identify the technical and economic parameters for cost-effective utilisation of solar water heaters in Ghana;
- to undertake pilot projects to encourage the use of solar water heaters.

The findings of the study were that major users of solar water heaters are hospital where a number of installations were identified. Pilot projects have been undertaken in four of the country's hospitals. Some problems hindering the widespread use of the technology were identified as high initial capital cost and the inability of the systems to produce hot water all year round. Also the system could not meet the hot water needs of the hospitals due to their high usage rate. However, this could be attributed to possible improper sizing of the systems.

Another study that has been carried out is entitled "Photovoltaic (PV) Solar Energy Application In Ghana. The objectives of the study were;

- assessment of PV technologies in Ghana
- prediction of the future market of PV technologies in Ghana.
- identification of short, medium and long term PV technology usage in Ghana.
- Drawing up of a market strategy for the realisation of the third objective.

In its findings, the report concluded that the high cost PV solar modules, tax on solar systems, inadequate user training, unavailability of PV assembly plant are some of the problems affecting the use of PV systems in the country.

Limitations of the three studies that have been conducted in the country:

Under the broad heading of solar energy utilisation the studies only looked at solar PV and solar water heating. However their findings will be used as an input in this study which is focused at: describing the present situation in the solar subsector, analysing the cost factors and recommending possible areas for donor assistance.

Current Status of Solar Energy Application

The current status of the various solar energy technologies is presented in tables 1, 2, 3, ...

Table 2 - Breakdown of Solar Photovoltaic Installations in Ghana, May 1997

Application	Number	Installed Power (kW)
Telecommunication	505	293.10
Lighting (Solar lamps)	59	16.86
Refrigeration	82	18.72
Water Pumping	11	11.70
Ventilation (fan & airconditioning)	3	1.00
Electric Fencing	1	0.02
Computer & Office Equipment	1	0.30
Battery Charging	4	2.37
Lighting and Battery Charging	1	0.40
Combined Installations		
Lighting & Telecommunication	1	0.30
Lighting & Refrigeration	1	0.30
Lighting & Water Pumping	2	1.60
Lighting & Ventilation	6	0.60
Lighting, Refrigeration & Communication	4	2.00
Lighting, Computer operation, Telecommunication	21	4.50
**Misc. (General purpose)	26	10.00
	728	363.77

. The solar power unit runs two to three end-use devices
.. The solar power unit runs more than three end-use devices

Source: Ministry of Mines and Energy, Ghana, 1997.

Market share by Manufacturers of Solar PV systems

In all a total of 365 systems which were assessed in terms of the known quantities and their makes indicated that BP Solar has market share of 38%, Siemens 28% and Solarex 16%. The others are Kyocera 7%, Holec 5%, Photowatt 4.4%, AEG 1% and RJM 0.6%.

The analysis reveals that all the solar PV systems are imported and BP Solar has the largest market share in the country, followed by Siemens, then Solarex. The high quantity of 134 solar modules were installed by a public organisation (Ghana Railway Corporation). These systems were purchased from a grant or loan that was given to this corporation by the country of origin of the systems. However, it should be noted that the BP systems do not constitute the majority of the systems found on the open market.

Siemens system were found to be the majority on the open market. Siemens systems have mostly been installed by financially sound organisations like Social Security and National Insurance Trust (SSNIT) and Produce Buying Agency of Cocoa Board who bought these systems on the open competitive market.

Majority of the public organisations like Ministries of Mines and Energy and Health, Ghana Telecomm, Ghana Police, World Health Organisation (WHO) Onchocerciasis Control Programme are also using Siemens systems. This is an indication that the Siemens systems might have performed efficiently in earlier installations.

Solar Pumping

Solar PV application for water pumping is not widely exploited. Currently 12 systems have been identified in the Eastern, Northern, Upper West Regions of the country.

The field visits revealed that a 1KW solar pump has been installed at the Abuakwa State College at Kibi, Eastern Region to pump water to supplement their water supply. Solar Energy System, an NGO, in collaboration with Ghana Water and Sewage Corporation (GWSC) have installed a solar pump at Buadu in the Easter Region to pump water for drinking. GWSC has also installed two solar pumps in Bole and Chereponi all in the Northern Region. DENG has also installed a pump in the Upper West Region.

Solar Battery Charging

The Ministry of Mines and Energy has completed and put into use a 1.5 KWp solar PV battery charging station at Wechiau in the Upper West Region using Siemens and Photowatt modules, which is an indication for future expansion of Siemens market share in the country.

Solar Lanterns

There has been recent entry into the solar PV market by Switzerland. The Burden Rotary Club International of Switzerland presented 205 solar lanterns, manufactured by NESTE Advanced Power Systems, to the Non-Formal Education Division of Ministry of Education for promoting learning by literacy classes in both the Upper East and West Regions.

Local Production/Assembling of Solar PV Components

The University of Science and Technology, Mechanical Engineering Department in collaboration with Universty of Regina and Canadian Internal Development Agency (CIDA) is building local capacity for the assembling of solar PV components in the country. They have assembled charge controllers & light fixtures and also installed two solar battery charging stations of 290Wp capacity each at Addonkwanta, a town in the Eastern Region, Asuahyia in the Ashanti Region and Dromankese in the Brong Ahafo Region.

Table 2 - Status of Solar Water Heaters Installed in Ghana, May 1997

User	No of Units	Manufacturer	Application	Date of Installation	Status/Remarks
Presby Hospital, Donkorkrom	3 Flat-plate thermosiphon	Avotrain, Abetifi	Domestic, Pre-heating water for irrigation	1991	Functioning
Presby Hospital, Bawku, UER	1 Flat-plate thermosiphon & 1 Vacuum type	Fakt, Germany	Washing, Bathing & Laundry	1990, 1991	Functioning
St. Mary's Hospital, Drobo, B/A	3 Flat-plates thermosiphon	Built by a German locally	Washing, bathing & pre-heating for irrigation	1990	Functioning
Juaben Hospital, Ash. Region	I Flat-plate thermosiphon	Edwards Hot Water System, UK	Washing and Bathing	1992	Functioning
Northern Volta Charity Hospital, Jasikan, VR	1 Flat-plate thermosiphon	A Foundation in Holland	Washing & Bathing	1989	Functioning
Presby Hospital, Agogo, Ash/R	1 Flat-plate thermosiphon	Omnisol, Holland	Washing & bathing		Not functioning
Mampong Orphanage, Mampong, Ash/R	1-Flat-plate thermosiphon	Technology Transfer Centre, Kumasi	Washing and bathing		Not functioning
Renewable Energy Centre, Appolonia, GA/R	3	Mega Sun, Greece Flogg, Cyprus	For demonstration	1997	Operative
Police Hospital, Accra, GA/R	2	Avotrain	Bathing	1995	Operative
Ridge Hospital, Accra, GA/R	2	Avotrain	Bathing	1995	Operative
Govt. Hospital, Bolgatanga, UE/R	3	Avotrain	Bathing	1995	Operative
Govt Hospital, Wa, UW/R	3	Avotrain	Bathing	1995	Operative Water supply to hospital has been disrupted

Abetifi Vocational Training Centre, Abetifi (AVOTRAIN)E/R	Flat-plate thermosiphon	Avotrain	Washing and bathing, etc.		Their product is the first generation type
Private individuals	14 Flat-plate thermosiphon	Imported	Bathing and washing	1995-1997	Operative

Total 38
Avotrain - Abetifi Vocational Training Centre
Source: Ministry of Mines and Energy, Ghana, 1997

About 99% of solar water heating installations are found in the hospitals where they are used mainly in the area of laundry.

About 70% of the systems were assembled and installed by local manufacturers. This could be attributed to the fact that solar water heating technology is relatively simple. The two producers are Danafco Engineering and Abetifi Vocational Training Centre.

Danafco Engineering Limited Ghana (DENG) is a limited liability company which has engaged in a number of engineering project in Ghana. DENG, has under the DANIDA Private Sector Programme, benefited from starting up a project for Ghana involving the production of solar heating systems for hot water in collaboration with Aidt Miljo (AM) and O.I. Electric A/S of Denmark. Currently, DENG has the most well equipped solar water heating manufacturing factory in Ghana. The factory is manned by highly qualified manpower personnel. Their installations at both Achimota and Children Hospitals in Accra were visited and were observed to be very efficient, a fact which was attested by both users.

Abetifi Vocational Training Centre offers training in vocational subject. One of the department is the plumbing Department, which in addition to its plumbing task, engages in the assembling and installation of solar water heaters. The type system that the Centre produces is the first generation solar water heaters which are not very efficient.

The high market share of the locally assembled solar water heaters could be attributed to the relatively low cost of the systems as against the imported ones. It is expected that in the near future DENG system will dominate the market since they are now being highly recommended by the user institutions (consumers).

Table 3 - Status of Solar Crop Dryers Installed in Ghana, May 1997

Location	No. & Type of Dryer	Produce	Year Installed	Status/Remarks
Tsokome, GA/R Okushibiade GA/R Ablekuma GA/R Gobi C/R Anomabu C/R Essamang (via Edina)	Tent dryer " " " " "	Fish Pepper Maize Cassava Fish Pepper	1987 1987 1987 1988 1988 1988	Brokendown. There was no follow-up by the installer
New Owuborong	3 Tent dryers	Pepper	1987	All brokendown

(Amate), E/R Yensiso	1 Tent dryer	Maize	1991-2	and abandoned. There was no follow-up by the installer
Nyinahin Ash/R	5 cabinet dryers	Pepper	1989	Not effective:not pleasing to users even though operative
Tamale NR	2 cabinet 2 flow-through dryers	Pepper, okro, maize	1987	Brokendown but performance was pleasing to users
Agona Asafo C/R All built by UST Ministry of Mines and Energy sponsored	2 mixed mode natural convention dryers (1 tonne capacity each)	Pepper, cassava chips	1995	Operative

TOTAL 10 Tent Dryers
9 Cabinet Dryers
2 Mixed Mode Dryers

Source: Ministry of Mines and Energy, Ghana, 1997.

Most of the solar crop dryers were installations found in the rural areas. They were being utilised for drying pepper, maize, cassava chips and fish. Although some of these installation date as far back as 1987 as demonstration projects, little progress has been made in the development of this technology in the country. This technology which could have contributed in no small way in the reduction of post-harvest losses was not given the due recognition by governmental and private organisations, and the farmers themselves. It is observed that earlier organisations like Food Research Institute, that went into the demonstration of this technology did not link up with the appropriate Ministries and other bodies for effective promotion of the technology among the targeted users.

Recently, the Ministry of Mines and Energy in collaboration with University of Science and Technology has constructed two commercial solar crop dryers of same capacity each at Agona Asafo in the Central Region, which will soon be put into commercial use by the farmers in the area.

SOLAR BATTERY CHARGING STATION

LOCATION	CAPACITY (Watts)	MANUFACTURER/INSTALLER	STATUS
Addonkwanta, Eastern Region	290	Kyeocera / UST	Functioning. The facility is used to charge any battery sent there
Dromankese, Brong Ahafo Region	290	- do -	- do -
Asuhyia, Ashanti Region	290	- do -	- do -
Appolonia, Great Accra Region	200	Siemens/ UST	- do -
Wechiau, Upper West Region	1500	Siemens, Photowatt/ UST, Kumasi	- do -

Solar Cooking

This technology has been experimented in most parts of the country. The experience of Ministry of Mines and Energy is that the adoption of solar cooking especially in the rural areas is very low because of the Ghanaian dietry pattern. For instance, most homes in Ghana prepare meals like Banku, Tuo Zafi (TZ), Akple, Konkonte, etc which requires stirring. Solar cooker is not ideal for this kind of cooking practice. Solar cooker could be used for cooking rice, yam, plantain, etc. But the problem for its adoption is that the system will normally take a long time for cooking and the time (in the evening) that cooking is done especially in urban areas will not allow for the proper functioning of the system.

LIST OF INSTITUTIONS/ORGANISATIONS VISITED

DENG
SSNIT
GREDA
P&T
Railways Corporation
Hugh
Ministry of Health
Ministry of Food and Agriculture
Oil Marketing Companies (Shell, Goil, Mobil, Elf, Total)
Ministry of Mines and Energy, Accra
Ministry of Education (Non-Formal Education)
Solar Technology Associates, Accra
Solar Energy System, Accra
Ghana Solar Energy Society (GHASES)
Japan Motors, Accra
Shangri-La Hotel, Accra
Ridge Hospital, Accra
Police Hospital, Accra
Sakumono Estates
Mr Peprah
Addonkwanta
Agona Asafo
Dromankese
University of Science and Technology, Kumasi, Mechanical Engineering Department
Wechiau
Bilfaco
Bolgatanga District Assembly
Non-formal Education, Bolgatanga
Wa District Assembly
Non-formal Education, Wa
Kokrobite
Volta River Authority

SALES AND MAINTENANCE

There are about thirteen marketing outlets in the country. Ten of these deal in solar PV systems with the other three marketing solar water heaters. The dealers, usually do not stock the solar systems in large quantities for sale. Rather, most invariably, they import the system for the prospective users when approached. The reason for this state of affairs is due mainly to very low demand for solar systems in the country and the very high capital outlay required for the solar business. It therefore normally takes about a month for a solar system to be delivered and installed for the user. The dealers usually render design, installation and after-sales service for their consumers.

Apparently, there is no effective coordination of the dealers of solar energy systems in the country. Most prospective users of the solar technology are ignorant of the type of after-sales services currently available. Design and installation services are taken for granted by the consumers. They often do not bother about warranty on the systems and parts during procurement, delivery and installation of the devices.

Supplies of solar systems have not put into adequate advertisement in the local media at least to create the necessary consumer awareness on the operation and use of systems as compared to other new technologies like mobile communication systems which are quite new technologies that have cut on. Presently, a lot of consumers even those in the very high income group who are literate know very little about the operation of solar systems.

Most of the supplies of the solar systems hire local technicians who often do not have adequate knowledge on solar energy technology to install the systems. This has led to improper installation of some of the systems that were visited on the field.

On the other hand, users find it difficult to detect the appropriate state of charge of the battery subsystem. Lack of knowledge in the operation of the batteries technology for instance checking and topping acid water of batteries has in most cases rendered most the solar systems non-functional. Controller and Accountant General and Ghana Education Service solar communication system at the districts and regions had this problem.

CONSUMER PERCEPTION

During meetings with users, they confirmed that solar energy technology is a viable energy alternative especially for people who live areas remote from the electricity grid. The category of users interviewed were in solar communication, solar refrigeration, solar water pumping, and solar water heating. All the category of users emphasised that though the technology is capable of providing the expected results in these different areas of application, the high cost of solar systems on the local market, which could be attributed to import duty and sales tax levied on them, accounts for the low patronage of solar energy systems in the country. Consequently, they advocated for the scrapping off of import duty and sale tax on imported solar systems in order to reduce the price. They also called for credit scheme that will hve repayment period of 3 to 5 years (i.e. corresponding to the life span of the battery) to encourage people to buy and use the technology. About 30% of the users visited complained that their systems developed operational problems during the initial stages of installation. This was attributed to improper installation works. Majority of the users therefore proposed that since solar technology is relatively new, there should be a coordinated programme to train technicians in the design, installation and maintenance of solar systems.

Due to the reliability of the solar systems, most of the organisations have installed solar communication systems as back ups for period that grid electricity goes off. Majority of them of them who are now not connected to the grid agreed that they will continue to use solar systems even if when get connected. Controller and Accountant General and Ghana Education Service complained there were occasional battery failures which is due to the operators ignorance in the daily check on the batteries to ascertain the correct acid water levels. These organisations are of the view that some sort of training should be provided them and prospective users especially operators on how to maintain batteries.

The low maintenance cost of the system was one of the facts that was substantiated by these users, indicating that for three to four years that most of them had their systems installed no maintenance cost has been incurred.

The users of vaccine refrigerators (hospitals and clinics) indicated that the refrigerators are playing a positive role in health delivery in the rural areas. Nurses interviewed indicated that due to availability of these systems in the rural areas, the potency level of vaccines for children are maintained all the time and this has helped to reduce morbidity and mortality rates. They further spoke of the importance of hot water in the health delivery set up and therefore called for the provision of water heating systems, preferably solar water heaters, in hospitals and clinics.

OPPORTUNITIES FOR SOLAR TECHNOLOGY UTILISATION IN GHANA

Solar energy has enormous opportunities in almost all the economic sectors in the country; ranging from Agriculture/Industries to Health).

Agricultural Sector

In line with the Government, World Bank and Donors recent policies for increased food production and food security in order to improve the social and economic status of the rural population, particularly the poorest and most vulnerable groups in society demand for energy is expected to increase.

In the light of this solar energy would prove to be the core energy resource for achieving this goal. This commitment to achieve self sufficiency in food production would depend to a large extent on increase productivity in the rural areas. These activities will be possible if irrigated farming is introduced in most parts of the country. Solar powered water pumping and solar drying techniques could serve as reliable alternative to otherwise expensive diesel and electric systems for small scale irrigation and mechanical dryers in remote areas of the country. In this respect, it is believed that there would general improvement in the living standards of the country's predominately rural population with solar power.

Immediate Opportunities On Irrigation and Solar Drying

Irrigation

A visit to the Anlo traditional area revealed that small-scale irrigation farming is carried out in this area by certain categories of farmers i.e. those who can be classified as high and middle income farmers. They rely basically on electric, diesel and petrol pumps, manufactured by PEDROLLO of Italy, to pump water from both hand-dug and tube wells to irrigate their farms.

For a 400x150 sq. ft farm, a daily average of four gallons is consumed by a petrol pump for irrigation, and three gallons for a diesel pump. The farmers indicated that depending wholly on either diesel or petrol pump is very expensive; thus compelling most of them to switch to electric pumps. They find electricity far cheaper because at the end of every month they pay a flat rate of ¢18,000 as compared to ¢420,000 a month for petrol and ¢297,00 for diesel. For those who have switched to electricity, diesel or petrol pumps are used as back-ups in the event of power outage.

With the introduction of electricity for pumping, the cost of the energy component in the total investment of small-scale irrigation farming has been reduced from 30% to15%. Additionally, the electric pump has an advantage of low operational and maintenance cost as compared to petrol/diesel pump.

After the above investigations, the farmers were introduced to solar pumping technology as a substitute to electric and petrol/diesel pumps which would help eliminate some of these problems that were being raised. Other issues that came out from this interaction with the farmers were:

- very high acceptance level for the adoption of solar pumps as far as it was going to be the cheapest alternative to electric and petrol/diesel pump.
- the problem of maintenance was identified since competent and qualified technicians are not located in the area.
- the problem of security of the solar installations was raised in the sense that since the farms are far from their homes, there is likelihood of thieves removing these systems at night.

The farmers proposed that a pilot solar pumping irrigation farm should be established to demonstrate the viability of the technology.

The Extension Division of the Ministry of Food and Agriculture indicated that they have mapped out areas where tube well technology will be used for irrigation farming and solar technology is one of the options that is being considered to pump the water.

Drying

The export of non-traditional products are catching on very fast in the country. Nevertheless, the question of high quality of the product is paramount, for dried produce. Solar crop dryer eliminates any contamination of dried produce such pepper, cassava chips, cola nuts, salted fish, etc.

In 1996, === tonnes of pepper were dried by two tonnes capacity natural convection solar crop dryers installed at Agona Asafo, Central Region for export to USA. Under this contract only 40% of the export product was achieved due to limited size of the dryers. Meanwhile, a lot more of such high quality solar dried produce (like cola nuts, cassava chips, salted fish, etc) for exports exist as revealed by Ghana Export Promotion Council.

Health

With the government's policy of providing health facilities in every community of population of 2000 and above, solar water heaters, solar vaccine refrigerators and solar lanterns will continue to be a favourable option in rural health delivery system. One of the examples of how solar technology has contributed significant in rural health delivery was observed at Binde Health Centre.

A visit to Binde Health Centre which is owned by a Dutch NGO in the Northern Region, revealed that for the past five years solar technology has met the refrigeration, lighting and operating theatre equipment needs of the Centre. Binde, a town in East Mamprusi District whose population is predominately farmers was noted for high incidence of snake bites. This was the reason why the Dutch NGO established this health facility in the village. As an additional measure to reduce the high incidence of snake bites in this town, solar lanterns were introduced to the farmers in this community since the main cause of these snake bites was due to non-existence of outdoor lighting systems in the night. By this measure the health facility has been able to reduce this high incidence of snake bites. This is one area where solar technology could be used to achieve the health delivery needs of the rural people.

How did Binde Health Centre promote the solar lanterns? The farmers in the first place were educated on the need to get an outdoor lighting system in the night. The Health Centre operated the charging unit. All that the farmers needed to do was to bring the solar lanterns to the Centre for charging in the morning whilst they are on their way to their farms. They come back in the evening through the Centre to collect the charged lantern for use. At the time of the visit, this was being experimented to determine the acceptance level of the technology and the subsequent mode of payment/renting of the systems.

Rural Electrification

Under the National Electrification Scheme (NES) all communities are expected to enjoy electricity services by the year 2020. It is obvious that even when the NES is completed many remote communities will still lack electricity. For these communities, solar PV systems would be valuable option to provide electricity services.

The Ministry of Mines and Energy has already identified this problem and has established a pilot solar PV battery charging station at Wechiau in the Upper West Region. By this system, individual households who are required to purchase batteries and lighting fixtures would have their batteries charged at this station for a fee.

This an area where private and/or donor support will be required in extending electricity to remote communities in the country.

Housing

With the recent increasing private investment in estate development, solar PV and solar water heaters could be incorporated into the modern housing architecture. A discussion with Ghana Real Estate Development Association, indicated that these technologies are viable and would be cost effective in view of the expected increases in electricity tariff and petroleum prices. The estate developer considered solar PV serving as back ups for periods of power outages against the use of diesel electricity generators to be most favourable. They also considered solar water heaters as a cheaper option against electric heaters.

Industry/Commerce

In both industrial and commercial sectors, the need for hot water is high. A few of the food processing industries and hotels visited appreciated the need for installing solar water heating systems for preheating water in order to cut down cost on electricity bills and fuel cost.

Telecommunication

A lot of business is expected to boom in the telecommunication sector for solar PV dealers. In view of the rampant power outages and expected rising cost in electricity tariff, a lot of organisations have accepted that solar would be a viable option for powering their communication equipment.

In the southern part of the Volta region where the water table is shallow, the farmers in this area make use of electric pumps to pump well water to irrigate their farms. They were hitherto using diesel or petrol pumps which were very expensive to run due to high fuel and maintenance costs.

The economic analysis suggest that the solar pump is very competitive with the electric pump and therefore when introduced, the farmers will readily shift to solar. Some farmers who were interviewed in the area, suggested that for those farmers that are very remote from the grid, solar pumps will be welcome if introduced since they would be less expensive than diesel pumps.

In the industrial sector, opportunity exists in using solar water heaters to preheat water in the rural cottage industrial

IDENTIFICATION AND ANALYSIS OF MAJOR CONSTRAINTS MILITATING AGAINST POPULARISING SOLAR ENERGY SYSTEMW IN GHANA

4.1 Price of PV Systems

The prices of the systems are not affordable for an average income earner to purchase. For example, the market price of a solar PV system providing power of 120 Watts to house is about ¢2,000,000.00. Assessing the income of workers in the middle income group, a worker earns an average of about ¢5,000,000.00 per annum. Using this income as a basis, a PV system will take about 40% of that worker's annual income. Such an investment is could be considered too high for people in this income group.

A careful examination of the price of the above indicates that the CIF value is about ¢1,400,000.00 and tax component of 25% of CIF value amounts to ¢350,000.00. Assuming the importer takes 18% of CIF value as his margin, which is about ¢250,000.00, the price of the referred 120 Watts systems comes to ¢2,000,000.00.

Looking at the above breakdown, the 25% of CIF value which is the tax element that government is imposing on this new technology, which is acclaimed world-wide as an environmentally friendly energy substitute, is too high. By this analysis it is recommended that either the total 25% of CIF value as tax is completely removed or reduced to about 10%. This will considerably reduce the market price of solar systems and make them affordable for the average income earner.

If importers can take advantage of tax exemption on imported components for the assembling of solar systems locally, it should be expected that the market price of solar systems will be reduced considerably.

4.1 Perception of Users

Majority of Ghanaians, both in rural and urban areas, do not have adequate knowledge of solar technology. This is because the technology has not been effectively promoted by the Ministry of Mines and Energy and dealers, either through advertisement or by any other media facility in the country. Up to date, radio and television, the most popular advertising medium does not carry a single advert on solar systems. Citing the example of the promotion of cellular telephone systems in comparison to solar technology, one would observe that the cellular telephone systems have gained rapid market expansion within a period of three years after the introduction of the technology in the country and consumer acceptability has been found to be high due to the effectiveness of the advertising techniques that were deployed for their promotion. If solar technology is also given the same level of promotional effort it will gain high popularity among Ghanaians.

Both the Ministry of Mines and Energy and donor agencies can contribute effectively towards raising consumer awareness of the solar technology by running educational campaigns, workshops/training and demonstration sessions for various categories of people in the country.

Operational Problems

It was identified during the visit to solar installation sites that about 90% of users did not have adequate knowledge of how solar technology functions or operates. This is due to the fact that installers, after the initial training on the use of the system do not give user manuals or maintenance checklist to users to enable them undertake routine check and maintenance on the systems.

It is recommended that donor agencies should assist recognised organisations/associations involved in the promotion of solar technology in the country to draw up a suitable user manual and checklist on the various solar systems to create the necessary user knowledge for the operation and maintenance of these systems.

Another problem identified was that most of the installers do not engage qualified solar technicians to do the installation works. This, in most cases, has resulted in improper siting and installation. It is recommended that donor agencies should assist NGOs in organising training programmes, periodically, to equip technicians with the necessary installation skills.

ENERGY NEED IN AN AFRICAN FAMILY

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Introduction

When we talk of Energy needs of an African family we may first need to define the status of the African family we wish to discuss. As we shall see the energy needs vary significantly from one group to the other. For the purposes of this discussion we shall consider the four basic groups; the African family in rural area, the rural-urban dweller, the middle class family and the upper class family. The family sizes will normally depend on where they leave and the position on the economic ladder. It is most possible that the rural family will have a large family, because they need more hands to work on the farm. But for the purposes of this discussion, it is assumed that the families are of the size.

The Family

Suppose we consider that the family is made up of the couple and four children (an average one). In the rural areas the family may live in a hut. Their energy needs are basic, and these can be met by what is available in the neighborhood. The main energy needs of the family is for cooking heating and drying of farm products.These energy needs can be met from farm residue or fuelwood and solar energy.

For the semi-urban family, the energy needs are slightly more. The family's abode may be a room and a parlour. They require energy for lighting, cooling (a fan),cooking and heating. These needs can be met as follows:-

- For cooking - firewood, charcoal or kerosene.
- For lighting - kerosene, candle light (or electricity if they are lucky)
- For product drying - solar energy
- Transportation - public transport, petroleum.

For the middle class family, their abode is likely to be a two or three bedroom apartment. Their energy needs may be:-

- For cooking – charcoal, kerosene or LPG'
- For lighting - electricity

They may have one or two air conditioners in the house. Both husband and wife may be working in offices where there are fans or air conditioners. If they are lucky they may own a car for which they use petroleum products.

The upper class family is likely to own a house or leave in Government or Company provided apartment: The energy needs may be as follows:-

- Cooking - Electricity or gas
- Lighting - Electricity
- Cooling - Electricity for air conditioning
- Transportation - Own a fleet or air conditioned vehicles - petroleum

Work, live and travel around in air-conditioned environment. Thus the summary of the energy consumption of an Africa family may be summarised as follows:-

Item	Rural dweller	Rural-urban	Middle class	Upper class
Cooking	Farm residue, firewood. Dung	Firewood, charcoal kerosene	Charcoal, kerosene LPG	Kerosene LPG Electricity.
Heating(if any)	Farm residue firewood	Firewood charcoal	Charcoal	
Lighting	Dung "Hurricane lamp" oil lamp	Hurricane lamp candle light kerosene lamp Electricity If available.	Hurricane lamp, kerosene lamp Electricity candle light	Electricity Gen-set (fossil fuel)
Cooking	Natural	Natural Electric fan (if any	Natural, Electric fan, Air conditioning Gen set (if any)	Electricity Gen-set
Transportation	Animal, human	human, public system, motor-bicycle (fossil fuel)	Public system own vehicle fossil fuel	Own or Government provided vehicles. Fossil fuel
Production	Animal, human labour	Human labour, firewood, charcoal depending nature of work.	Electricity	Electricity
Leisure	Hardly any except maybe drink local brew and make babies.	Some leisure:- Cinema: Electricity	Electricity dependent	Electricity dependent.

From the foregoing, we see that the energy need of the rural and semi-urban family hardly comes into the energy equation because it is mainly non-commercial form of energy. But these families form the greater proportion of most African Countries as most Africans live and work in rural areas, except these days that we have the rural urban drift for the amenities that clean like clean energy that are not available in the rural areas.

The above result confirms the findings of a study that main source of energy in the rural areas are farm residue and fuel wood.

In rural Africa, fuelwood accounts for over 90% of the main sources of energy, especially for cooking and heating. The reasons adduced to this is the high cost of other energy sources, brake down of devices and easy availablity of fuelwood compared to other sources.

Women and children are also the main suppliers of fuelwood – their relative percentage contributions are ; women –60%, children –23%, men –13%, house-help- 4%.

Furthermore, it can be deduced from the above table that the main beneficiaries of the public expenditure and energy related infrastructure are the middle and upper classes.

Besides, the produce of most African countries come from the rural areas, these produce earn the foreign exchange with which various infrastructures are provided. Thus to stem the rural-urban drift, and ensure that the people remain on the land, it is necessary to increase the acess to energy and other good things of life that are found in the urban areas, to rural dwellers.

Since most rural areas are far from the grid, the easiest and readily available energy source that can be provided are renewables. These are cheap and environment friendly. Some of these renewable sources are Solar PV systems, Photothermal (flat plate collectors) solar driers,solar cookers and biogas digesters.

The technologies for some of these are within the reach of most African countries and the raw materials are readily available. Unfortunately the costs of these units are beyond the reach of most rural dwellers because unlike conventional energy sources they are not yet being subsidised by Government. For example, the Government should provide community centres where people can gather for a few hours in the evening, in the rural areas

These centres could have such facilities as electricity for television viewing, and other communal activities.

In addition, Government must subsidise these units by writing off part of the costs and spreading the rest over a long period.

SENEGALESE EXPERIENCE ON SOLAR RURAL ELECTRIFICATION

By Mamadou KANOUTE
Mechanical Engineering

INTRODUCTION
Energy situation of the country
The demand for commercial energy is dependent on the oil imported;
Exploitation of forests for more than half (1/2) the total energetic consumption.
Characteristics of Senegalese Rural Area
Difficult accessibility and isolation
Scattered villages
Low energetic consumptions
Low incomes
Necessity to use New Renewable Energies
Important potential
Adaptation to rural area
Preservation of the Environment

POTENTIAL SOLAR ENERGY
5.8 Kw/m²/year
3,000 hours' irradiation/year

WIND ENERGY
4 to 5 m/s between Saint-Louis and Dakar on a 30-40 km stripe
3 to 4 m/s in the Low Coast line

BIOMASS
Important agricultural and agro-industrial by - products: sugar cane residue, rice, cotton and groundnut husks;
Important forest reserves in Casamance and East Senegal.

MICRO – HYDRO
The Senegal River
The Gambia River
For a potential estimated to 1 million MW/year.

INSTITUTIONAL ENVIRONMENT
Structures
Ministerial Departments
Training and Research – Development Institutes
Test and control Laboratory
Private sector
N.G.Os

Statutory written references
Prime Minister's circular letter, n° 1022, December 21, 1978. A solar Energy alternative in public markets for energy supply;
Law n° 81-82, June 25, 1981: taxation advantages for investments in solar Energy;
Decision n° 0706/DGD/DERD/BE1: Exoneration from income Taxation and VAT (cancelled with the enforcement of the UEMOA TEC)

Decision n° 29/MEMI (Ministry of Energy, Mines and Industry), April 21, 1999: Bureau for the quality control of solar photovoltaic components.

MAIN ACHIEVEMENTS
Individual lighting: 3,000 SHS (Solar Home Systems)
Centralised lighting: 7 solar power stations
Education: > (more than) 30 elementary and secondary schools + alphabetisation centres
Health: > (more than) 4 health structures
Drinking water supply and irrigation: > (more than) 200 pumps
Solar water – heater
Battery recharging: Television, lighting, etc...
The Training of local technicians
Adoption of norms
Government official plan for Rural Electrification through Solar energy

ISSUES
At the institutional level
Lack of means for the New Renewable Energy service
Difficulties in coordinating
Import taxation and VAT (TEC UEMOA)

In the financing
Costly initial investment
Lack of adapted financing

Organisation Chart
No well-defined organisation chart for the management of solar energy Electrification projects
Shortage of specialists in repair and maintenance

At the level of the ability reinforcement
Few on – going trainings for local specialists
Little or no integration of New Renewable Energies into teaching syllabuses.

Perspectives
Organization Chart
Adoption of one or many organization charts
Setting up financing adapted to non drastic conditions

Resort to other sources of Renewable Energies
Solar heating
Wind energy
Biomass

Institutional framework
Enforcement of existing statutory written references
Foreseeing other incentive statutory and taxation measures.

I.E.C.
Campaign of sensitisation and information
Integration of New Renewable Energies into school syllabuses
Training of agents.

Conclusions

The development and promotion of New and Renewable Energies require also:

The integration of New Renewable Energies into the national energy policy

The existence of an incentive institutional framework

The Training and information of all the agents.

GRID CONTROL FOR HYBRID SYSTEMS

Mr. Paolo Pinceti [2]

Introduction

The paper focuses on the design and implementation of the Grid Master Control System (GMC) defined for the European Project JOR3-CT97-0158 - PV System Technology for the Gradual Penetration of Photovoltaics into Island Grids.

The aim of the project is to clearly indicate a way to transform isolated grids powered by diesel generators into hybrid ones with the main power contribution coming from distributed PV inverters and with battery storage capability allowing further evolution to PV/battery only. Throughout the evolution process of a typical isolated system, the GMC goal is to achieve relevant improvements in terms of power availability, frequency and voltage regulation, fuel and maintenance savings, air emission and noise reduction. The project goal is to achieve economical, environmental and social benefits. It advances a clean technology to be integrated in a wide variety of small utility grids, enhancing the quality and the reliability of the energy delivered to customers, contributing to energy savings, and furnishing employment opportunities in the hamlets where the systems will be implemented. End users of such technology are both utilities and their customers.

The GMC strategies have been defined in order to obtain the above mentioned improvements with the lowest impact over existing systems assuring the maximum implementation easiness. Distributed PV inverters are considered autonomous devices, equipped with an autonomous control logic that leads to a globally co-ordinated behaviour, which is able to maximise the solar energy production and the overall efficiency. Frequency and voltage regulation are performed by the GMC through diesel power gen-set's voltage and speed regulators and a Central Energy Buffer System's (CEBS) with bi-directional power modulation capability.

Different control strategies and operating modes are defined to cope with the forecasted system evolution. GMC's tasks include configuration management, control strategies management and battery charging management.

The technical solution outlined for the implementation of the GMC, is based on the use of a fuzzy logic. This is due to the specific skills of fuzzy controllers in dealing with uncertain information, not clearly shaped constraints or limits, and their ability to work on systems for whom mathematical models are not available or are difficult to be developed, handled or modified. The paper shows how the fuzzy controller will carry out some GMC's tasks.

The European Project JOR3-CT97-0158

The EP "PV SYSTEM TECHNOLOGY DEVELOPMENT FOR THE GRADUAL PENETRATION OF PHOTOVOLTAICS INTO ISLAND GRIDS", was sponsored by the European Commission for Non Nuclear Energy Programme - Joule III. Partners in the project are: ANIT (Italy), CRES (Greece), ISET (Germany), TOTAL Energie (France).

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The project focused on the problem of the integration of renewable energy in small and weak utility grids such as those of small islands or remote hamlets. More exactly, the aim of the project is to clearly indicate a way to transform isolated grids powered by diesel generators into hybrid ones with the major contribution coming from photovoltaics. The development of the required set of modular components was the target of the project as well. Such set of components includes a 3 kW grid connected tolerant inverter, a Central Energy Buffer System (CEBS) and a the appropriate Grid Master Control System (GMC) which is the topic of this paper.

All the above mentioned components have been integrated in an experimental pilot plant since May 1999. The project started in July 1, 1997, and got over at the end of 2000.

Application area

The application area for the technology developed throughout the Project is in the multitude of isolated networks having the following characteristics:

- population ranging from about one hundred to twenty thousands permanent residents;
- installed power capacity of diesel generators ranging from about 100 kW to up to about 15 MW. The yearly electric energy consumption ranges from about 150 MWh to up to 40,000 GWh and it is expected to increase from 5% to 8% per year;
- production cost of electricity ranging from about 12 cEuro/kW (approx. 0.1 $/kW), for large size networks, to up to about 1 Euro/kW (approx. 1$/kW) for the small ones;
- Even though already cost competitive in some islands or remote communities, photovoltaics are not introduced by utilities on a large scale due to the following main concerns:
- stability of the local utility grid with high PV penetration
- performances of PV systems with low grid power quality
- uncertainty regarding the real diesel fuel saving
- reliability of PV systems

Electricity costs and Power Quality in isolated networks

Data from Greek, Italian and French islands (the only "isolated systems" in Europe) were collected and analysed for project purposes. Even if some differences have been pointed out among the different utilities (energy costs, development policies, actual structure and renewable penetration), many common problems can be highlighted:

- electricity production cost is very high compared to interconnected electric systems, thus enabling PV systems to be competitive as fuel saving devices;
- large variations in grid frequency, up to 6-10 %, are usual;
- large variations in grid voltage, up to 20%, are usual;
- frequent grid failures caused by grid weakness.

It should be noted that such a poor power quality is an obstacle to the diffusion of most commercial grid tied PV systems, since they usually requires much more narrow frequency and voltage limits for continuous operation.

This obstacle is overcome by the development of an appropriate grid tied tolerant inverter, suitable for the interface between PV systems and the isolated grid.

Problems related to high PV penetration

Major problems related to the high penetration of PV systems in isolated grids concerns grid stability and PV power excess and/or shortage. As regards to grid stability, it has been noted that commercial inverters for grid tied PV systems requires frequency and voltage limits that are very often exceeded in isolated grids. Such constraint violations are responsible for inverters disconnection from the grid, thus emphasising stability problems. In fact, if an overfrequency limit is exceeded due to a load reduction, as an example, this would cause the simultaneous disconnection of most of the PV systems. If PV power contribution is conspicuous, such an event may lead to a load excess that could evolve to the system black-out, or at least to greater frequency oscillations.

Another important issue concerns PV power excess. As previously mentioned, the electrical load of the considered islanded system is variable during the day/month/year. If the installed PV power is a considerable percentage of the peak load occurred throughout the year, let's say 30% to 40% or more, then it is expected that the PV power will exceed the load demand for several hours during the year. The conventional approach to solve this problem is to remotely control the PV inverters, with high costs and complexity increase. An alternative solution that does not requires centralised control is presented hereinafter.

Technical approach

The strategy for the gradual penetration of photovoltaics in islanded grids can be summarised into four phases:

- Phase1: the total PV contribution is significantly lower than the instantaneous load demand of supplied loads. Tolerant PV systems are required to allow for economic operation of PV;
- Phase 2: PV contribution on the island approaches the instantaneous load demand in some periods of the year. The technical limitations to additional introduction of PV are overcome by appropriate control strategies involving distributed PV power modulation;
- Phase 3: Economic losses associated to growing PV power wastes due to additional introduction of PV are overcome by a centralised energy buffer;
- Phase 4: Further increase in PV penetration and energy buffer capacity allows for temporary switch off of diesel generators.

A Grid Master Control unit (GMC) is required to manage diesel, energy buffers and PV generators. The Grid Master Control has to solve the following problems:

- frequency and voltage regulation;
- interaction between the centralised energy buffer, the diesel generators and distributed photovoltaics generating units;
- daily operating modes policy;
- alarms and emergency management;
- black-start procedure

The paper is focused on the first two points in order to define grid voltage and frequency regulation policy and to define interfaces between the GMC and the various generating units.

GMC OBJECTIVES

The Grid Master Control goal is to achieve the following improvements for the typical island systems:

- Power Quality;
- Power availability; the GMC is expected to bring considerable improvements in terms of stability of the local utility grid, reducing faults disturbances due to small isolated systems' intrinsic weakness
- Frequency regulation; to fully satisfy standards' requirements for frequency range in non-interconnected electrical systems, the grid frequency must be kept within rated frequency ± 2% over 95% of a week, and rated frequency ± 15% over 100% of a week. The target is to reach better results with a narrow frequency deviation.

- Voltage regulation; according to international standards, the system voltage, in normal operating conditions, must be kept within VR ± 10%, where VR is the system rated voltage.
- Costs Savings;
- Fuel savings; appropriated design of the GMC and its strategies should lead to diesel fuel savings
- Maintenance and machinery life cycle; the GMC implementation will positively affect the rotating generating units availability and will reduce the maintenance costs.
- Environmental issues returns;
- Air emission reduction;
- Noise reduction

A must of the project is to allow the transformation of existing conventional grids into hybrid grids to be gradual, in order to gain acceptance from local utility companies. Therefore, great importance is given to technical solutions which guarantee easiness, adaptability and low impact over existing systems.

SYSTEM DESCRIPTION

When the large scale penetration of PV systems is reached, the electric system of a typical island grid appears as it's schematically shown in figure 1. In such a system the main actors are identified as follows:

- loads, to be considered for the absorbed power;
- tolerant grid tied PV inverters (PV), to be considered for their power injection;
- Diesel Generator(s) (DG), which are able to perform frequency and voltage regulation or power control;
- the Central Energy Buffer System (CEBS), which allows for a bi-directional power flow according to the control strategy implemented by the GMC

It has to be noted that while DG(s) and CEBS are located in the power plant, and therefore easily accessible from the control room, PV systems and loads are distributed along the system, and not subject to any remote control.

System evolution

The maximum PV penetration on an grid is reached gradually, and four phases can be identified:

- Ph. I: The PV penetration is low. The diesel generator is the only actor and PV's power contribution just reduces fuel costs.
- Ph. II: Due to increasing PV penetration, PV's generated power approaches, and sometimes exceeds, the load demand. The CEBS is not yet installed. For most of the time, the diesel generator is the only actor or the main contributor. However, in some midday hours we have to deal with two power contributors needing some co-ordination action.
- Ph. III: With further growing of PV contribution, to avoid economic losses due to PV's energy waste and to stabilise the system operation, the CEBS must be installed. This allows to absorb exceeding power from the grid and to return it when necessary. In this phase three different generation entities are present (distributed PVs, diesel generator and CEBS), and a GMC is necessary.
- Ph. IV: With a further increase in PV and CEBS capacities, the CEBS is able to cover the entire load demand, allowing to temporarily switch off the diesel generator. Finally, it will be possible to run the system using only the CEBS and distributed PV's generators, while the DG should be used in extra-ordinary situations or high load seasons.

Table I summarises the various system's configurations to be handled throughout the system evolution.

Table I - Power System configurations

	DG	distr. PV contr.	CEBS Inverter/Rectifier		Conf. name (abbr.)	comments	GMC
Phase I	ON	low	X	X	CONVENTIONAL (C)		not required
Phase II	ON	high	X	X	DIESEL/PV (DP)	PV contr. approaches or exceeds instantaneous load demand. Actions are needed to avoid power excess	not required
Phase III	ON	high	ON	X	DIESEL/PV/CEBS Inverter mode (DPBI)	Frequency and voltage regulation are possible in various ways	required
	ON	high	X	ON	DIESEL/PV/CEBS Rectifier mode (DPBR)	Battery charging methods have to be considered	
Phase VI	OFF	high	ON	X	PV/CEBS Inverter mode (PBI)	Frequency and voltage regulation have to be considered	required
	OFF	high	X	ON	PV/CEBS Rectifier mode (PBR)	Frequency and voltage regulation have to be considered	

Notes to table I:

- for each phase, only configurations different from those listed in previous phases are considered
- each phase includes all the system's configuration related to the previous phase, although not listed according to the previous statement

Distributed PV inverters control

Commercial PV inverters are designed to run in Maximum Power Point Tracking (MPPT) mode, using the grid frequency to synchronise the inverter, provided that grid voltage and frequency operating limits are respected. This feature, allows to maximise the PV system efficiency for any given solarisation condition and has no drawbacks as long as the PV inverter is tied to an interconnected grid. However, when the PV power contribution becomes an important part of the total generated power, a more complex control logic is needed. In fact, the gradual increase in PV systems installation leads to a situation (envisaged as the Phase 2) in which the PV power contribution needs to be modulated, i.e. reduced with respect to the MPPT value, in order to allow the diesel generator to remain within its operating limits. To solve this problem, a frequency droop is introduced in the inverter control logic to lower the power injected into the grid. When the frequency rises above a given threshold, the output power is reduced accordingly to the frequency error with a settable gain (droop). Such a logic doesn't require any remote control action from the GMC, with the following advantages:

- power availability is not reduced by the presence of the communication network (required if a remote control has to be performed);

- distributed PV inverter are traditionally autonomous devices; changing such a philosophy may have unexpected effects on the behaviour of a proven technology;
- the GMC machine can be downsized, since no communication task is required;
- eliminating the communication and remote control simplifies the software structure of the GMC, thus increasing its availability and maintainability;
- legal troubles arising from the different properties of inverter (users) and grid (utility) are avoided;
- the global efficiency of the system is maximised.

Central Energy Buffer System (CEBS)

The CEBS is made up of three main elements as shown in figure 2:

- a Two Way Inverter (TWI), allowing bi-directional power flow
- an Accumulator Battery (AB), providing the energy storage capability
- a CEBS Control System (CCS), driving the TWI according to the GMC strategies and monitoring the whole apparatus.

The CCS drives the TWI in two different operating modes: current mode or voltage mode.

In current mode the TWI injects real and reactive power into the grid, by controlling the rms value and the displacement factor of the current. The real and reactive power values are the input signals for the CCS and are provided by the GMC. In this operating mode, the CCS uses the grid frequency to synchronise the inverter.

In voltage mode the TWI controls the grid voltage on the connection node of the CEBS with the grid. Therefore, the power flow is determined by the grid real and reactive power demand. This is the typical operating mode for a UPS (Un-interrompible Power Supply), that's why it's also referred to as "UPS mode" in this paper. It must be pointed out that in this operating mode the CEBS is able to generate power or to absorb power according to the grid requirements. This particular feature is crucial to the practical feasibility of phase IV of the project. When the voltage mode is selected, the GMC sets the voltage and frequency reference to the CCS.

It has to be noted that, due to power electronics technology adopted, the CEBS performances in terms of frequency and voltage control are better than those of traditional power generating units. Such a characteristic is very useful in order to improve the power quality of the grid. The CEBS is located in the power plant, near the DG units, so their co-ordination is quite simple.

Control strategies

This chapter outlines the control strategies which are implemented to perform frequency and voltage regulation in the various system's configurations (defined in 4.1). The various control strategies are presented in the same order of the project's phases, so that it's easy to understand how the GMC functions will be gradually introduced in a typical islanded system.

Conventional configuration (C)

In this configuration, the Diesel Generator is the main power contributor.

This is the only configuration possible as long as the PV penetration inside the electrical system is low, but it's also very common in phase II of the project, since PV contribution is solarisation dependent and the battery storage facilities is not yet available. Moreover, such configuration can be obtained even if the project is in more advanced phases, according to GMC policy or due to system's faults.

When the system is in C configuration, both frequency and voltage control are carried out by the DG as in any conventional electrical grid. This is accomplished by the existent DG regulators also when GMC system is installed and the C configuration is selected.

Diesel/PV configuration (DP)

This configuration is reached with the gradual penetration of PV inverters, when the PV power contribution approaches the instantaneous load demand (phase II).

In such a condition, it becomes impossible for DGs to manage grid master functions, unless the PV generated power is somehow regulated or lowered, since DGs cannot run below their minimum power rate (Pdmin). On the other hand, they cannot be switched off all together, because a system with only PV power contribution is unstable since no device performs frequency control.

The DP configuration is very important since it represents the very first technical obstacle for a large scale introduction of photovoltaics into islanded grids.

A major feature of the presented technical approach is that frequency and voltage regulation are carried out by the DG in almost the same way of configuration C, just introducing some minor modifications to the DG's speed regulator. This is achieved thanks to the autonomous control logic of the tolerant PV inverters developed for the project (see 4.2). The control strategy is based on the fact that decentralised inverters lower their generated power whenever the grid frequency exceeds a specified value (fH) for a given time, and that they come back to MPPT mode when the frequency returns below a given value (fL) for a defined time.

To assure that decentralised PVs lower the power supplied to the grid before the DG reaches its minimum real power limit (PDMIN), a threshold level on the DG's throttle actuator is introduced, so that the following behaviour can be obtained:

Until the PV power contribution is low with respect to the instantaneous load demand, DGs regulates the frequency as they usually do (SC characteristic in figure 3). The system is running in its Conventional operating mode.

As PV power contribution approaches instantaneous load demand, DG's speed regulator gradually closes the Diesel throttle until the introduced threshold is reached. DG's throttle is not closed anymore even if the frequency error remains. The system enters into DP mode and any further increase in PV power injections, or a load demand lowering, makes the DG accelerate, and the frequency rise (SDP characteristic on figure 3)

As frequency exceeds the value fH, decentralised PV inverters leaves the MPPT mode and lower their power injection into the grid until the frequency is stabilised within acceptable values.

If the PV power becomes lower or the load demand increases, the frequency goes below the value fL, and the PV inverters switch back to MPPT mode; the system returns into its Conventional operating mode.

Diesel/PV/CEBS Inverter mode configuration (DPBI)

This configuration becomes possible with the introduction of the Central Energy Buffer System and the Grid Master Control system. The GMC does not control directly the PV inverters. Their effect is indirect through the grid power balance. In the power plant, both DG and CEBS have the capability to perform frequency and voltage regulation. A control strategy is implemented to co-ordinate their operation and to satisfy the grid demand (PG and QG). The DPBI configuration and its control strategy are shown in figure 4 and table II.

The major feature of the control strategy defined for the project are the following:

- The DG runs at constant power rate, receiving the reference power value PD* from its interface with the GMC
- the real power is balanced by the GMC through the CEBS, controlled in current mode; the GMC measures the power PG (t) requested from the grid and drives the CEBS to inject the power value PI (t) = PG (t) - PD*

Voltage regulation is carried out by the DG's voltage regulator

The CEBS reactive power injection into the grid is proportional to its real power injection through a constant value, K, set from the GMC

Table II - DPBI control strategy

CEBS (inverter mode)	PI (t) = PG (t) - PD* QI (t) = k PI (t)	active power control - frequency regulation fixed real/reactive power ratio
Diesel Generator	PD (t) = PD* QD (t) = f(V)	fixed power according to GMC system strategies reactive power control - voltage regulation

This technical solution is expected to be very effective, in fact:

- CEBS ability to perform fast power regulation improves power quality in terms of frequency stability and power availability;
- fixed power operation of the DG improves its energy efficiency with fuel savings to be added to those due to PV contribution;
- running the DG at fixed power rate brings considerable benefits in terms of combustion's results emission and noise reduction;
- fixed power operation has positive effects on machines' life cycle and maintenance costs.

DIESEL/PV/CEBS Rectifier mode configuration (DPBR)

In DPBR configuration, the CEBS charges the batteries absorbing power from the grid, while the DG is running and decentralised PVs inject power into the grid.

DPBR configuration accepts both positive and negative values for PG (and QG). As for DPBI configuration, distributed PV inverters are not involved in GMC activities. Their power contribution is considered in PG and QG values.

The control strategy implemented when the system is in DPBR configuration is exactly the same implemented for DBPI configuration. The only difference is in the direction of the power flow in the CEBS. Thus, the same benefits are expected. The charging power fed to batteries (i.e. the charging current) is modulated from the CEBS according to GMC control signals. Table III and figure 5 summarise the DPBR configuration and its control strategy.

Table III - DPBR control strategies

CEBS (rectifier mode)	PR (t) = - [PG (t) - PD*] QR (t) = k PR (t)	real power control - frequency regulation fixed real/reactive power ratio
Diesel Generator	PD (t) = PD* QD (t) = QD (V)	imposed power according to GMC system strategies reactive power control - voltage regulation

PV/CEBS Inverter Mode and PV/CEBS Rectifier Mode configurations (PBI / PBR)

These configurations are reached from configuration DPBI/R when the DG is switched-off (phase IV). In such a configuration, the CEBS is the only device capable of grid master functions.

From the power plant point of view, the whole grid is considered as a variable load, absorbing the real power PG(t) and the reactive power QG(t). The grid is supplied through the inverter using the energy stored in batteries; this is the typical job of a UPS. This is true unless the total PV generated power is lower than the total load demand, and the system is in the PBI configuration.

When the PV generated power exceeds the total load demand, the power excess results in a power flow from the grid to the CEBS. This is possible only if the battery State Of Charge (SOC) allows such a power flow. Since the CEBS makes no difference about power flow direction, PBI and PBR configurations can be considered together as one.

Major features of this control strategy are the following:

- the GMC switches the CEBS to voltage mode when the DG is switched-off
- the CEBS' control system drives the TWI, imposing the voltage on the grid
- the voltage and frequency values are set by the GMC

Table IV and V, and figure 6 summarise the PBI and PBR configurations and their control strategy.

Table IV - PBI control strategy

CEBS (Inverter mode)	PI (f) = PG (t) QI (t) = QG (t)	real power balance voltage/frequency regulation reactive power balance

Table V - PBR control strategy

CEBS (Inverter mode)	PR (f) = - PG (t) QR (t) = QG (t)	real power balance voltage/frequency regulation reactive power balance

When the PV power capability exceeds the total load demand, a PV power excess occurs. The exceeding power is used to charge the CEBS's batteries, provided that the batteries SOC is below its maximum acceptable value (to avoid batteries damage), and that the power excess is within the TWI rated power. Whenever one of these conditions is missing, the PV generated power must be reduced. This is achieved driving the CEBS to increase the grid frequency, so that distributed PV inverters reduce their power contribution. The frequency value is set by the GMC according to its knowledge of the system status.

Fuzzy Grid Master Control

The name "Grid Master Control" indicates the set of devices, logic, information management, strategies and control activities, required to manage the electrical system. The GMC decides the actions to be taken according to the objectives to be reached and the knowledge about the system and its requirements. The GMC manages different kinds of information, with different time frames, summarised in the following list:
Resources; system's elements availability (DG units, CEBS power and energy, PV contribution).
Short term objectives; power quality (power availability, frequency and voltage regulation).
Operating/technical limits; min and max power limits of DGs and TWI, frequency and voltage operating ranges of grid connected devices, max and min batteries state of charge etc.
Mid-term objectives; costs saving (fuel saving, maintenance reduction) and environmental benefits (noise and pollution reduction).

On the basis of such elements, the GMC has to carry out the following major decision tasks:

- system's configuration management (e.g. ON/OFF switching of Diesel units, CEBS operating mode selection, etc.);
- control strategies management (e.g. PD* assignment);
- charging methods management (e.g. refresh charge of battery string, etc.).

The technical solution outlined for the implementation of the GMC is based on the use of a fuzzy logic since the environment seem to be proper for such an application:

- the system to be controlled is subject to an evolution process in terms of capacities of its components, and such an evolution affects control strategies;
- control variables (f, V, SOC, PI, PD* etc.) are continuous, and the range of their values is subject to interpretation depending on the actual operating conditions; this implies that it's not easy and even not effective to define fixed tripping thresholds, like in conventional control;
- configuration changes have to be decided according to uncertain information and parameters (PV power availability and load demand forecasts, state of charge calculation, etc.); such parameters might better be represented with linguistic variables (like "medium", "high", "very high" etc.) then with numerical variables;
- a mathematical model for the purpose does not exist, and it might result very difficult to develop or handle, since it would be subject to many changes according to experiences gained during pilot plant tests.

A fuzzy logic approach fits point to point all the needs just mentioned, since:

- it is possible to develop a control strategy for any system configuration, switching among them according to the system's requirements;
- fuzzy logic allows to interpret continuous variables between the values true/false of Boolean logic, thanks to the membership function concept;
- fuzzy sets are extremely suitable for representing linguistic variables, and the degree of membership with a fuzzy set brings information about the value trustworthiness;
- fuzzy controllers are made up of rules describing the actions to be taken on each combination of control variables; this results in a friendly controller development process and is particularly useful to translate in a control logic the experience gained during the plant operation.

DG power set-point assignment

The assignment of the real power set-point value to the DG is one of the major task to be performed by the GMC when the system is running in DPBI or DPBR configuration (Diesel

Generator and CEBS connected to the grid). Although not a time critical task, the PD* assignment task is important in order to gain the expected benefits from the project implementations. This is true for the cost saving issues, the environmental issues and the power quality issues as well. In fact, the PD* assignment task affects the fuel consumption of the DG and the management of the CEBS energy storage capability. On the other side, it affects the power flow in the CEBS, which has to be kept within its operating limits, thus having some responsibility on grid stability. Therefore, the assignment of the DG power set-point value (PD*) involves variables that are different in terms of their nature and importance, and requires actions with different characteristics, as it's shown in table VI.

The possibility of a configuration change is considered in the field "kind of action", since it could be an output of the controller. However, only the DPBI configuration is considered in the example reported in this paper.

From table VI the following input variables to the fuzzy controller are defined:
act_DG_pow; is the actual value of PD* assigned to the DG;
act_INVERTER_pow; is the actual value of the power supplied from the CEBS to the grid;
SOC_error; this variable blends together the last three variables of table 8 and is due to the following need: for the optimum usage of CEBS facilities, information about battery SOC must be evaluated as referred to many parameters, like the time of the day, the load demand and the PV contribution expected in the mid/short term. In fact, the same value of SOC (e.g. 50%), is good or even high if the system is going to perform a charging cycle, but it's low if the CEBS has to perform a discharge cycle. Therefore, SOC_error is defined as follows:

$$\mathrm{SOC\_error\%} = 100\frac{(\mathrm{act\_SOC}) - (\mathrm{des\_SOC})}{\mathrm{des\_SOC}}$$

where des_SOC is the desired state of charge for that moment, and act_SOC is the actual state of charge of the batteries.

Table VI - Variables used in PD* assignment

variable	nature	importance	reaction	kind of action	target
actual value of DG generated power (or actual PD* value)	technical economical	medium / high medium/ low	fast slow	change PD* value and/or configuration	to run the DG with high efficiency, according to other needs and avoiding overload or minimum power limit
actual value of the power supplied/absorbed by the CEBS	technical functional	high medium/high	very fast medium/fast	change PD* value and/or configuration	to run the CEBS within its operating limits and assuring adequate safety margins
batteries state of charge (SOC)	technical economical	high medium / low	medium slow	change PD* value and/or configuration	to schedule adequate charge reserve and avoid overcharge
load demand forecast	functional economical	low / medium low	medium slow	change PD* value and/or configuration	CEBS scheduling according to daily load profile and avoid unsafe operating conditions

available PV power forecast	functional economical	mean/high low	medium/slow	change PD* value and/or configuration	batteries scheduling to avoid PV energy wastes and unsafe operating conditions

The only output variable discussed in this paper is the variation assigned to the DG power set-point value: DG_set_change.

Figure 7 shows the fuzzy sets and the inference rules (with associated rule weights) defining the fuzzy controller for the PD* assignment task; power values are expressed in percent of devices rated power, while the SOC_error is expressed as a relative error.

Summarising the inference rules set:

- act_INVERTER_pow higher than "normal" results in PD* increases in order to avoid overload risks for the TWI; since this issue concerns the system stability, the weight of these rules is high.
- act_INVERTER_pow lower than "normal" results in PD* decreases in order to avoid frequent oscillations between the DPBI and the DPBR configuration; since this issue doesn't concern the system stability, the weight of these rules is low.
- act_DG_pow higher or lower than "normal" results in PD* changes in the direction that drives to a "normal" value (where such values set is centred near the maximum efficiency power rate of the DG); this issue concerns both economical and technical considerations, thus the rule weights are quite high.
- positive SOC_error results in PD* decreases while negative SOC_error results in PD* increases in order to manage the batteries according to the energy storage policy; since this issue concerns mainly economical items, the weight of these rules is medium, increasing for very large errors.

The model is implemented with the Matlab Fuzzy Toolbox. Figure 8 to 10 show the rules fired for three different combinations of the input variables.

When the system is running near optimum condition, the DG is running at a good efficiency power rate, the CEBS is feeding power to the grid within good safety margins and the battery SOC error is near zero (figure 8). In such conditions, the output variable value is "keep", i.e. no changes are required to the DG power set-point.

If a load change now causes the CEBS to supply an "high" power value, the rule number 4 is fired (figure 9), the output of the controller becomes "keep" + "increase lightly", and the defuzzyfication algorithm returns a positive value (about +5%), to increase the DG power set point and gain system's safety.

Figure 10 shows an input variables combination in which different needs are evaluated by the controller; while DG efficiency would require an increase in DG power set-point, the large positive SOC error requires a PD* reduction to allow the CEBS to discharge the batteries.

The controller behaviour is further shown with the control surfaces displayed in figure 11 to 14.

Figure 11 and 12 display DG_set_change vs. act_INVERTER_pow and SOC_error for two different values of act_DG_pow. Both figure 11 and figure 12 show that the power supplied by the CEBS has minor effects on the set-point value unless safety margins are approached. On the other hand, SOC_error has greater effects when the CEBS is within such safety margins. Figure 12 shows higher values for DG_set_change since the lower actual DG power rate requires a PD* increase for DG efficiency. Such behaviour is even more evident in the next figure 13, which is referred to a lower value for act_DG_pow.

Figure 14 displays the control surface obtained for DG_set_change vs. act_DG_pow and act_INVERTER_pow when the SOC_error is equal to zero. The output value is mainly affected from DG efficiency needs, unless the CEBS approaches the safety margins.

Using fuzzy logic and a very simple model, we managed to achieve some encouraging results for the DG power set-point assignment task. Better results can be achieved with further investigations and experience. With the same methodology, other tasks of the GMC should be designed, in order to perform the whole configuration management.

Conclusions

The paper presents the criteria that drive the project of a Grid Master Control system for an hybrid system for small-medium size islanded power systems. The basic idea of the design is not to centralise the control of the distributed PV inverters in order to reduce costs and to increase system simplicity and reliability. Such a non conventional solution requires some special control actions that are described in the paper. The strategic control is performed by a fuzzy controller that seems to manage properly the variable system structure and heuristic behaviour.

The Grid Master Control and all the other devices necessary to create a stable hybrid system are now under test in the CRES Laboratory, in Greece, before installing them in a small island of the Mediterranean See.

Author short biography

P. Pinceti, PhD, works at the University of Genoa (Italy), where he teaches Industrial Measurements and Control at the Electrical Engineering Dept. His research activities are focused on digital control systems based on fieldbus technology. Paolo is the advisor of the ISA Student Section of Genoa University since 1998.

GRID MASTER CONTROL TECHNICAL SPECIFICATION

INDEX

SCOPE

The aim of this document is to describe the Grid Master Control (GMC) main requirements and characteristics. This discussion is not exhaustive and is mainly focused on the control logics and the interactions between the GMC, the Diesel Generator (DG) and the Central Energy Buffer System (CEBS) to be developed. The control performances of Tolerant Inverters (TI) for the distributed PhotoVoltaics (PV) arrays are specified as well.

FOREWORDS

The Grid Master Control (GMC) strategies are specified to solve the following problems:

- Frequency and voltage regulation;
- Interaction between Central Energy Buffer System (CEBS), Diesel Generator (DG) and distributed PhotoVoltaics generating units (PV);
- Daily operating modes policy;
- Alarms and emergency management;
- Black-start procedure

Within each of these points, main problems are pointed out and possible solutions have to be suggested.

OBJECTIVES

The Grid Master Control goal is to achieve the following improvements for the typical islanded systems:

- Power quality;
- Power availability; the GMC is expected to bring considerable improvements in terms of stability of the local utility grid, reducing faults disturbances due to small isolated systems' intrinsic weakness
- Frequency regulation; to fully satisfy standards' requirements for frequency range in non-interconnected electrical systems, like those of the small islands involved in this project, grid frequency must be kept within rated frequency ± 2% over 95% of a week, and rated frequency ± 15% over 100% of a week [2]. The target is to reach better results with a narrow frequency deviation.
- Voltage regulation; according to international standards [2], the system voltage, in normal operating conditions, must be kept within VR ± 10%, where VR is the system rated voltage.
- Costs savings;
- Fuel savings; appropriated design of the GMC and its strategies should lead to diesel fuel savings
- Maintenance and machinery life cycle; the GMC implementation will positively affect the rotating generating units availability and will reduce the maintenance costs. This theme will be given considerable importance.
- Environmental issues returns;
- Air emission reduction;
- Noise reduction

The transformation of existing conventional grids into hybrid grids to will be gradual. Therefore, great importance is given to technical solution which guarantee easiness, adaptability and low impact over existing systems.

GENERAL CONSIDERATIONS ABOUT DISTRIBUTED PV CONTROL

Distributed PVs will be networked by mean of an effective communication link, should it be obtained through a fieldbus or through power lines.

Communication facilities between distributed PVs and the central control system bring some useful capabilities that can be grouped into two sets according to communication topics and targets:

Table A - Communication capabilities

	description	communication topics	targets
INFORMATION	capabilities related to the knowledge of the electrical system's status (total generated power, PV generated power, number of PVs connected to the grid)	instantaneous loads demand PVs power contribution number of distributed PVs connected to the grid	system's statistics purposes short term and medium term planning purposes
CONTROL	capabilities related to a control action of the central control system over the distributed PVs	on/off switching of remote PV Inverters PV power modulation	power quality purposes secondary control

Even if the distributed PV is networked, we deem that the central function of the GMC, which ensure the electricity availability to users, should not depend on the communication channels. Such a decision has its major justifications in the following points:

- power availability must not be reduced by the presence of a communication network
- distributed PV inverter are basically autonomous devices; changing such philosophy may have unexpected effects on the behaviour of a proven technology
- a control action of the central control system over a great number of decentralised inverters can overload it's operation
- any additional element or function involved in the grid master control represents a possible fault source for the system;
- by now, it's not clear whether distributed PVs will be property of the electric power company or customers' property; depending on local laws, a control action of the electric power company over customers' generating units could be dealt in different ways
- all the available renewable energy should be used; thus all PV inverters should run always in Maximum Power Point mode, and any control action making them run in different conditions should be avoided as long as possible

Therefore we specify here a technical solution which doesn't involve any control action of the GMC over the distributed PV inverters.

As explained in the following chapters, the proposed control strategies maximise the solar energy production and the overall efficiency. The system can guarantee satisfactory performances with no need of communication, since all the PV inverters are equipped with an autonomous control logic that leads to a globally co-ordinated behaviour. Communication will be used for voltage and frequency secondary control, that is to improve the power quality, not to ensure an acceptable power supply to users.

SYSTEM ANALYSIS

The following points must be considered in the design of the GMC:

- we have do deal with systems that are expected to evolve from traditional diesel supplied generation systems, through hybrid diesel/photovoltaics ones, and possibly to PV/battery only
- during this evolution, many actors will work together in the system; some of them will be present since the very first step of the project implementation, while some others will be added later
- through the whole evolution of the system, the GMC will have to meet the objectives listed in 4.

The GMC strategies and control logics must be adapted to the various Phases as described in the next chapters:

System evolution

The PV penetration will be reached in 4 phases:

Phase I:	The PV penetration is low. The diesel generator is the only actor and PV's power contribution just reduces fuel costs.
Phase II:	Due to increasing PV penetration, PV's generated power approaches, and sometimes exceeds, the load demand. The CEBS is not yet installed. For most of the time, the diesel generator is the only actor or the main contributor. However, in some midday hours we have to deal with two power contributors needing some coordination action.
Phase III:	With further growing of PV contribution, to avoid economic losses due to PV's energy waste and to stabilise the system operation, a Central Energy Buffer System (CEBS) will be installed, allowing to absorb exceeding power from the grid and to return it when convenient. In this phase we'll have to deal with three different generation entities (distributed PVs, diesel generator and CEBS), and one of them will be able to run either feeding power to the grid or absorbing power form the grid.
Phase IV:	With a further increase in PV and CEBS capacities, the CEBS will be able to cover the entire load demand, allowing to temporarily switch off the diesel generator. Finally, it will be possible to run the system using only the CEBS and distributed PV's generators, while the DG should be used in extra-ordinary situations or high load seasons.

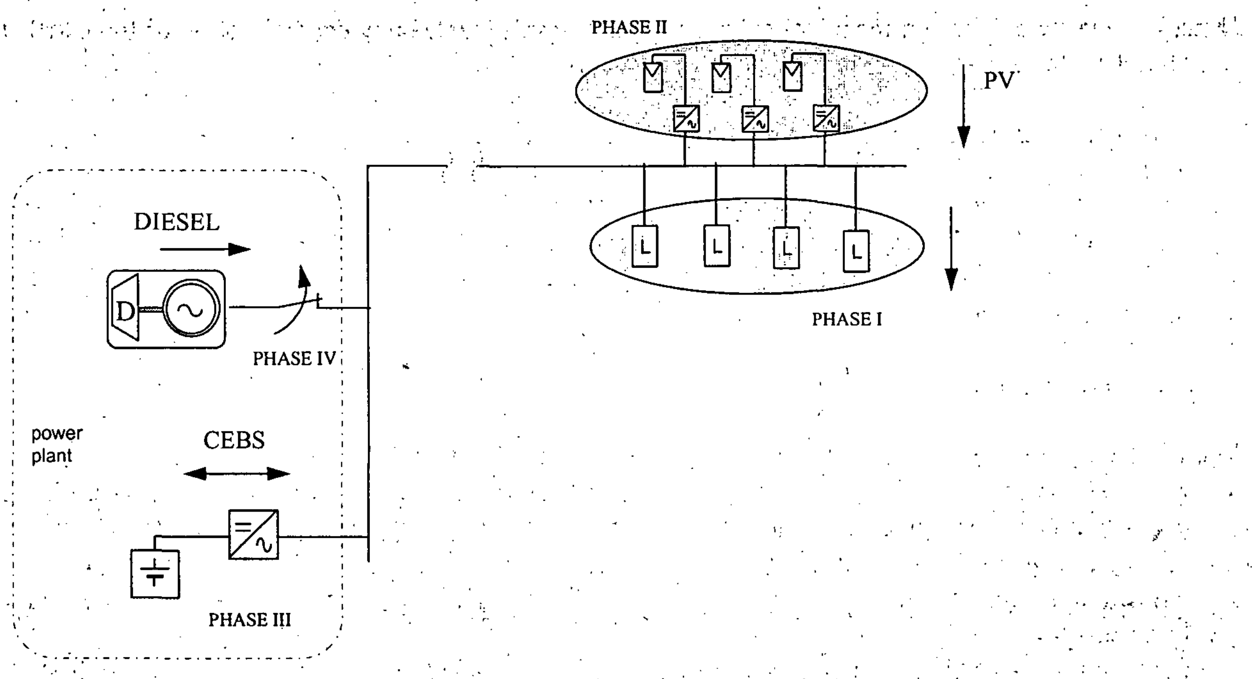


Figure A - System's evolution

System configurations

In the table below, the various system's configurations are summarised.

Table B - System's configurations

	DG	distr. PV contr.	CEBS Inverter/Rectifier		Conf. name (abbr.)	comments	GMC
Phase I	ON	low	X	X	CONVENTIONAL (C)		not required
Phase II	ON	high	X	X	DIESEL/PV (DP)	PV contr. approaches or exceeds instantaneous load demand. Actions are needed to avoid power excess	not required
Phase III	ON	high	ON	X	DIESEL/PV/CEBS Inverter mode (DPBI)	Frequency and voltage regulation are possible in various ways	required
	ON	high	X	ON	DIESEL/PV/CEBS Rectifier mode (DPBR)	Battery charging methods have to be considered	
Phase VI	OFF	high	ON	X	PV/CEBS Inverter mode (PBI)	Frequency and voltage regulation have to be considered	required
	OFF	high	X	ON	PV/CEBS Rectifier mode (PBR)	Frequency and voltage regulation have to be considered	

Notes:
- for each Project Phase, only configurations different from those listed in previous phases are considered (i.e. we don't show the configuration corresponding to low PV contribution in Phase II related configurations, etc.)
- each project phase includes all the system's configuration related to the previous phase, although not listed according to the previous statement (e.g. a CEBS unavailability in phase III would lead to the same configurations listed for phase II)
- in the "GMC" field we pointed out whether the Grid Master Control is required or not to guarantee the power supply

System's components

The islanded power system is made by:
- Loads
- Diesel Generator(s) (DG)
- distributed PhotoVoltaics arrays (PVs)
- Central Energy Buffer System (CEBS)
- Grid Master Control (GMC)

Diesel Generator (DG)

Features

The DG delivers real and reactive power to the grid, and is commonly used taking in charge frequency and voltage regulation functions in conventional configurations. Technical limitations include maximum total power (SDMAX), minimum real power (PDMIN) etc. Its main purpose in phases II and III is to cover the widest part of the daily load demand.

Optimum usage.

DG optimum usage would be to run only at a constant power rate, corresponding to its maximum efficiency power rate. Load-following due to frequency regulation causes higher fuel consumption, higher pollution and noise emissions, and has negative effects on the machine life cycle and maintenance costs.

Grid master functions.

The DG is commonly used as a grid-master device3. Its dynamic behaviour in terms of real power regulation is mainly affected by the electro-mechanical nature of the power conversion process. Therefore, its frequency regulation performances are conditioned by its mechanical characteristics. In spite of this, a DG allows effective voltage regulation functions, and reactive power fluctuations do not affect its performances.

Location.

The DG is located in the power plant and is accessible only to authorised personnel. Whenever possible, we'll run the DG with constant real power.

[3] We call grid-master device any generating unit that performs frequency and voltage regulation.

Distributed PhotoVoltaics array (PV)

Features.

Distributed PVs deliver real power to the grid according to solar energy availability, with a power factor very close to the unit value. Their power contribution is somehow predictable (like weather forecast), but not dispatchable. This means that we could have an idea of the amount of power available from PV arrays, but we cannot decide to generate a defined amount of PV power at a given hour and for a given time.

PV inverters are designed to run in Maximum Power Point (MPP) mode, taking the grid frequency as their common reference to control the inverter. This means that, in each moment, they usually inject the higher power they can, on an energised grid. Technical limitations include maximum and minimum frequency and voltage limits.

Optimum usage.

To maximise the energy efficiency of PVs inverters, they should run in MPP mode.

About grid master functions.

Distributed PVs cannot be used as grid-master devices, because they take the voltage frequency from the grid to synchronise themselves. This implies that they are not able to maintain the voltage frequency by themselves. Moreover, they haven't a reactive power regulation. In spite of this, a real power control does exist, and it could be used for frequency regulation purposes when a grid master device is imposing the frequency on the grid.

Location.

Typically, they are rooftop devices located in customers property. They are supposed to be spread over the whole electrical system. Whenever possible, we'll avoid any kind of centralised control over distributed PVs.

Central Energy Buffer System (CEBS)

The detailed description of the Central Energy Buffer System to be developed by ANIT is available in [3]. The CEBS will be made up of three mains elements:

- a Two Way Inverter (TWI)
- a Accumulator Battery (AB)
- a CEBS Control System (CCS)

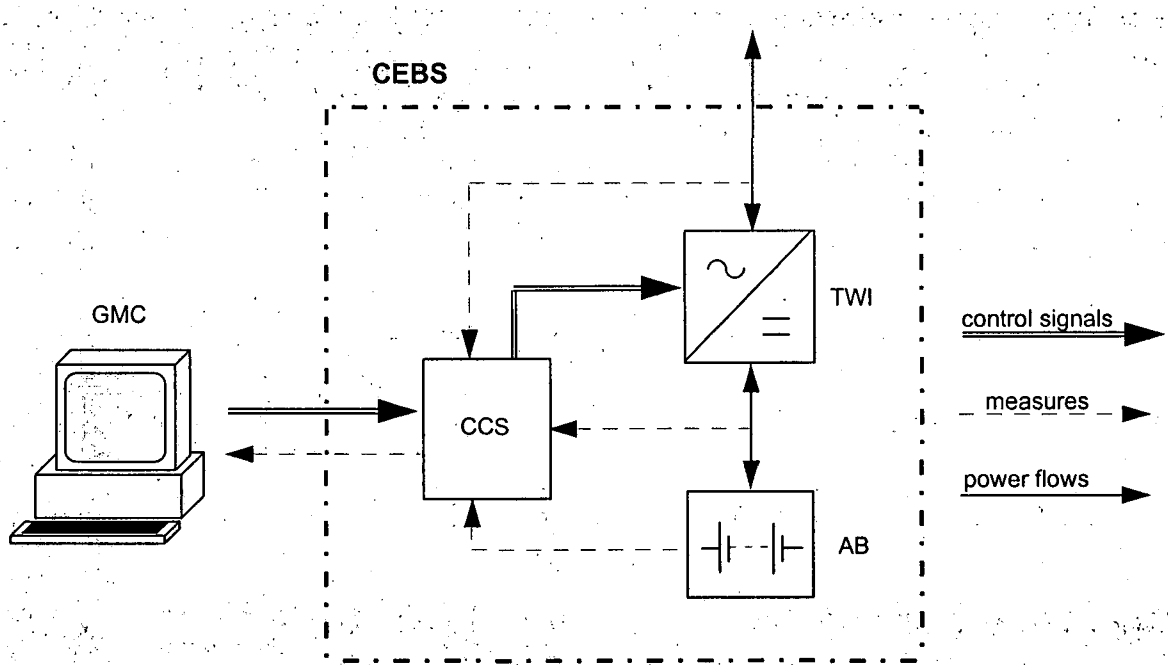


Figure B - CEBS elements

Features.

The TWI will allow bi-directional power flow between the system's grid and the Accumulator Battery. It will be able to run in various operating modes thanks to its switching technology and control system. It will be able to operate both as a grid master device (i.e. imposing its own voltage and frequency on the grid, supplying real and reactive power like an Uninterruptible Power System's inverter), or modulating the power flows according to BCMI requests. Moreover, while running as a grid-master device, it will allow the power to flow from the grid to the battery.

The AB will be used to store energy according to the GMC strategies. Many different charging methods are possible. Great attention must be given to this issue to avoid battery performances degradation.

The CCS will have the responsibility of many tasks:

- main TWI controller when the CEBS is used as the grid-master unit
- interface to the higher control level when the TWI activity is driven from the GMC (i.e. when the DG is the grid-master device)
- battery monitoring, and State Of Charge (SOC) calculation
- global CEBS monitoring

Optimum usage.

TWI
The TWI efficiency is lightly affected from the operating power rate. This means that we can run the TWI in the whole power range, within its maximum power limits, with minor effects on the power conversion efficiency. This is true either the TWI is running in the inverter mode or in the rectifier mode.

Grid master functions.

The CEBS can be used as a grid-master device. It will be able to perform voltage and frequency regulation functions on a passive grid, like any industrial UPS, but it will also allow bi-directional power flow whenever the grid might become an active load. We should think of it as a kind of unusual UPS with recovery capability. This particular feature will be crucial to the practical feasibility of phase IV of the project. This point will be widely discussed onward.

In addiction, the CEBS will accept real and reactive power input signals from the GMC, while the DG is running.

It has to be noted that, due to power electronics technology adopted, the CEBS performances in terms of frequency and voltage control are higher than those of traditional power generating units.

Location

The CEBS is located in the power plant, near the DGs units. It's accessible to qualified personnel only. The CEBS will be used in the way assuring the best improvements in terms of the Project's objectives described in chapter 4.

Grid Master Control (GMC)

Features

With the name "Grid Master Control" we indicate the set of devices, logics, information management, strategies and control activities, required to manage the electrical system in order to reach the project's objectives as defined in chapter 4. The GMC function is to decide the actions to be taken on the system, according to objectives to be reached and knowledge about the system and its requirements. Figure 2 shows that the GMC manage different kinds of information, that we can summarise in the following list:

RESOURCES	system's elements availability (DG units, CEBS power and energy, PV contribution)
SHORT TERM OBJECTIVES	power quality (power availability, frequency and voltage regulation)
OPERATING/TECHNICAL LIMITS	min and max power limits of DGs and TWI, frequency and voltage operating ranges of grid connected devices, max and min state of charge for AB etc.
MEAN TERM OBJECTIVES	costs saving (fuel saving, maintenance reduction) and environmental benefits (noise and pollution reduction)

The GMC main outputs will be:

SYSTEM'S CONFIGURATIONS	units commitment for DGs and CEBS
CONTROL STRATEGIES	to be implemented on each generating unit
CHARGING METHODS	to be selected

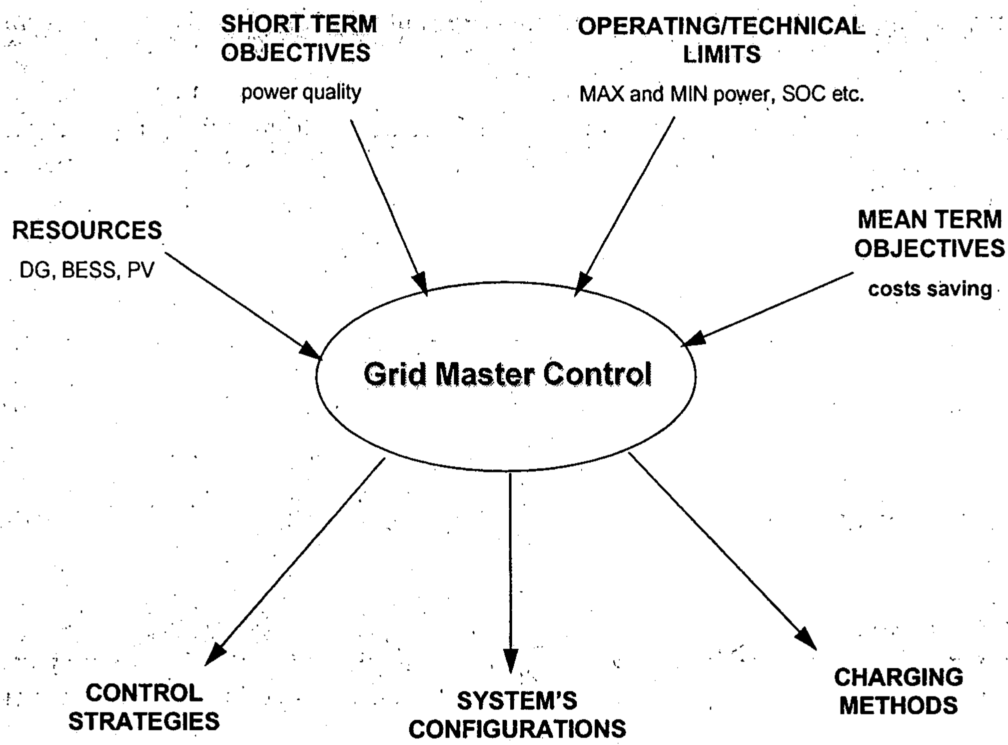


Figure C - GMC role

Data transmission

The data exchange between the GMC and the others system's components shall be achieved through a standard fieldbus (IEC 61158).

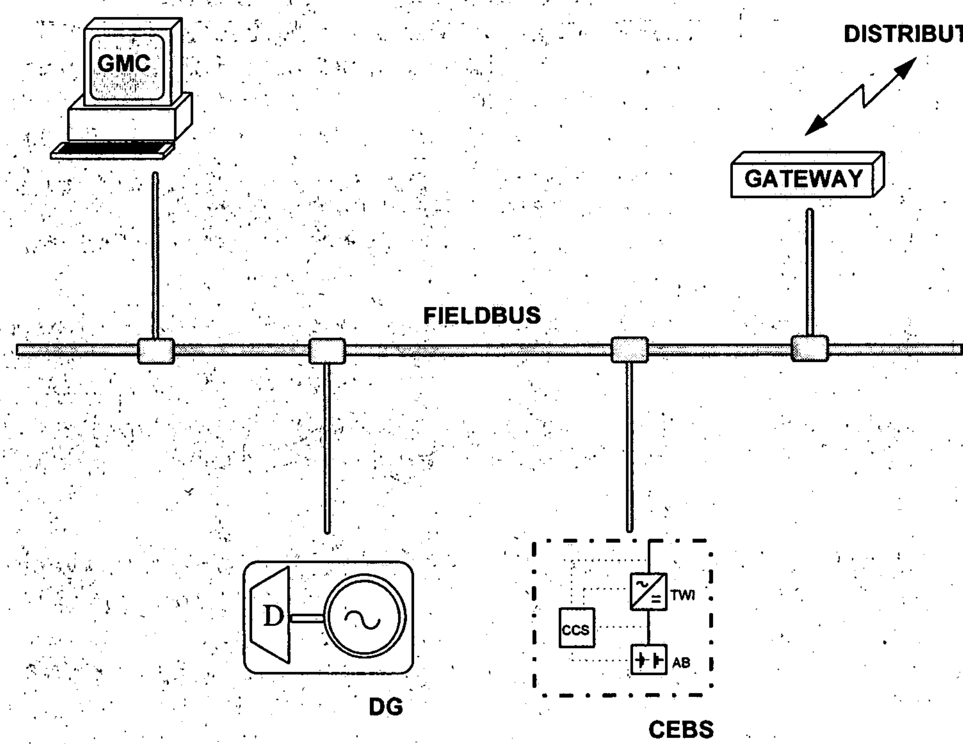


Figure D - Proposed GMC layout

Grid Master strategies

Using information and notes collected in the previous chapters, we can now outline a possible solution for the development of the Grid Master Control philosophy. We'll follow the order of the project's phases, as described in 6.1, to discuss the control strategies of the various system's configuration, defined in 6.2.

Conventional (C) configuration

Description

In this configuration, the Diesel Generator is the main power contributor. Until the PV penetration inside the electrical system is low, this is the only configuration possible. Moreover, this configuration is very common in phase II of the project and can be obtained even if the project is in more advanced phases, according to GMC policy or due to system's faults.

Implementation

When the system is in configuration C, frequency and voltage regulation must be carried out by the DG. This should be accomplished by the existent DG regulators also when GMC system will be installed.

Diesel/PV (DP) configuration

Description

This configuration will be reached with the gradual penetration of PV inverters, when the PV power contribution approaches the instantaneous load demand (phase II). In such condition, it becomes impossible for DGs to manage grid master functions, unless the PV generated power is somehow regulated or lowered. In fact, DGs cannot run below their minimum power rate (PDmin). On the other hand, they cannot be switched off all together, because a system with only PV power contribution would result unstable. At this point, two different ways can be chosen:

- to send a control signal, from the central control system to decentralised inverters; this implies that a communication link is provided, and that a central control system (or GMC) has to be developed to reach phase II.
- to use decentralised inverters provided with an autonomous controller; such solution has minimum requirements on the existing systems side.

As discussed in chapter 5, the second solution is preferable from many points of view, including system's reliability and availability. Moreover, such solution assures the lowest impact over existing systems. Thus, the second way will be taken.

Implementation

As previously stated, the defined solution we implies that decentralised PV inverters are equipped with an appropriated autonomous controller. A possible implementation of such controller will be described in a following document. For the purposes of this description, what we need to know is that decentralised inverters lower their generated power whenever the grid frequency exceeds a specified value (fH) for a given time, and that they come back to MPP mode when the frequency returns below a given value (fL) for a defined time. In this configuration, frequency and voltage regulation will be carried out by the DG, in almost the same way of configuration C. However, some minor modification are needed to the DG's speed regulator. In fact, we have to be sure that decentralised PVs will lower the power supplied to the grid before the DG reaches its minimum real power limit (PDMIN). This can be accomplished introducing a threshold level on the DG's throttle actuator, so that the following behaviour can be obtained:

Until the PV power contribution is low with respect to instantaneous load demand, DGs perform speed/frequency regulation function as they usually do (SC characteristic in figure 5).

The system is running in its Conventional operating mode.

As PV power contribution approaches instantaneous load demand, DG's speed regulator gradually closes the Diesel throttle until the introduced threshold is reached. Since then, DG's throttle cannot be closed anymore.

The system enters its DP operating mode.

Further increases in PV power injections, or load demand lowering, implies that the DG will accelerate, causing the frequency to rise (SDP characteristic on figure 5). As frequency exceeds the value fH (to be defined), decentralised PV inverters leaves the MPP mode and lower their power injection into the grid until the frequency is stabilised within acceptable values. As PV power reduces because of solarisation changes, or load demand increases, the frequency goes down and below the value fL, causing distributed PV inverters to return to MPP mode. The system returns in its Conventional operating mode.

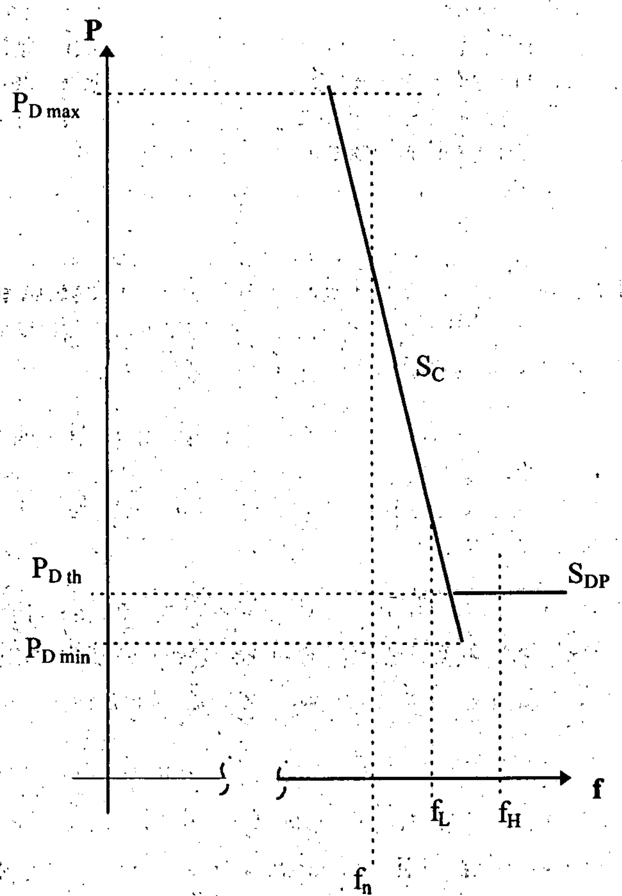


Figure E - DG regulation characteristics

Notes

DP operating mode has to be considered critical from the following points of view:

- Power quality is negatively affected by frequency alterations
- Diesel units runs at very low power rates, with low energy efficiency
- PV devices are not used in the most effective way, causing renewable energy wastes

For such reason, this operating mode should be avoided whenever possible, and although it could be mandatory in some extra ordinary conditions, it shouldn't be considered a normal operating mode; otherwise, project objectives will be vanished. Thus, when PV penetration approaches phase II, the installation of the CEBS has to be considered as a need, and not as an option.

Diesel/PV/CEBS Inverter mode (DPBI) configuration

Description

This configuration will be available with the introduction of the Central Energy Buffer System. In DPBI configuration, the CEBS, together with the DG and decentralised PVs, feeds power to grid.

Since distributed PVs are dealt as autonomous devices, they are not involved in GMC activity, and they can be considered only for their effects on the net load demand, i.e. the difference between the actual load demand and the actual PV power contribution. Calling PG and QG respectively the real and reactive power supplied to the grid from the power plant, and with obvious meanings of other symbols, the DPBI configuration is schematised below.

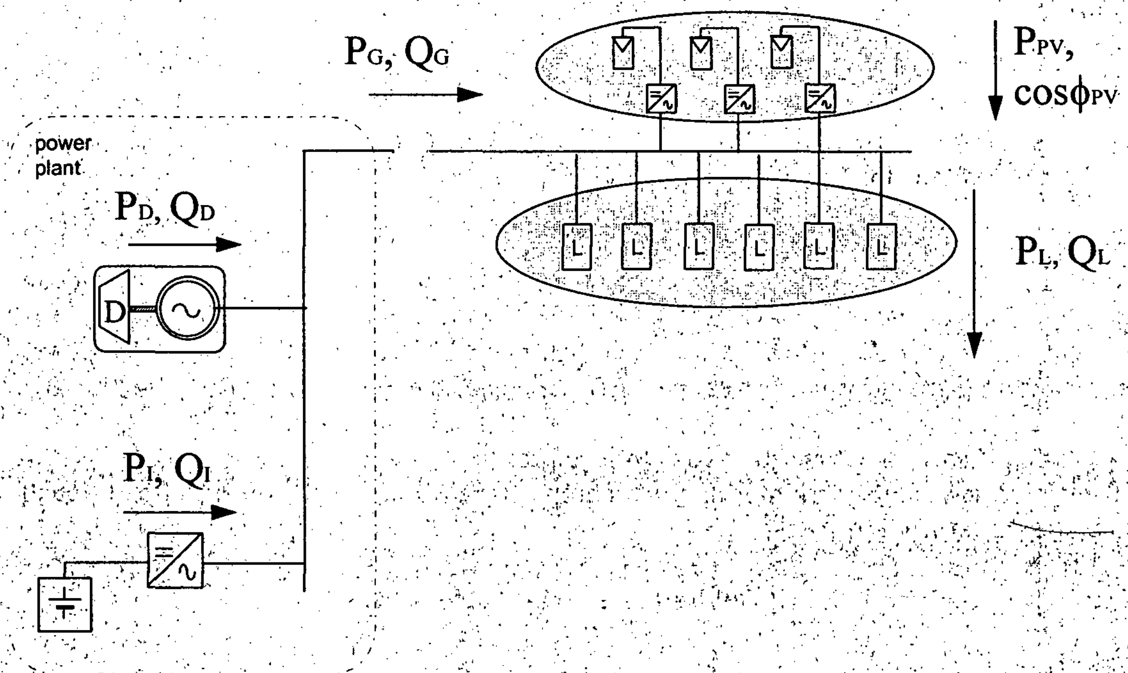


Figure F - DPBI configuration

In the power plant, both DG and CEBS have the capability to run as grid master devices (as discussed in § 6.3), therefore a control strategy has to be implemented in order to co-ordinate their operation and satisfy PG and QG requests.

Best advantages in terms of our objectives (§ 4) and system's components usage can be gained by the following implementation.

Implementation.

The control strategy to be implemented when the system is in configuration DPBI is summarised in figure 7 and table 3.

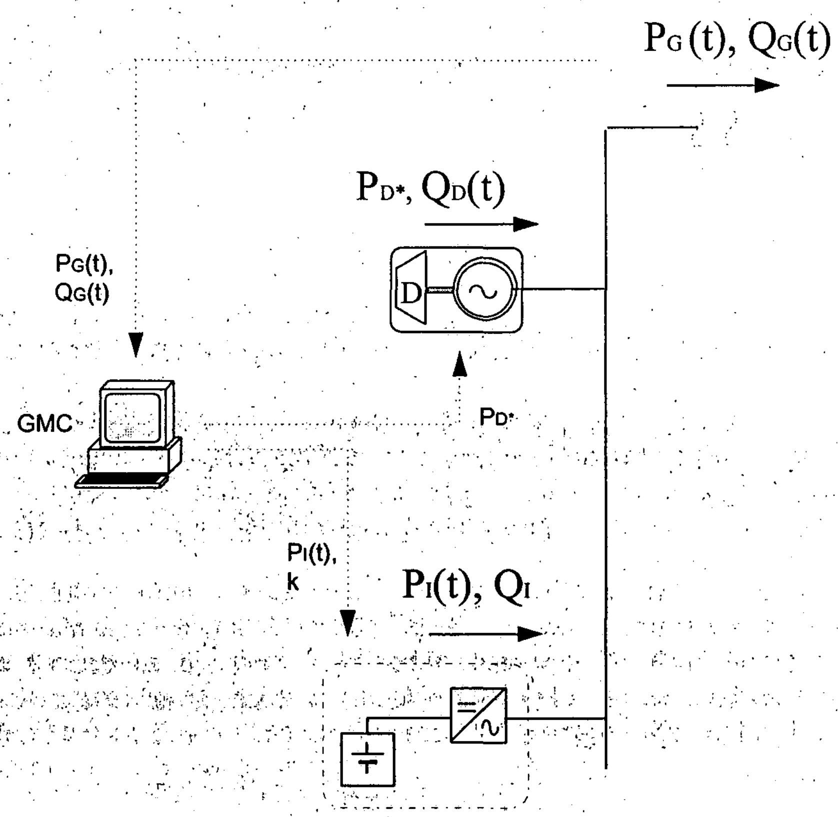


Figure G - Control strategy for DPBI configuration

Major features of the control strategy are the following:

The DG runs at constant power rate, receiving the reference power value PD* from its interface to the GMC

Real power balance is carried out by the GMC through the CEBS; the GMC measures the power PG (t) requested from the grid and drives the CEBS to inject the power value PI (t) = PG (t) - PD*

Voltage regulation is carried out by DG's voltage regulator

The CEBS reactive power injection into the grid is proportional to its real power injection through a constant value, K, set from the GMC

(How the GMC sets PD* and K values will be discussed in chapter 8)

Table C - DPBI control strategy

CEBS (inverter mode)	PI (t) = PG (t) - PD* QI (t) = k PI (t)	active power control - frequency regulation fixed real/reactive power ratio
Diesel Generator	PD (t) = PD* QD (t) = f(V)	fixed power according to GMC system strategies reactive power control - voltage regulation

This technical solution meets both our objectives, as stated in chapter 4, and components requirements, as described in § 6.3, in fact:

- CEBS ability to perform fast power regulation will improve power quality in terms of frequency stability and power availability
- fixed power operation of the DG will improve its energy efficiency with fuel savings to be added to those due to PV contribution
- running the DG at fixed power rate will bring considerable benefits in terms of combustion's results emission and noise pollution; moreover, it will have positive effects on machines' life cycle and maintenance costs

DIESEL/PV/CEBS Rectifier mode (DPBRI) configuration

Description

In DPBR configuration (figure 7), the CEBS charges the AB absorbing power from the grid, while the DG is running and decentralised PVs injects power into the grid. It has to be noted that for our discussion is not relevant either the total PV power injection is null or it exceeds the actual load demand. In other words DPBR configuration accepts both positive and negative values for PG (and QG). As for DPBI configuration, distributed PV inverters are dealt as autonomous devices, and they are not involved in GMC activities. Their power contribution is considered in PG and QG values.

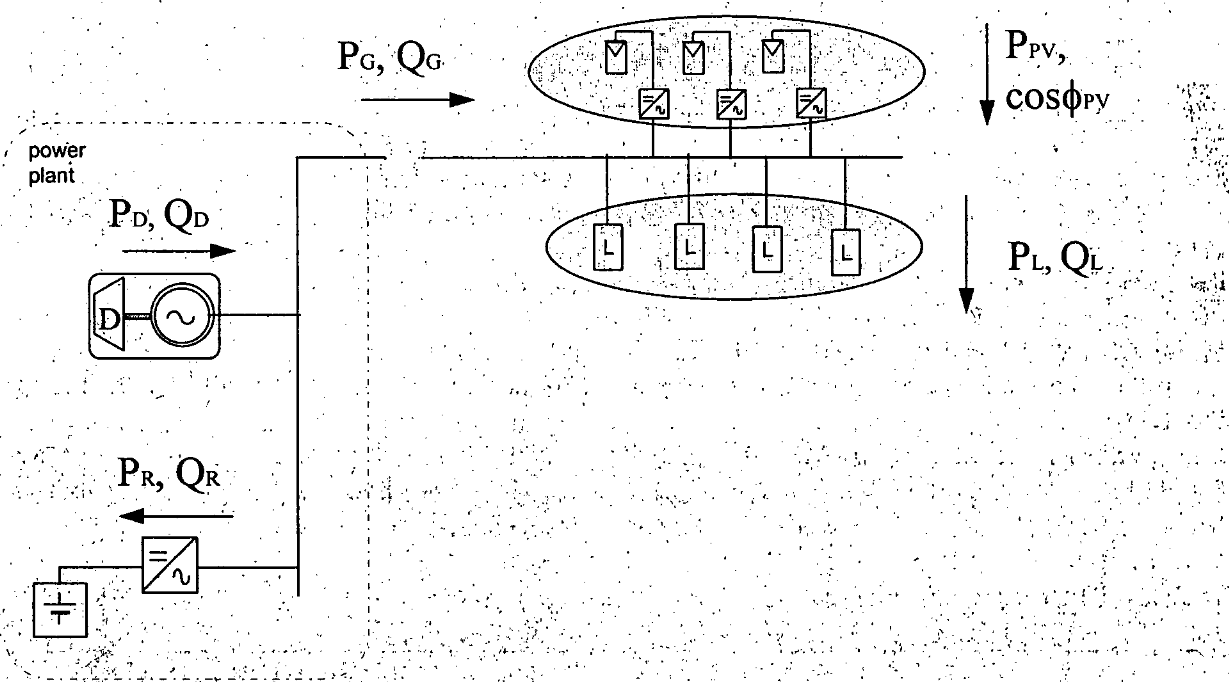


Figure H - DPBR configuration

Implementation

The control strategy to be implemented when the system is in configuration DPBR is analogous to that implemented for DBPI configuration, and is summarised in figure 9 and table4.

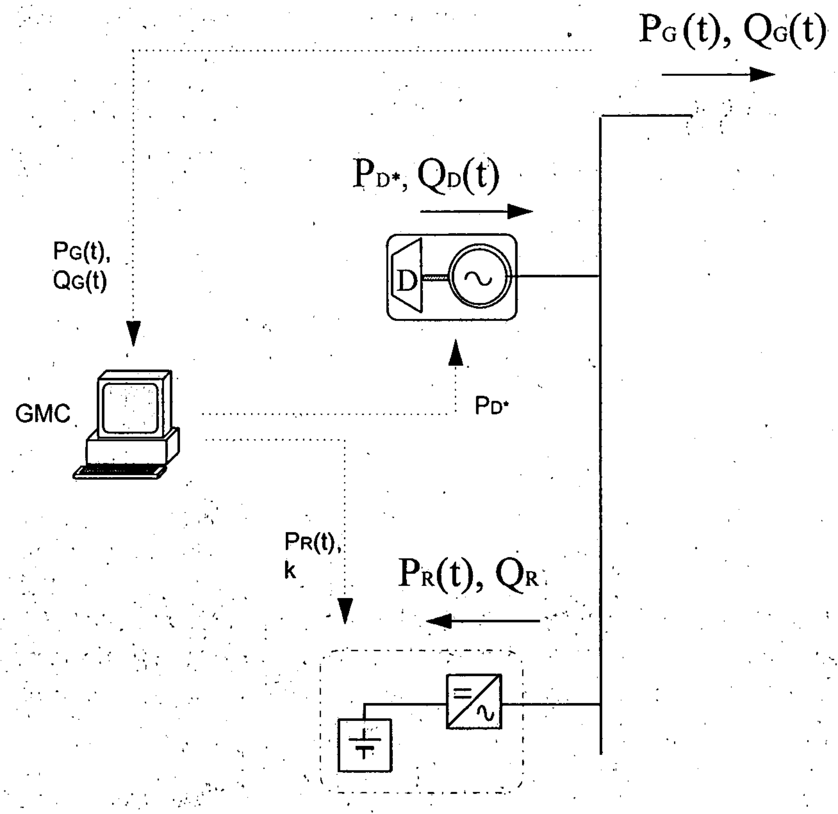


Figure I - Control strategy for DPBR configuration.

Major features of the control strategy are the quite the same mentioned for DPBI:
The DG runs at constant power rate, receiving the reference power value PD* from its interface to the GMC
Real power balance is carried out by the GMC through the CEBS; the GMC measures the power PG (t) requested from the grid (or in excess from the grid) and drives the CEBS to absorb the power value PR (t) = PD* - PG (t)
Voltage regulation is carried out by DG's voltage regulator
The CEBS reactive power absorption from the grid is proportional to its real power absorption through a constant value, K, set from the GMC

(How the GMC sets PD* and K values will be discussed in chapter 8)

Table D - DPBR control strategies

CEBS (rectifier mode)	PR (t) = - [PG (t) - PD*] QR (t) = k PR (t)	real power control - frequency regulation reactive power as required from the rectifier
Diesel Generator	PD (t) = PD* QD (t) = QD (V)	imposed power according to GMC system strategies reactive power control - voltage regulation

This technical solution will be made possible from the particular features described for the CEBS (§ 6.3.3).

Such solution allows exactly the same improvements brought from control strategy proposed for

DPBI configuration:

CEBS ability to perform fast power regulation will improve power quality in terms of frequency stability and power availability

fixed power operation of the DG will improve its energy efficiency with fuel savings to be added to those due to PV contribution

running the DG at fixed power rate will bring considerable benefits in terms of combustion's results emission and noise pollution; moreover, it will have positive effects on machines' life cycle and maintenance costs

Effects of charging power modulation against AB have to be investigated; however, battery manufacturers asserted that Lead-Acid cells are not damaged from such charging operations.

PV/CEBS Inverter Mode (PBI) configuration

Description

This configuration will be reached when decentralised PV penetration and, above all, CEBS power and energy capacities allows temporary switch-off of DG (phase IV). PBI configuration is shown in figure 10.

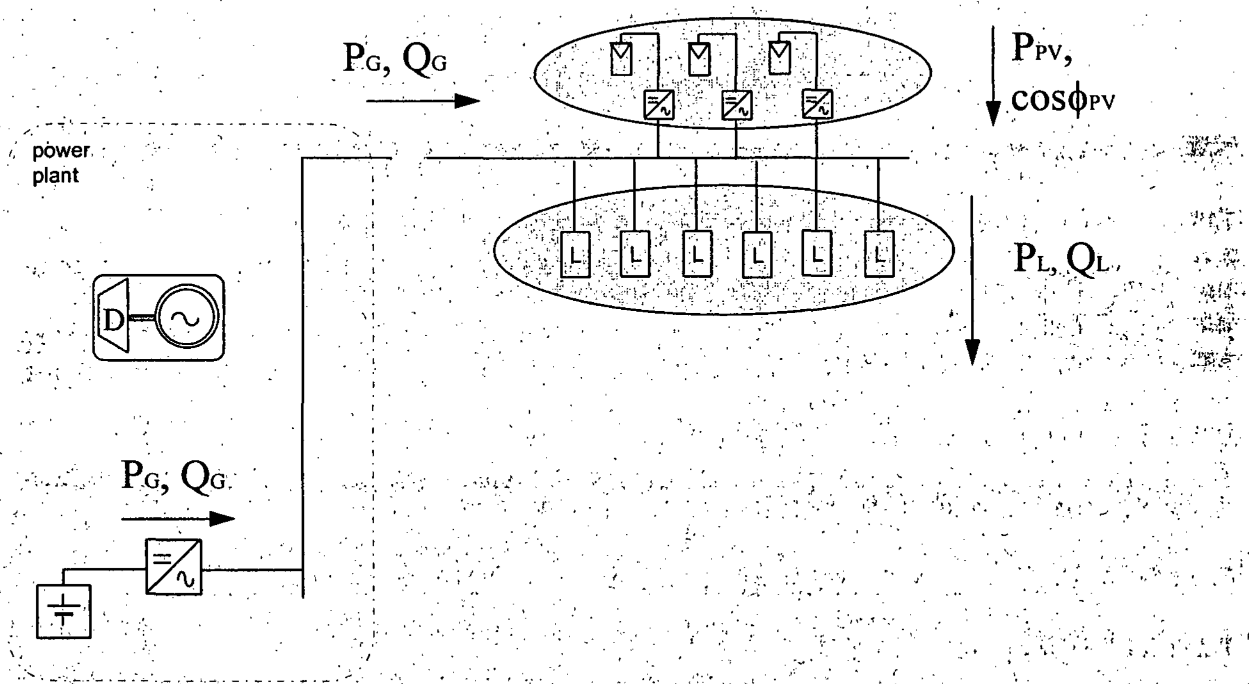


Figure J - PBI configuration

In such configuration the CEBS is the only device capable of grid master functions. In fact, decentralised PV inverters are not able to synchronise themselves without the common reference signal represented by the grid frequency. Moreover, they are dealt as autonomous devices, so that they are seen from the power plant only for their effects on the instantaneous load demand. From the power plant point of view, the whole island grid can be considered as a variable load, absorbing the real power PG (t) and the reactive power QG (t), and supplied through an inverter using the energy stored in batteries; this is the typical job of an Uninterruptible Power System (UPS).

Implementation

When the system is in PBI configuration, all the grid master functions will be carried out by the built in control system of the CEBS, as shown in figure 11 and table 5.

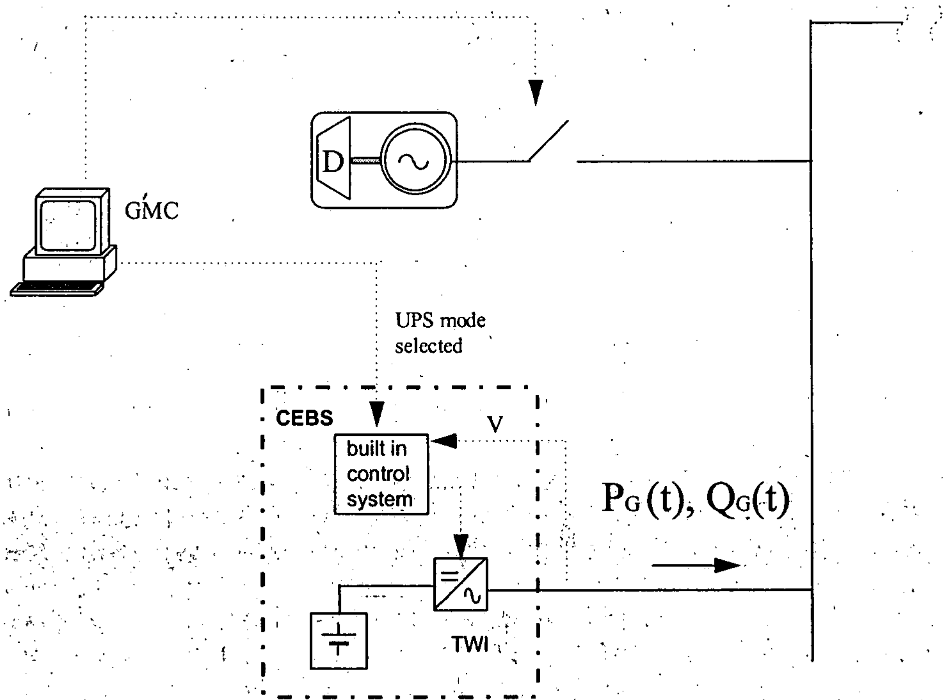


Figure K - Control strategy for PBI configuration

Major features of the control strategy are the following:
the CEBS is put in UPS operating mode by the GMC when the DG is switched-off
the CEBS' control system drives the TWI, imposing the frequency on the grid
the voltage control loop performed by the CEBS' control system assure real and reactive power balance as required by the grid

Table E - PBI control strategy

CEBS (Inverter mode)	PI (f) = PG (t)	real power balance
		voltage/frequency regulation
	QI (t) = QG (t)	reactive power balance

IMPORTANT NOTE:

When the DG set is not running the short circuit currents are dramatically reduced. Protective relays will be studied to protect the grid from:

- phase to phase short circuit
- phase to earth short circuit

PV/CEBS Rectifier mode (PBR) configuration

Description

This configuration differs from PBI configuration for the direction of the power flow in the CEBS.

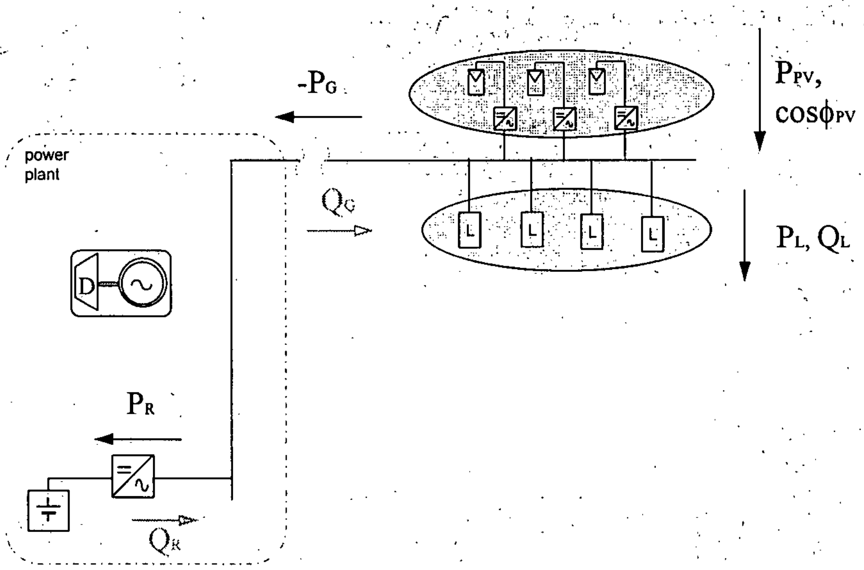


Figure L - PBR configuration

Since the CEBS will make no difference about power flow direction when it is in UPS operating mode, PBI and PBR configurations could be considered together as one. Of course there will be different problems in terms of operating limits (SOC, VDC etc.), but not in terms of control implementation.

Implementation

As it is shown in figure and table the control strategy is the same of PBI configuration. In fact, the CEBS doesn't mind if PG and/or QG are positive; i.e. flowing to the grid, or negative, i.e. flowing to the battery.

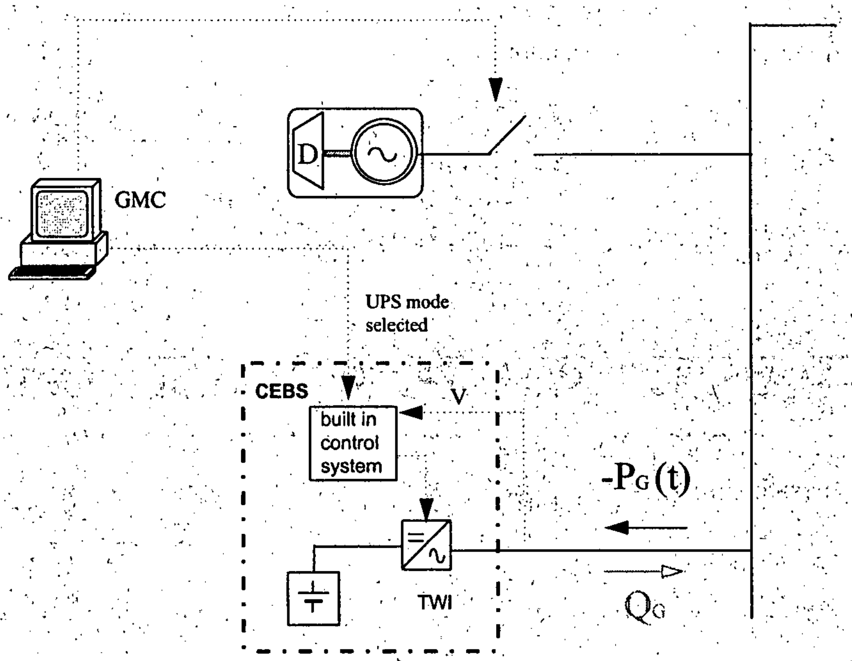


Figure M - Control strategy for PBR configuration

Table F - PBR control strategy

CEBS (Inverter mode)	PR (f) = - PG (t) QR (t) = QG (t)	real power balance voltage/frequency regulation reactive power balance

IMPORTANT NOTE:
When the DG set is not running the short circuit currents are dramatically reduced. Protective relays will be studied to protect the grid from:

- phase to phase short circuit
- phase to earth short circuit

Table G - Operating modes and control strategies summary

configuration		PV CONTRIBUTION Low High C		DP	
DIESEL ONLY	targets	PD (t)=PD(f) f regulation	QD (t)=QD(V) V regulation	PD (t)=PD(f) f regulation	QD (t)=QD(V) V regulation
	operating limits	PD MAX	VMIN	PD MIN	VMAX
		fMIN		f MAX	
				SOCMAX during fast charging	

configuration		CEBS OPERATING MODE Inverter Rectifier DPBI		DPBR	
DIESEL + CEBS	DIESEL targets	PD =PD* fixed power	QD(t)=QD(V) V regulation	PD=PD* fixed power	QD(t)=QD(V) V regulation
	INVERTER / RECTIFIER targets	PI(t)=PG(t)-PD* f regulation	QI (t)=kPI(t)	PR(t)=PD*-PG(t) f regulation	QR (t)=kPR(t)
	operating limits	PD MAX	VMIN	PD MIN	VMAX
		PI MAX	VDC MIN	PB MAX	PI MIN
		fMIN		f MAX	VDC MAX
		SOC MIN		SOCMAX	

configuration		CEBS OPERATING MODE Inverter Rectifier PBI		PBR	
(CEBS ONLY)	targets	PI=PI (t) real and reactive power balance V / f regulation	QI=QI(t)	PB=PB(t) real and reactive power balance V / f regulation	QB=QB(t)
	operating limits	PI MAX	VMIN	PB MAX	VMAX
		QI MAX	VDC MIN	QB MAX	PI MIN
		SI MAX		SB MAX	VDC MAX
		SOC MIN		SOCMAX	

Fuzzy Grid Master Control

As explained in § 5.3.4, the GMC will have the following major decision tasks:

- system's configuration management
- (e.g. ON/OFF switching of Diesel units, etc.)
- control strategies management
- (e.g. PD* assignment)
- charging methods management
- (e.g. refresh charge of battery string, etc.)

The technical solution we outline for the implementation of the GMC is based on the use of a fuzzy logic to deal the following points:

- the system to be controlled will evolve in terms of capacities of its components and such changes affects control strategies
- control variables (f, V, SOC, PI, PD* etc.) are continuous, and the range of their values is subject to interpretation depending on operating conditions; this implies that it's not easy and even not effective to break them down into discrete segments
- configuration changes have to be decided according to uncertain information and parameters (PV power availability and load demand forecasts, state of charge calculation, etc.); such parameters might better be represented with linguistic variables (like "medium", "high", "very high" etc.) then with numerical variables
- a mathematical model for the purpose does not exist yet, and it might result very difficult to develop or handle, since it would be subject to many changes according to experiences gained during pilot plant tests.

A fuzzy logic approach fits point to point all the needs just mentioned:

- it is possible to develop a control strategy for any system configuration, switching among them according to system's requirements
- fuzzy logic allows to interpret continuous variables between the values true/false of Boolean logic, thanks to the membership function concept
- fuzzy sets are extremely suitable for representing linguistic variables, and the degree of membership with a fuzzy set brings information about value trustworthiness
- fuzzy controllers are made up of rules describing the actions to be taken on each combination of control variables (e.g.: if inverter_power is "very high" and diesel_power is "normal" and state_of_charge is "low", then diesel_set_change is "increase widely"); this implies they are easy to prototype and implement, and they can be maintained, modified and extended with great accuracy according to experiences on the system.

In the following chapter we'll outline a solution to manage DPBI configuration.

DG power set-point assignment

The aim of this chapter is to show how the development of the GMC can benefit from the use of fuzzy logic. As an example we chosen the PD* assignment task. Thus a step by step procedure is presented, starting from variables identification to end with an overview of possible implementation of a fuzzy controller.

Variables identification.

The first step defining a fuzzy controller is to identify its input and output variables. The assignment of the DG power set-point value (PD*), when the system is in DPBI or DPBR configuration, involves variables that are different in terms of their nature and importance, and requires actions with different characteristics, as it's shown in table 8.

Table H - Variables used in PD* assignment

variable	nature	importance	reaction	kind of action	target
actual value of DG generated power (or actual PD* value)	technical economical	mean / high mean / low	fast slow	change PD* value and/or configuration	to run the DG with high efficiency, according to other needs and avoiding overload or minimum power limit
actual value of the power supplied/absorbed by the CEBS	technical functional	high mean/high	very fast mean/fast	change PD* value and/or configuration	to run the CEBS within its operating limits and assuring adequate safety margins
batteries state of charge (SOC)	technical economical	high mean / low	mean slow	change PD* value and/or configuration	to maintain adequate charge reserve and avoid overcharge
load demand forecast	functional economical	low / mean low	mean slow	change PD* value and/or configuration	CEBS usage planning according to daily load profile and avoid unsafe operating conditions
available PV power forecast	functional economical	mean/high low	mean/slow	change PD* value and/or configuration	batteries usage planning to avoid PV energy wastes and avoid unsafe operating conditions

Whenever other variables should be considered important for PD* evaluation, they could be added very easily. It has to be noted that in the field "kind of action" we also considered the possibility of a configuration change, since it could be an output of the controller. For simplicity sake we'll consider only the the DPBI configuration; therefore we won't deal configuration changes, and we consider the CEBS only in its Inverter mode.

Using table 8 it's possible to identify the following input variables:
act_DG_pow; is the actual value of PD* assigned to the DG
act_INVERTER_pow; is the actual value of the power supplied from the CEBS to the grid
SOC_error; this variable blends together the last three variables of table 8 and is due to the following need: for the optimum usage of CEBS facilities, information about battery SOC must be evaluated as referred to many parameters, like the time of the day, the load demand and the PV contribution expected in the mean/short term. In fact, the same value of SOC (e.g. 50%), is good or even high if we're going to perform a charging cycle, but it's low if the CEBS has to perform a discharge cycle. We can define SOC_error as follows:

$$\text{SOC\_error\%} = 100\frac{(\text{act\_SOC}) - (\text{des\_SOC})}{\text{des\_SOC}}$$

where des_SOC is the desired state of charge for that moment, and act_SOC is the actual value measured by the CEBS.

The only output variable we consider in the example is the variation of the DG power set-point value:
DG_set_change

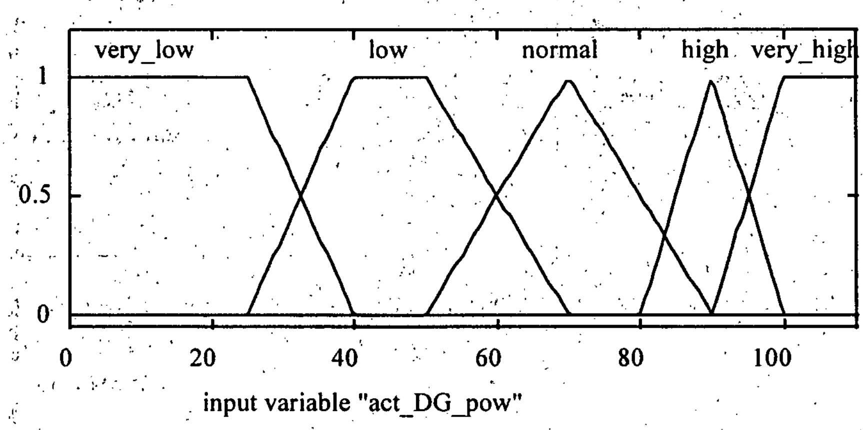
Variables fuzzy values (membership functions definition)

To define the values of input and output variables we have to describe, for each variable, the membership function of each fuzzy set. The behaviour of the fuzzy controller is strictly related to this definition.

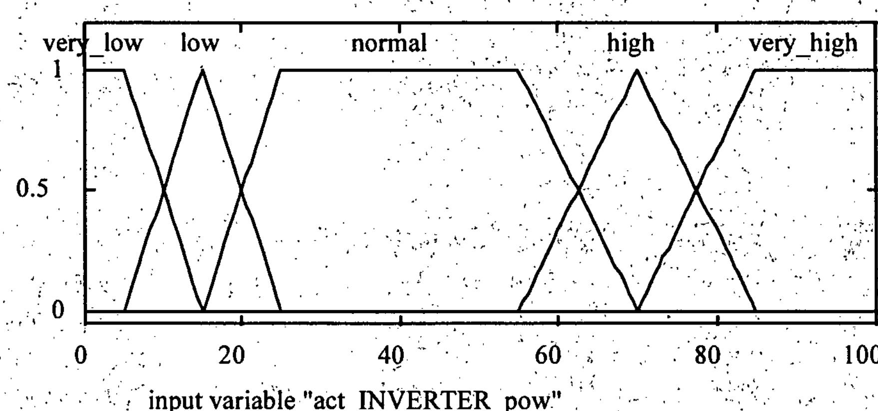
Membership functions with very different shapes can be used, including triangular, gaussian, trapezoidal and many other shapes. In fact, almost any kind of function could be used. In the example, we use only very simple functions, as triangular and trapezoidal.

The number of values defined of each variable is also important for the performance of the controller. In order to simplify the example, we define only five values for each input and output variable.

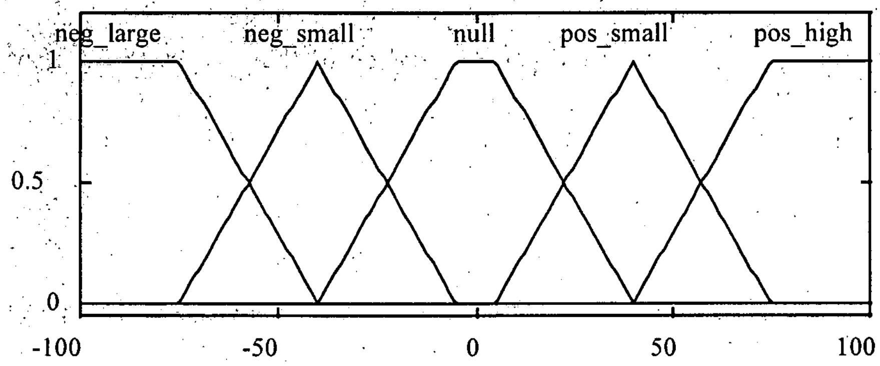
act_DG_pow;



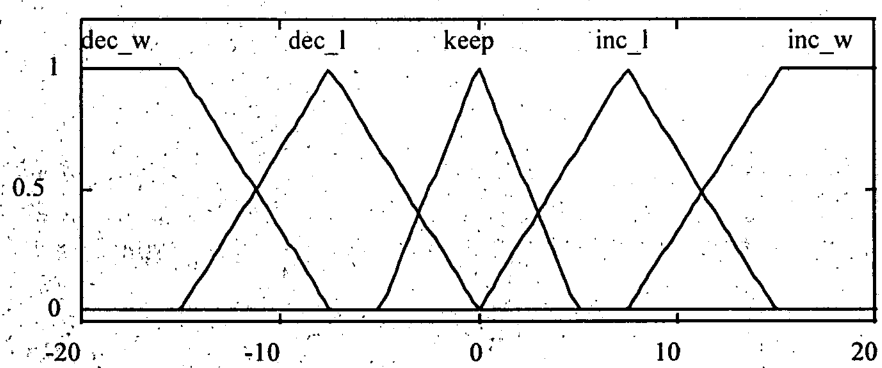
act_INVERTER_pow



SOC_error



DG_set_change



Power values are expressed in percent of devices' rated power, while SOC_error is expressed as a relative error.

Inference rules definition

Once fuzzy sets and membership functions have been defined, the controller model is completed by writing the rules that describe the action taken on each combination of control variables.

In our example we roughly associated an action to any value of the input variables.

rule number	rule description	rule weight
1.	(act_INVERTER_pow==normal) => (DG_set_change=keep)	(0.2)
2.	(act_INVERTER_pow==low) => (DG_set_change=dec_l)	(0.2)
3.	(act_INVERTER_pow==very_low) => (DG_set_change=dec_w)	(0.2)
4.	(act_INVERTER_pow==high) => (DG_set_change=inc_l)	(1)
5.	(act_INVERTER_pow==very_high) => (DG_set_change=inc_w)	(1)
6.	(act_DG_pow==normal) => (DG_set_change=keep)	(0.2)
7.	(act_DG_pow==low) => (DG_set_change=inc_l)	(0.8)
8.	(act_DG_pow==very_low) => (DG_set_change=inc_w)	(1)
9.	(act_DG_pow==high) => (DG_set_change=dec_l)	(0.8)
10.	(act_DG_pow==very_high) => (DG_set_change=dec_w)	(1)
11.	(SOC_error==null) => (DG_set_change=keep)	(0.2)

12.	(SOC_error==neg_small) => (DG_set_change=inc_l)	(0.5)
13.	(SOC_error==neg_large) => (DG_set_change=inc_w)	(0.8)
14.	(SOC_error==pos_small) => (DG_set_change=dec_l)	(0.5)
15.	(SOC_error==pos_high) => (DG_set_change=dec_w)	(0.8)

Every rule is associated a weight; this value affects the effect of each rule on the calculation of the output variable.

We defined such values considering the characteristics listed in the "importance" and "reaction" field of table 8.

The fuzzy controller model is now completely defined, as it's shown in figure 14.

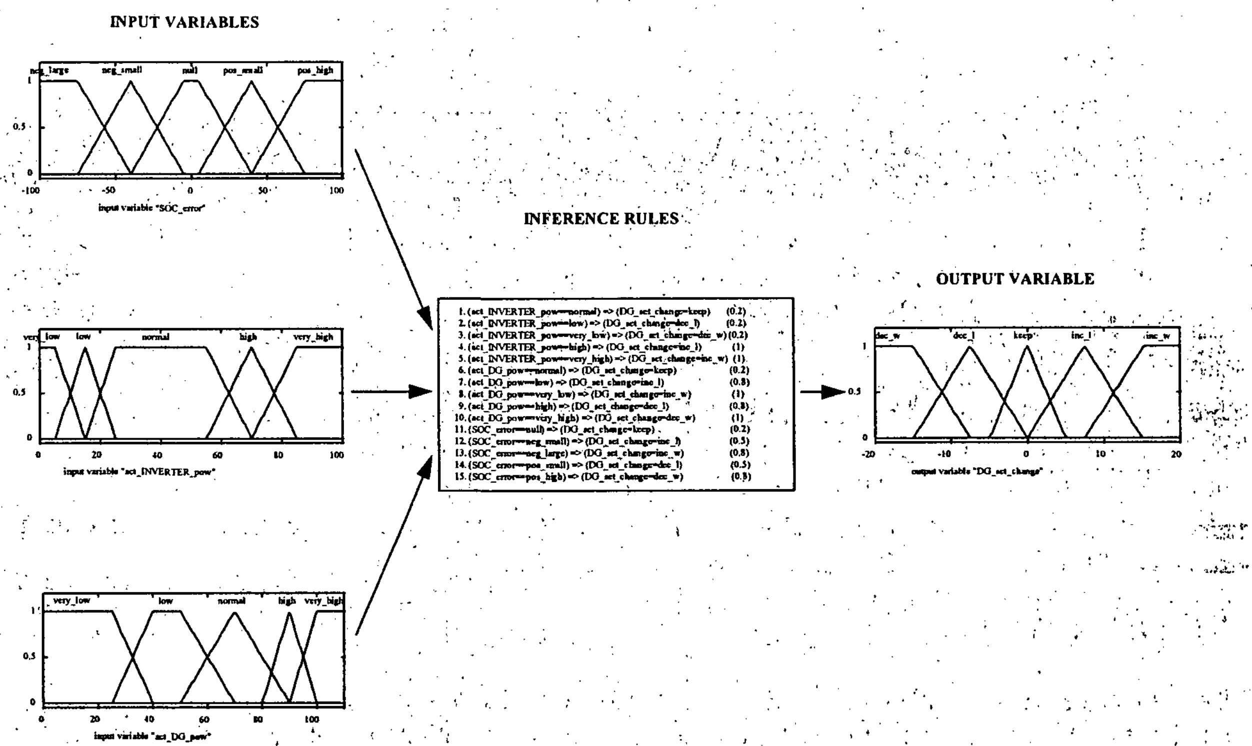


Figure N - Fuzzy controller model for the assignment of PD* value

Controller behaviour

The model defined in previous paragraphs has been implemented with the FUZZY TOOLBOX running with MATLAB under the WINDOWS environment, in order to investigate the feasibility of a fuzzy control. Two different kinds of graphical outputs are used to describe the behaviour of the control logic.

Figure 15 to 17 show the rules fired from three different combinations of the input variables.

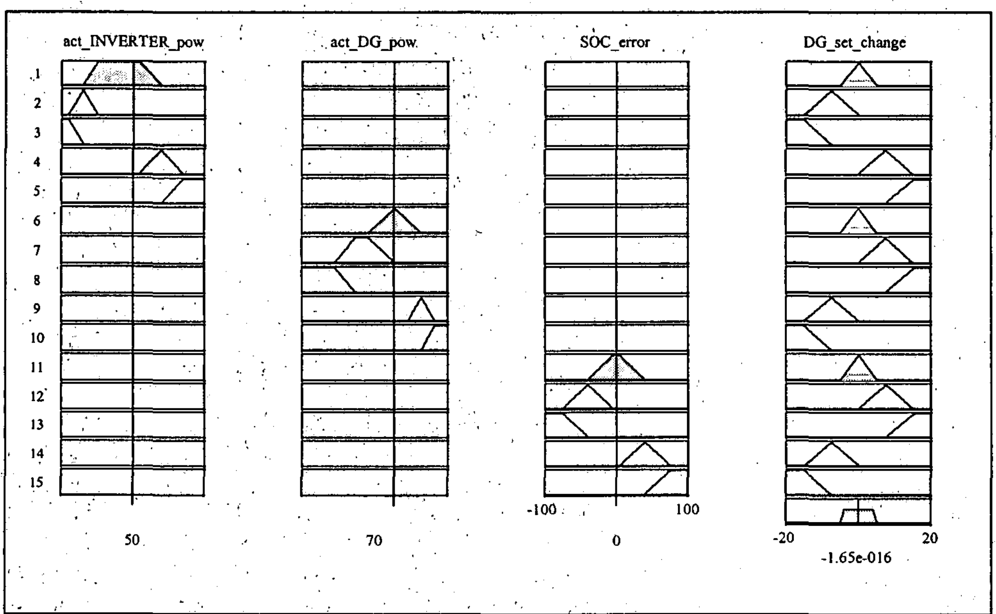


Figure 0

When the system is running near optimum condition, the DG is running at a good efficiency power rate, the CEBS is feeding power to the grid within good safety margins and the battery SOC error is near zero (figure 15). In such conditions, the output variable value is "keep", i.e. no changes are required to the DG power set-point.

If a load change now causes the CEBS to supply a power value we consider "high", the rule number 4 is fired (figure 16), the output of the controller becomes "keep" + "increase lightly", and the defuzzyfication algorithm returns a positive value (about +5%), to increase the DG power set point and gain system's safety.

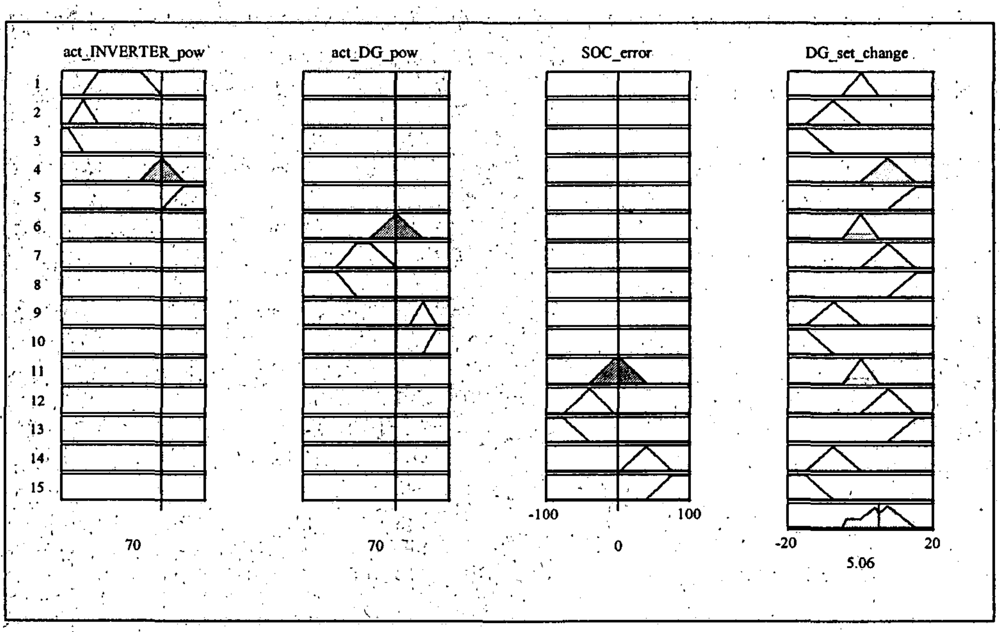


Figure P

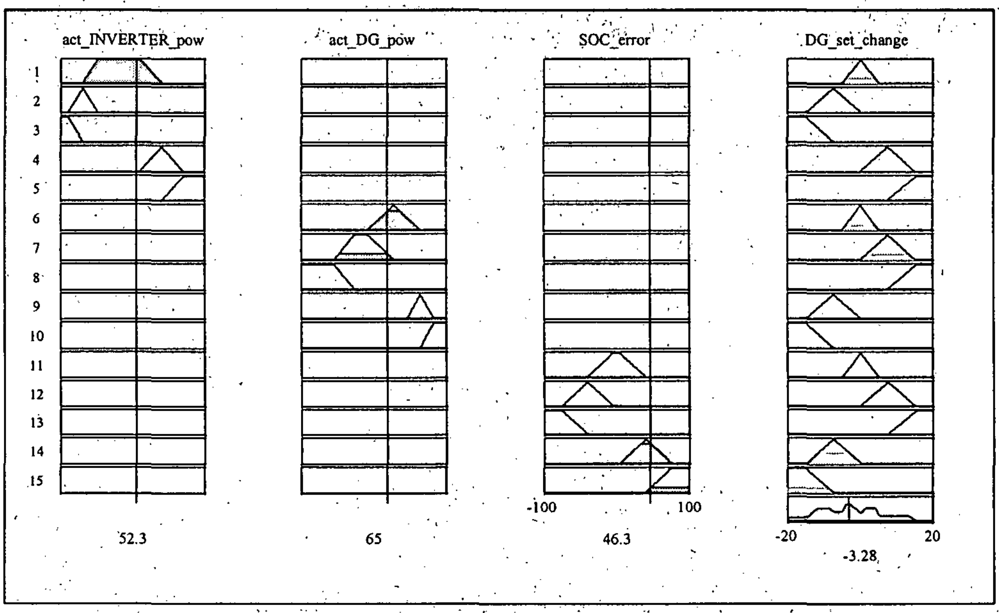


Figure Q

Figure 17 shows an input variables combination in which different needs are evaluated by the controller; while DG efficiency would require an increase in DG power set-point, the large positive SOC error requires a PD* reduction to allow the CEBS to discharge batteries.

Another effective way to describe the controller behaviour is to display control surfaces. Such surfaces display the output variable values vs. any combination of two input variables, when other input variables are fixed.

Figure 18 and 19 display DG_set_change vs. act_INVERTER_pow and SOC_error for two different values of act_DG_pow.

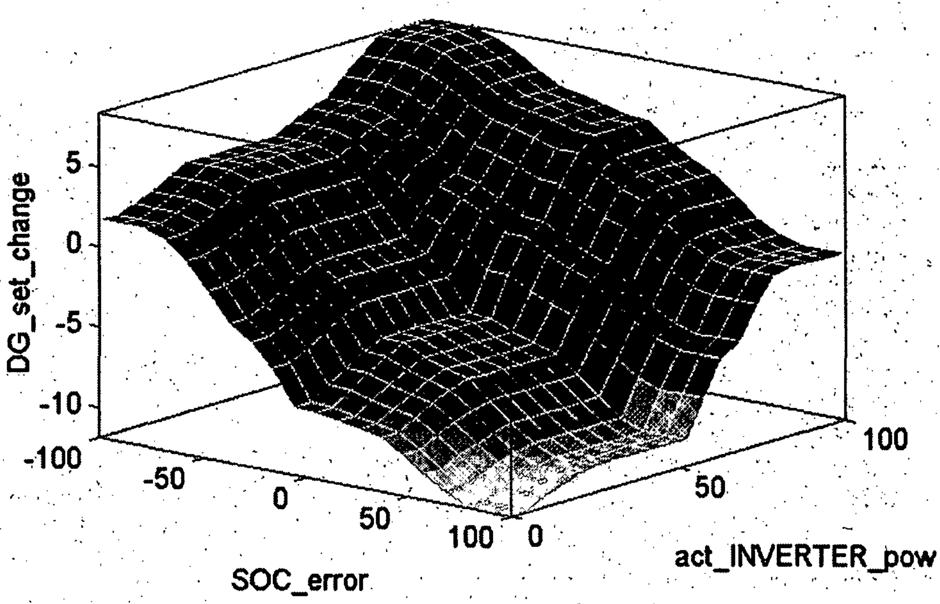


Figure R - act_DG_pow = 90%

Both figure 18 and figure 19 show that the power supplied by the CEBS has minor effects on the set-point value unless safety margins are approached. On the other hand, SOC_error has greater effects when the CEBS is within such safety margins.

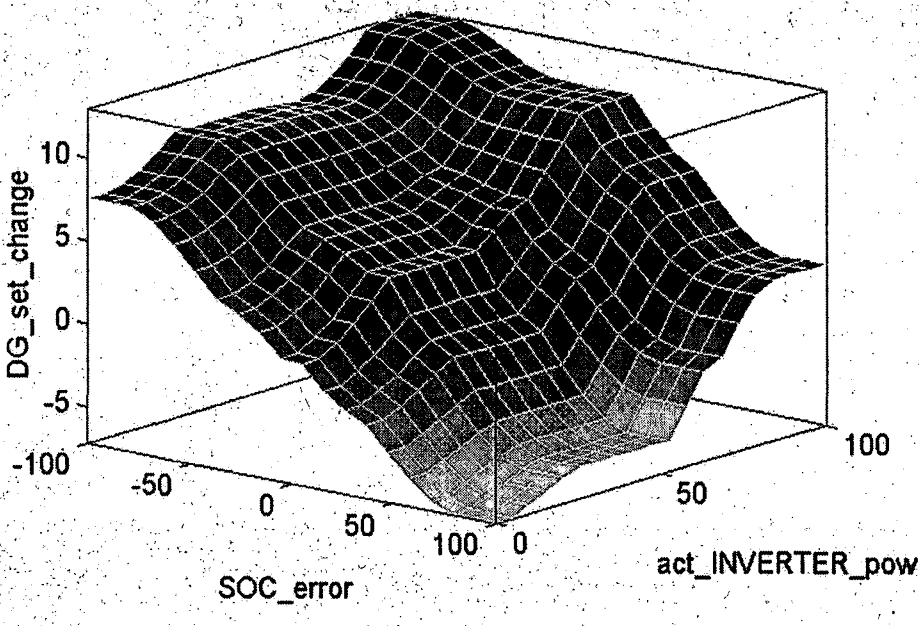


Figure S - act_DG_pow = 60%

Figure 19 shows higher values for DG_set_change since the lower actual DG power rate requires a PD* increase for DG efficiency.

Such behaviour is even more evident in the following figure 20.

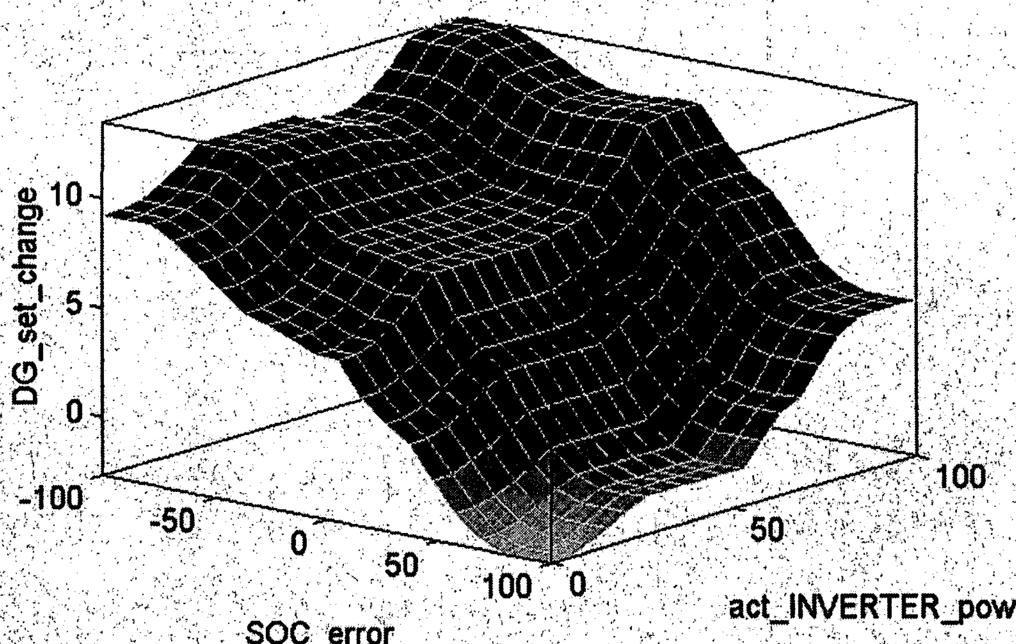


Figure T - act_DG_pow = 35%

Figure 21 displays the control surface obtained for DG_set_change vs. act_DG_pow and act_INVERTER_pow when the SOC_error is equal to zero. The output value is mainly affected from DG efficiency needs, unless the CEBS approach the safety margins.

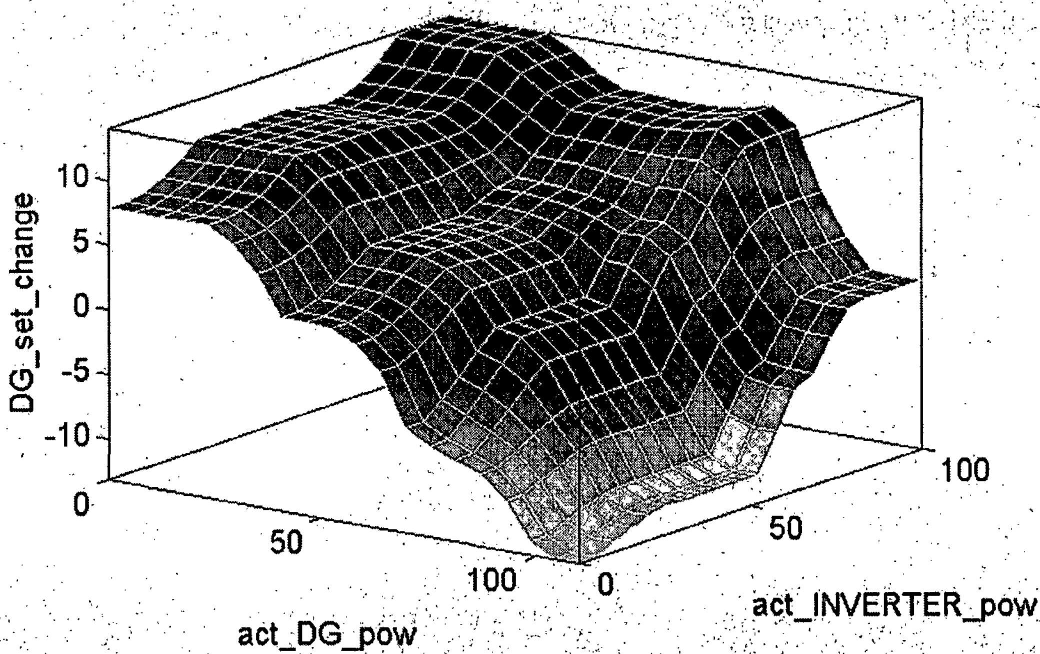


Figure U - SOC_error = 0%

Conclusions

Using fuzzy logic and a very simple model, we managed to achieve some encouraging results for the DG power set-point assignment task. Better results can be achieved with further investigations and experience. With the same methodology, other tasks of the GMC should be designed, in order to perform the whole configuration management. The availability of fuzzy software tools, assures the possibility to test the GMC behaviour with de-facto standard simulation software, such as SIMULINK and MATLAB.

LIST OF ACRONYMS

DG	Diesel Generator
TI	Tolerant Inverter
PV	PhotoVoltaic
GMC	Grid Master Control
CEBS	Central Energy Buffer System
TWI	Two Way Inverter
AB	Accumulator Battery
C	Conventional configuration
DP	DG / PVs configuration
DPBI	DG / PVs / CEBS Inverter mode configuration
DPBR	DG / PVs / CEBS Rectifier mode configuration
PBI	PVs / CEBS Inverter mode configuration
PBR	PVs / CEBS Rectifier mode configuration

EXPERIENCIES OF MALI IN THE FIELD OF SOLAR PHOTOVOLTAIC

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1 Introduction

Mali is a very big unlock country of 1.250.000 km2 with a population of 9.240.000 hts. The population density is about 1 to 5hts in the km2 and the main activities of the population were agricultural, cattle and fishing. The renewable energy and mainly the Photovoltaic (PV) had been required since the independence. The solar equipment had been introduced by the governmental sector for experimental and demonstration purposes and had been financed by the international and technical cooperation.

In 1964, the first institution called « Laboratoire de l'Energie Solaire » (LESO) had been created to promote the solar energy and to contribute to the energy policy.

In 1968, the activities of LESO had been extended to wind, biomass and energy saving.

With some technical and economic partners many demonstration and experimental actions have been undertaken with successful results. In 1970 with the concrete actions and efforts of Bernard Verspieren pioneer of PV pumping systems in Mali with "Mali Aqua Viva project" many solar pumping systems have been installed.

In 1990, le LESO became National Center for Solar Energy and Renewable Energy (CNESOLER).

In 1990, much solar business centers for solar energy have been created and were operational for the furniture of solar components and services (installation, maintenance, assembly/adaptation, and engineering).

2 EXISTING POLICY

The energy policy in Mali is mainly oriented on:
- the improvement of the production and distribution;
- the improvement of the rate of rural electrification;
- the sustainable energy development ;

This policy is based on:
- Valorize the important potential of the hydroelectric of the state (1.050 MW of available for a capacity of production of 5.700 GWh/an) ;
- Promote the energy of substitution to the oil and the wood ;
- Develop the technologies, which can reduce the consumption of the wood and make available the adapted energy equipment for the rural population at a lower cost.
- Use the enormous potential of renewable sources (solar energy is estimated at more than 5 to 6 kWh/m2/d annual mean for an irradiation of about 6 to 9 h/d)
- Contribute efficiently to the regional, sub-regional and international Energy program.

2.1 INSTITUTIONAL

Ministry of Mining, Energy and Water is the one presently in charge of the solar energy program and policy in Mali.

National Direction of Energy (DNE) is the one designed to conduct the energy program and policy in Mali and the CNESOLER which is the specialized center for the renewable energy sector in Mali is design to realize the objectives

To promote the energy sector in Mali, the government is associated with many organisms:
- ECOWAS (Economical Community of West African State) which created the CRES (Regional Center for< Solar Energy) in Mali (1985 to 1994).
- CILSS Inter State Community for Fighting Against Hunger (September 1973) which had participated to the CRES project
- OMVS (1972) by three state (Mali, Mauritania and Senegal) to build and exploit the hydroelectric equipment of the Senegal River and others.
  - La CEDEAO:
  - L'OUA:
  - L'UMEOA:

In Mali there are many local services for the development and the promotion of solar energy:
- the training services like schools (ENI, ENSup, ECICA)
- National association of solar energy business ;
- regional association professional in solar energy which members are from Benin, Burkina Faso, Mali, Mauritania, Senegal and Niger.

2.2 REGLEMENTATION

- creation, organization of the structure which have to study, to develop, to implement and to diffuse the renewable energy sector ;
- put to gather the needed text to regulate, to facilitate, to help and to improve the strategy of using solar energy ;
- take the decret 94-199 of June 3 1994 to stop the taxes on the solar equipment imported for 5 years
- take the ordonance 0019/P-RM of March 15 2000 to organize the Electricity sector ;
- put in application the text n°98 – 13/MFC-SG of January 1998 to fixe the taxes of the equipment of the project PAPEMER
- put in application the letter n°216 /MFC-SG of February 1997 to fixe the taxes of the equipment of the Project PEPLS.

3. CAPACITIES (SERVICES ET PRESTATIONS)

In the field of research, studies, installation and uses of solar PV, Mali had very big experiences. But we have to say that the 95 % of the human and financial resources are concentrated in Bamako.

3.1 Research, Development and training:

CNESOLER with technical team of 80 persons (engineers, technician's etc...) for research, studies, development, training, installation, maintenance, animation and awareness is the one really in charge the solar energy program in Mali. The cnesoler had in charge to promote, to advise, to implement and to organize the solar energy sector in Mali.

National Engineer School (ENI) had a training program on the field of solar energy. More than 200 engineers have been trained since 1984 from all African countries.

National High School (ENSUP) had a training program on the field of solar energy;

CRES had organized from 1984 to 1994 more than 10 training sessions for the engineers and the technicians

Cnesoler had organized more 20 training program and form individually more than 300 technicians from all others the word;

More than 300 documents are available on the field of solar energy in Mali

3.2 Commercial Services:

The private sector is well install and establish in Mali. In 1996 the department of Energy had identified more than 15 commercial offices which are specialized in studies, installations, maintenance, engineering and sealing. All the commercial offices are concentrated in Bamako. The most important commercial offices are: Diawara Solar Energy, Horonya, SES Corporation, ZED, Würth Solar Energy , Sinergie, SOMIMAD, ERC, AFRITEC, GID Solar, GAP – I3E, etc...

3.3 Organizations:

The village had a local organization, which is very important for given information, for sensibilization, commercialization and loans for the villagers.

In the cotton area (CMDT) where cotton is the most important agriculture activities they have at least one existing village association (AV) since 20 years. This AV is very experimented, played the role of link between the distributors and his members and had a very important consideration with the banking system. Also the Niger Office (ON) which is specialized in the production of rice had the same experiences.

3.4 NON Governmental Organization (NGO)

In Mali we had more than 100 NGO mainly for the rural development and more than 30 % of them are involved in the energy sector. Some of them are involved to promote solar energy mainly for drinkable water, lighting and refrigeration for health center. They are also very active for the transmission of all kind of information about the characteristics, the advantages and the limit of the use.

3.5 Financial Structures:

The most important financial structures in this field are presently the project from international agencies, state and very few privates.

The immigration (mostly from village located in the West of the Sahel) is very old phenomenal from the village to the town, and from the town to the out side of Mali. The migrants of different localities are organized and help a lot for the use of solar energy in their villages.

3.6. Fabrication

Only the research center and the school have initiated a fabrication program of some components of the PV system (regulators, inverter, lamps etc...). The result show than it is more costly to pay a component then to fabric.Actual Mali had no production unit of solar PV

4. PV IN MALI (INFRASTRUCTURES ET EQUIPMENTS)

4.1 Pumping:

More than 600 SPV(Solar Pumping System) are installed in Mali since 1977, for about more than 600 kWp. The most important equipment is installed in the area of Ségou., Sikasso, Kayes, Koulikoro, Mopti and Tombouctou. The power of the system is from 60 W (SURFLO Pump) to 12 000 Wp (Pomp Siemens pump installed by Plan International in Banamba). The most important program had been executed by the Regional Solar Program (RSP) of CILSS and financed by the European Fund for Development. For 1.040 pump installed in 9 countries of Sahel: Senegal, Mauritania, Gambia, Cap Vert, Guinea Bissau, Mali, Burkina Faso, Niger and Chad, Mali had obtained 157 pumps.

4.2 Lighting

More than 15.000 SPV are installed in Mali since 1977, for more than 250 kWp. The most important power installed is in the big area. The power installed goes from 10 Wp (lantern) to 11520 Wc (Hospital alimentation of Dire, by AIFO, Italian NGO), the private sector had installed thousand of system. Some projects have installed systems for schools, medical center, cultural center, public places etc.....The RSP had installed 33 system for lighting and charging batteries, the Project of Public Lighting by Solar Energy (PEPLS) had installed more than 570 street lighting systems, 300 lighting systems mainly for the community centers, 100 lanterns and 15 pumping systems. The aim for the future will be for 5000 lighting system and 1000 street lighting before the year 2005.

4.3 Communication

More than 300 SPV are installed in Mali since 1977, for more than 350 kWp. The power is from 50 Wp to 10 780 Wp. The perspectives are very important for the development of the rural telecommunication.

4.4 Refrigeration

Approximately 100 SPV are installed in Mali since 1977, for 20 kWp mainly for the medical center.

4.5 Others applications

Over 500 others SPV are installed in Mali since 1977, for 30 kWp for many uses (charging batteries, portable lighting, airport system etc.). The power can be from e 0,5 Wp to 100 Wp.

Table - SPV installed in Mali (from 1963 to now)

Designation	Number of systems	Power installed estimated (kWp)	Observations
Surface pumps	100	100	Good
Deep pumps	500	500	Very good
Domestic Lighting	15.000	500	Very good
Street lighting	1000	100	Very good
Refrigerators	60	12	Very good
Communication	300	350	Very good
TV set	400	24	Very good
Sound set	100	3	Very good
Milling	4	5	Good
Others PV systems	ND	Not given	Good
Total of PV	17 464	1 494	

5. ACTUAL OFFER OF MATERIALS AND SERVICIES

5.1 Status

In Mali the physical offer can be presented by two forms:

- Formal which is conducted by the know official private sector with all necessary know how and services ;
- Informal which provide materials from any where with some time a very bad quality, a very bad installation and without parts and maintenance

5.2 Materials and Services Offert

Table of materials and services

Materials	Services
Modules, pumps and accessories	Water pumping
Modules, regulators, batteries, lamps and accessories	Individual lighting
Modules, regulators, batteries, lamps and accessories	TV set
Modules, regulators, batteries, lamps and accessories	Communication
Modules, regulators, batteries, lamps, refrigerators and accessories	Health centers
Modules, regulators, batteries, lamps and accessories	Schools and cultures centers
Modules, regulators, batteries, lamps and accessories	Animation
Modules, regulators, batteries, lamps and accessories	Street lighting systems
Modules, regulators, batteries, lamps and accessories	Others (airport, counters, meteorological stations, etc.)

6. EVALUATION of the Malian Experience

6.1 Economical and financial Aspects

6.1.1 Economical aspects:

The Malian experience has been evaluated in many times and the main coming out results is:

- solar pumping is accepted and integrated for giving water to the population and the animals. Most of the project integrate the population for there financial contribution to the equipment, and also organize them for take care of the maintenance. According to some studies the mean of coming water can be estimated at around 250 FCFA to 300 FCFA the cubic meter which correspond to 12500 F CFA the installed Watt peak.
- solar micro-electrification is improved with some very good result and actually the installing price is around 10.000 to 12.000 FCFA the Wp. Even the cost, we observe a very big use of the system in remote area from the private and public sectors.
- solar refrigerators are specially used for the medical center and the price of the Wp installed is around 20 000 to 25 000 FCFA. Most the programs are using the solar refrigerators for the conservation the medical product of the medical center.

6.1.2 Financial aspects

- From the public and the private market:

According to some studies, 90% of the fund used for the activities of PV came from the international agencies and the NGOs. In fact, according to the private sector, 80% of their business cam from government tenders (projects) and the others 20% from the NGOs and the individual

- Actual financial mechanisms:

The main financial mechanisms in Mali are:

- cash payment;
- credit payment;
- partial and total donation.

For the financial mechanism the financial can support the payment by using their system of credit.

- Financial mechanisms of running:

The most use system for charging the running cost is the cotizations, the redevancies, and the coming money from out side

- profitability of the installed equipment:

The capacity of evaluating the services from the PV systems is variable according to the use, the location and the level of organization of the users. The studies from the water pumping the lighting and the communication show that, the PV are economically better than the others conventional systems for the same services. In the remote area the PV is economically better.

6.2 technical aspects:

Friability of the systems:

This characteristics is define as the probability of good running time for a long cycle life without shortage. This define coefficient factor is very good for the PV systems and in Mali we say that the guaranted life time of the module can go for at least 15 years, the others components are from 2 to 7 years

6.3 Socio-organisationAl aspects:

6.3.1 The Systems Managing

According to the type and the use of technology, the population is organized to tray to get the best benefit from the installations. In our days we find:

- the local managing team (for the water pumping system, the health center, the school systems etc.) which is well informed for finding all the solution to the technical, financial and social problems.
- the account opening in the bank for the system replacement and maintenance ;
- the services for training to help the local population to get some new installation, to train them and to advise;
- others organisms or associations for animation and sensibilization of the population.

6. 3.2 Tendencies et Opportunities

The level of integration of the PV system in Mali in socio cultural aspect:

The communities which have the PV systems are aware about the efficiency of the system and his impact on the improvement of their conditions of life in terms of production, education, health, security, better life, energy saving and environmental preservation.

The most important difficulty is the investment cost of acquisition. From the evaluation of the demand to the social mobilization and the organization, the SPV do not have any significant problems of introduction because they give an answers to a real need like water, light, tv etc..

With the actual decentralization and the privatization of the energy sector, the technicians and the commercial will be install in the remote area. The main concerned organisms will be:

- the government for implementing the project and improving the local development ;
- the private sectors for making business
- the users for having a good quality of services at a lower cost ;
- the banking systems ;
- the national and international organism interested by the environmental problem and the poverty
- the producers and the importers of SPV materials.

6.3.3 Genre:

During a part of the evaluation we have seen that an energy program and basically a PV program can not be well conducted without an implication of the women. For this reason the entire PV program should include a participation of the women at all level (for the village to the decision). In fact the first and the last user of the energy product is the women. Who use the water, which put one the light and the tv, ? who use the medical center ? etc...From our point of view the women spent more time to use the product of the PV system than the man.

7 CONCLUSION

In Mali the SPV are really incorporated and required to be use by the population of the remote area. To improve and increase the use of PV material we need:

- very good quality of PV material in terms of cells, modules and systems;
- very simple systems with less maintenance;
- very low cost material;
- adapted systems to the remote area use;
- availability of the spare part every were at every time;
- availability of the local technicians.

COUNTRY REPORT ON RENEWABLE ENERGY SITUATION

By Bello Nassourou
Electrical Engineer

Energy potential map

Introduction:

Niger republic is a land-locked country with a dry tropical climate. It covers a land area of 1267000 km2 out of which about 2/3 is desert. Agriculture and livestock are the main activities of the population. Niger is one of the poorest countries of the world with about a GDP of 290 US dollars per capita (data of 1990). In 1996 its population is estimated to about 9.300.000 inhabitants.

The density varies from 2 to 80 inhabitants/km2. The population yearly increasing rate is 3,3 %. The rate of electrification is 3,6 %.

The national energetic consumption is estimated to 1,2 million of TEP out of which 91% of ligneous combustible (wood, coal); 7 % of oil products and 2 % electricity. 70 % of its electricity demand is imported from Nigeria and all its need in fuel products are imported.

However our country is located in a area with renewable energies sources potential mainly solar energy (see map at annex).The government sectorial policies in the field of renewable energy is focussed on harnessing renewable energy sources in other to alleviate hunger and poverty. To achieve the above objectives, the government plans to develop and promote rural electrification in order to provide:

Water for drinking, livestock and irrigation;

- The development of small-scale industries;
- The electrification of integrated health care centres.

II- Renewable Energies.

A wide range of renewable energy sources is available in Niger, out of which some are actually being developed.

- Solar energy;
- wind energy ;
- hydro-electric energy
- biomass.

2-1 Solar energy

Niger is located between the latitudes 12° and 23°north and the longitudes 0° and 16° East. The sun reaches its zenith on the 22 April and keepts this position up to 22 august.

2-1-1 potential

According to the country's meteorological data the annual average insolation is about 6 kWh/m²/j for a daily average irradiation of 8 hours.

2-1-2 Installations

Solar energy has been first used in Niger in the year 1965 by ONERSOL. ONERSOL is a state institute that carries out research and development on the following solar devices: distillers, solar cookers, water-heaters; oven ; dryer ; air conditions and cooling. Only water-heaters and distiller have been industrially developed. Under are tabulated the achievement of ONERSOL during the last ten (10) years.

Table 1 - Thermic Solar Installations Produced in Niger (1986 - 1997)

ITEMS	NUMBER	OWNERS	OBSERVATIONS
Water-heaters	281 204 23	23Administration Niger Private Foreign Private	 Burkina Faso, Bénin, Togo
Distillers	43 7	OPT - SPCN Garages Foreigners	 Burkina Faso, Bénin
Dryers	15	ONERSOL INRAN	
SOLAR Cookers	33	PMI, Privates CSI	

* Photovoltaïc

In the stream of photovoltaïc, Niger has implemented many installations in the following sectors:

- Communication: installed power = 100 Kwc
- Solar pomp: installed power = 236 Kw
- lighting, ventilation, refrigeration: installed power = 30 Kwc

*Communication

In this field photovoltaïc is used to supply the followings:

i) Hertzian relay for (office des postes et télécommunication (OPT):installed power =6 Kwc.
The first installations was carried out during the years 1973 - 1974.

ii) Emitters stations for the office de radio diffusion et télévision du Niger (ORTN).

iii) Telephone stations:
9 rural telephony stations are installed in order to improve the existent telecommunication system.

iv) There are also Emitter- Receiver radio for security forces and some rural projects.

v) Communities televisions
Niger has experienced scholar television since 1970. But it was only on 1979 that it has started a wide spread dissemination throughout the rural area. An over all of 1358 scholar and community televisions have been installed within the whole country out of which 1200 are supplied by PV systems.

Table 2 - Installed power in the field of communication:

applications field	number of installations	installed power(WC)
hertzian stations	46	95.98
rural telephony	9	2.94
TV Re-emitter	9	2.31
communities TV	1200	48
E/R radio	200	3
Sum		152.23

* Health

The first applications have been carried out over the year 1980.From 1985 to 1990 many rural health care centres are supplied by PV system. The under listed projects have financed the electrification of these centres:

- Programme Special Energy (PSE)
  Centre régionale d'énergie solaire;
- UNICEF;
- FKW;
- Le programme régional solaire;
- Le projet ALAFIA
- AFRICARE et USAID ;
- La FAO.

Table 3 - Statistic of health centres supplied by PV system.

financing sources	n° of installations	end used	Installed power(Wc)
PSE	33	lighting/ventilation	4.5
PRS	15	lighting/refrigeration	5.25
UNICEF	5	lighting/ventilation/cooling	1.9
CRES	1	Lighting/cooling	0.54
KFW	9	lighting/ventilation /cooling	4.5
ALAFIA	18	lighting/ventilation/cooling/ E-R	10.89
AFRICARE	4	cooling	0.8
FAO	2	lighting	0.6
USAID	4	cooling	0.8
SUM	91		

* Water pumping

Compared to telecommunication the applications in this sector started late. The first applications have been implemented during the year 1983. However the actions in this sector are continuously increasing and have reached by 1998 an installed capacity of 236 Kwc. The table below shows the under-listed projects and their results achieved between 1985 and 1986.

Table 4 - PV pumping system situation

donors	N° of units	installed power(Kwc)
FED/PRS	66	111.245
DANIDA	33	58.245
PSE	10	20.785
FAC	9	12.56
CFD	3	4.80
FAO	2	2.915
UNICEF	2	4.4
OTHERS	12	20.756
SUM	137	235.706

Table 5 - Installed power in different sectors

Sectors	installed power(Kwc)
communication	152
health	30
water pumping	236
sum	418

2.3 Wind energy

2.3.1 Wind potential

The national agricultural research institute (INRAN), through the wind energy projects (PEEN) has carried out from 1987 to 1992 data measurement operated on 10 stations. As a result a wind map displaying wind speeds and directions from south to north has been established. From these data we can read that Niger is located between a wind speed ranging from 2.5 to 5m/s. These figure s are convenient for harnessing wind energy for small size wind electricity generation water pumping and specially starting from the latitude 14°50 North.

2.3.2 Installations and present situation

Many types of commercial wind generator have been experienced in Niger out of which the following models can be listed: Dampster; Kijito; CW500; Delta Deutch industry. Only the CW500 has been locally produced. All together around fourty (40) wind generators have been installed out of which more than 60% are off used.

2.4 Hydro-electric energy

2.4.1 Potential

The hydro potential is mainly located on river niger and few on its temporary streams. The favorable sites located on river niger are listed below:

- kandadji dam with an installed capacity of 230 Mw
- Gambou dam with an installed capacity of 122 Mw
- Dyondyonga dam with an installed capacity of 38 Mw

Morever an EDF survey carried out during the year 1967 has identified some favourable micro dam sites along temporary streams of river niger

2.4.2 Installation

There is up to today no hydroelectric dam built in Niger.

2.5 Biomass energy

2.5.1 Potential

Niger biomass potential encompasses firewood, agricultural residues, animal dung. Without exact statistical data, the woodfuel stock reserve is about 15 millions hectares. The wood fuel is the most important source of energy and is used by more than 90% of the households. its production is estimated to 953900 TEP in the year 1995.

The yearly energy potential generated from agricultural residues(by-products of farming, cereal straw etc is about 73 Tj is less than 0.1% of the over all energy demand. Animal dungs are mainly available in slaugthtery, houses farms, ranches. the yearly energy potential generated from this is about 1600 to 3800 TEP.

2.5.2 Installation

In the biomass sector all the installations implemented are biogas. these results are achieved through bilateral co-operations with France and china. The over all number of installation achieved is 13 unfortunately none of then is presently operating because of maintenance shortage and simple abandon.

Example: In Toukounous ranch the generation of electricity through combined biogas and gas oil achieved a 60% of combustible saving.

Table of biogas installations

areas	number of unit	capacity(m3)	ends used
Lossa I	2 2	5 3	grinding machine
Lossa 2	1	20	to drive a generator
Chical	1	20	supplying a generator
Ndounga	1	6	cooking
Maradi	2	6	cooking
Kirkissoye	1	8	cooking
Toukounous I	1 1	6 8	electricity
Toukounous 2	1	60	supplying a generator
Niamey	2	6	cooking/sterellization²
sum	13		

III Institutional,Legislative,Regulation and Fiscal framework

3-1 Institutional framework

Three (3) types of institution are involved:

*public institutions

The ministry of Mine and Energy through its department of Electricity and Renewable Energy is endowed to implement and monitor the national policies as stated by the government.

National Centre for Solar Energy (CNES), is involved in the implementation of Renewable Energy policies. It carries out research and development activities and owns a fabric.

*Private institutes

They are exercizing in the field of commercialization, installation and maintenance of renewable energy installations. these are:

SNTT; TOUTELEC; ENTRELEC; SNEE.

*NON Governmental organizations
They undertake actions in the field of promotion, exploitation and development of renewable energy through installation of PV systems, mass sensibilization and training. These NGO are: EDR; ONVPE; Abdou Moumouni Foundation.

3.2 Legislative, Regulation and Fiscal framework

There is no regulation relevant to.he exploitation and applications of renewable energy. Renewable energy legislative framework is rather connected to the energy sector than to the technologies itself.

Hence we may meet some provisions influencing indirectly the development of renewable energy in the following legislative codes:
- Forestry;
- Electricity
- water
- Rural
- Commerce and customs.

IV- Development prospective of renewable energy in Niger

Taking into account the national and international awareness about renewable energy, we can state that there will be a bright and significant development of renewable energy during the forthcoming years.

Under this awareness we can remind:

*At national level: the economic recovery take -off programme.
Through this programme emphasized to reduce the gap of development between urban and rural areas has been stated. In accordance to our national energy polices we believe that the development of renewable energy can contribute to reduce our energy dependency and contribute to environment preservation and beyond promoting a sustainable development.

* At world level
Taking into account the proceeds of Rio summit held in 1992 in Brazil and recently those from Harare(Zimbabwe) in 1996, where the world solar programmes was launched we are then convinced that the activities under this programme are focussed on the used and the promotion of renewable energy as a mean to achieve sustainable development. After the world Solar Summit of Harare Niger has launched two demonstrative projects carried out by the centre National d'Energie Solaire. the two projects title are:
- Integrated solar village;
- Lighting of three(3) adult learning centres.

*We are convinced that Niger researchers, engineers and technicians must be fully involved in planning dimensioning, installation and maintenance in order to master renewable energy technologies. That is why CNES objectives are oriented to:
- undertake research and development activities for the used of renewable energy and ensure the vulgarisation of the results.
- Participate to the achievement of prospective surveys and diagnostics in the field of renewable energy utilisation for economic sector.

- Participate to promotion and diffusion of renewable energy materials;
- Undertake utilities service(engineering surveys, PV system installation etc)

* Training
Already in the field of renewable energy some learning Packages are introduced in the syllabuses of technicians and engineers from the school of Mines, Industry an geology (EMIG). This high school is inherit from formal CEAO. It can be considered as a sub-regional training reference centre.

CONCLUSION

Although Niger energy consumption is weak and make use of massive traditional energies it depends on importation to meet its energy demand. As a result its balance of payments is subject to a heavy financial burden, hence reducing our daily effort to achieve the assigned objectives.

Taking into account the above listed drawback effect many projects relevant to renewable energy sector have been elaborated and submitted to international donors who are not unfortunately urging in accepting or releasing the financial support.

PV DESIGN AND APPLICATIONS

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1. INTRODUCTION

In this presentation we shall discuss the design of PV systems. We shall use examples to illustrate the steps taken in such designs.

2.1 Design of a PV System for an apartment that requires a power of 300 Watts. Suppose the power is required for only 12 hours a day. (i.e the duty cycle is 12 hrs).

Daily energy required = 12x300
= 3600 watt-hours.

Allow for system losses (usually 40%) = 1440 Watt-hours

Total daily energy required = 3600 + 1440
= 5040 Watt-hours.

A. Battery Sizing

Daily Energy requirement - 5040 Watt-hours
Allow for 5 days autonomy - 5040x5 = 25,200 Watt-hrs.
Add 30% safety factor - 25,200 + 7560 = 32760 W-hrs.
Required battery capacity =32760 Watt-hrs
Suppose a 12-Volt system is used, the battery A-hr

$$\text{Rating} = \frac{32760}{12} = 2730 \text{ Ampere-hrs.}$$

Suppose the battery (40265 Deka Sealed battery) Ampere-hours capacity = 265 A-hr.
Then No. of batteries in parallel $= \frac{2730}{265} = 11$ No.

B. System Array Design

Module Specification - 5m55 (see Appendix 1)
Panel power required = module power x location factor (4).
= 220 Watt.
Suppose insolation period = 7 hrs.
Daily Energy available = 220x7 = 1540 Watt-hrs.

∴ No of panels in parallel required = Total Energy required / Daily available energy

$$= \frac{5040}{1540} = 3.27\ (3)$$

Controller Selection

(i) Array controller

Array short, circuit current = 3.45A (Appendix 1)

Multiplication factor - 1.25

∴ Maximum module current = 1.25x3.45

= 4.3 Amps

Since there are 3 modules, Total maximum array current = 12.9A

Suppose controller capacity is 30A.

Then we need only one array controller for all 3 modules in parallel.

(ii) Load controller/Inverter

Peak load current = Total DC load Power / Nominal System Voltage

$$= \frac{300}{12} = 25A$$

We therefore need 1No. 30A controllers

(iii) Battery controller/Inverter

Maximum DC Array Current = 17.2A

Therefore required battery Controller is 1No. 30A controller

System Configuration: Figure 1

Next we shall use recommended design practices of Sandia Laboratories to go through a few design examples.

Design tables will be brought along.

ENERGY SITUATION IN THE GAMBIA AND SOLAR PV APPLICATION

LAMIN A.M. NJIE
ACTING PRINCIPAL ENERGY OFFICER

BASIC FACTS ABOUT THE GAMBIA

* Area: 11,300 sq. km
* Population: 1.3 Million
* Density: 96 per. per Sq. km
* Growth Rate: 4.2%
* GNP per capita 1998: $340
* Foreign Direct Investment Inflows 1998: $14.3 Million
* Total Net Financial Inflows 1998: $36.0 Million

ENERGY SECTOR

The Gambia relies almost entirely on biomass fuels and imported petroleum products to meet its energy requirements. The energy options are very limited for even the once abundant forest resources are being depleted through bush fires, farming activities and uncontrolled over exploitation.

The cost of importing petroleum products constitute an increasing burden on the country's foreign exchange reserve.

Given the topography of the country, with an elevation of up to 40 meters above sea level, the potential for hydro power generation is minimal.

ENERGY POLICY

The main policy objectives of the sector are as follows:

- To provide reliable, efficient and affordable energy which is a basic pre-requisite for any socio-economic transformation,
- Diversify the energy resource base,
- Reduce our dependence on fuel wood and petroleum products
- Encourage alternative use of petroleum products
- To provide uninterrupted petroleum supply at affordable prices,
- To encourage the use of renewable energy technologies,
- Removal of customs duty on import of solar panels,
- To cooperate with other institutions in the field of renewable energy for research and development,
- Reduce pressure on natural forest,
- Increase reforestation and forest protection measures

STRATEGIES

- to encourage energy conservation in households, trade, industry and public institutions,
- to accelerate studies concerning the development of renewable energy sources,
- to continue prospecting for fossil-fuel deposits

- to reduce the unit cost of electricity by burning more Heavy Fuel Oil and improving the Transmission and Distribution of electricity,
- to promote rural electrification
- to encourage private sector participation in the petroleum product procurement, supply and distribution,
- to increase storage capacity and safety standards.

ENERGY RESOURCES

The Gambia's energy resource base is modest, it comprises mainly:

- Electricity
- Petroleum Products
- Fuelwood
- Liquefied Petroleum Products (LPG)
- Renewable Energy Sources

ELECTRICITY

The National Water and Electricity Company (NAWEC), under the Office of The President, is responsible for generation of electricity, water and sewage services to the general public. Public power supply is secured from Kotu Power Station. Firm capacity is 21 MW and it is estimated that over 34 MW is provided through private generator due to the shortage of supply from Kotu.

PETROLEUM PRODUCTS

This is the second most important energy source, representing over 26% of total primary energy consumption. The total imports per annum is still less than 100,000 tons.

BUTANE GAS

The Gambia participated in a regional project that was funded by the EU to promote the use of gas for domestic cooking. Today gas is highly consumed in the country.

UTILISATION OF RENEWABLE ENERGY SOURCES

The Gambia's geographic location endows it with abundant sunshine. It receives an annual daily radiation of over 4080 cal/cm2, and even more during the cloudless dry season.

There are opportunities for far reaching application of renewable energy technologies for:

- Photovoltaic (PV)
- Thermal energy
- Wind energy
- Biogas
- Biomass

SOLAR PHOTOVOLTAIC (PV)

PV, or the direct conversion of sunlight to electricity, is one of the most promising alternative renewable energy technologies in this country. For the rural areas in particular it is the only way that basic electricity supply can be provided in the foreseeable future. PV is the main source of energy for telecommunication centres and relay station and for refrigerators and lighting in the rural dispensaries and health centres throughout the country.

RENEWABLE ENERGY
IN THE DECENTRALIZED RURAL ELECTRICITY PROGRAMME IN GUINEA

By M. Alkhaly Mohamed Tahey Conde
Economic and Financial Advisor
of the Minister of Hydraulic and Energy
Guinea Conakry

The energy balance in Guinea is marked by:

- a low level of energy consumption per capita (0,5 tons of oil equivalent per year);
- a great use of traditional energy (firewood and charcoal) in the final consumption of energy (79%);
- the big part of petroleum products (18%);
- a low level of electric energy consumption(2%);
- an important hydroelectric capacity of 26000 gwh per year poorly exploited.

Guinea imports per year about 500 000 tons of oil with a cost of 120 billion GNF (in US$60million). The country receives an annual radiation about 2000/2700 hours, with an abundant sunshine. The daily radiation is estimated to 4.8 kwh per m2

In 1994, in order to stimulate private participation in the development of the energy sector, the Government engaged a programme of restructuration by creating two companies;

- a public company in charge of the physical Assets, equipments, investments, called ENELGUI;
- a private company, SOGEL with the state participation in the capital of 33.4%, in charge of the operation, production, transportation, distribution, commercialization. After bad performances (low productivity, loss of cash flow, poor maintenance, high price for the consumers), these two companies are now in bankruptcy. On a production of 600 GWH in 2000 only 33% was sold and recovered. The Government is preparing their dissolution to create a new company, responsible for investment, production and commercialization. Let us mention that this conventional sector is only oriented for 9% of the population (7,500,000 persons). In February 1998, the Government decided in a Letter of Policy to prepare a programme of Decentralized Rural Electricity, with the assistance of partners in Development (The World Bank, the GEF/Global Environment Facility).

The Government and several partners realize the new deal: the development of renewable energy is quick, economic, clean, and sustainable. This project – programme (five year in his initial stage) will be based principally on the promotion of solar power, small-scale hydropower, and in some cases wind power, and biomass. This national programme will help to reduce poverty, in particular in the rural regions, rural exodus, to improve the conditions of living and economic production in rural zones, to stimulate agro-business, small industry and enterprises to create jobs and revenues, to help women in development. This programme involves the private operators in production, transportation, distribution and commercialization, in the forms of Build-operate-own (BOO) or Build-operate and transfer contracts.

The Government must provide fiscal incentives by reducing taxes. An office in charge of the management of the project will be settled before the end of June 2001. The BERD (Bureau d'electrification Rurale Decentralisee/office of Decentralised Rural Electrification) will organize information, databases, education, documentation, training, quality control, analyses, evaluations, consultations, regulation, standardization, feasibilities studies, monitoring, planning, capacity-building, meetings, benchmarking, expertise.

In the present time, Renewable Energy are used in Health Care Centers, water pumping, telecommunication, radio, television, lighting, food conservation, Education, for some public or private equipments in rural zones, where 80% of the population lives. The dilemma is that in many cases, the PV System does not reach the poors.

The programme will be launched in June 2001, with a budget estimated about U$16.9 Million (1 Million for the contribution of the Government of Guinea, 5 Million for the World Bank, 2 Million for the GEF/Global Environment Fund, 8.9 Million for the private sector).

The Use of PV Based Systems in Guinea-Bissau

Raimundo Lopes Jaoa

INTRODUCTION

Guinea-Bissau has one population of about 1.134.000 habitants, which is characterized by a growth rate of 2,1 % per year. This makes possible his population to double every 30 years. The average income per habitant is weak, of order of 210 $US per year. At the dawn of the 21st century, the country yet presents patents signals of a deep undevelopment, such as:

- The predominance of rural communities. About 70 % of population, that is 794.000 peoples are living in rural areas;
- The very low rate of use of modern and renewable forms of energies. This rate is characterized by a very low level of consumption of commercial energy per habitant (approximately 300 ktep/year), a low rate of access to electricity (8,5 %, which means 91,5 % of the population live outside of the reach of electric grids) and low electric production per habitant per year (6,2 kWh);
- The destruction of the environment for the satisfaction of energetic needs;
- The low rate of access to others basic services, such as potable water, health care, education, etc,

THE POTENTIAL IN SOLAR ENERGY

Because of his localization in sahelian region, Guinea-Bissau is part of the group of African continent whose solar radiation presents at very good level (between 1.900 and 2100 kWh/m2). This, plus the advantageously geographic configuration of his land, means it has all parameters suitable for a broad utilisation of solar energy

IMPLEMENTATIONS

In Guinea-Bissau, despite of the spreaded knowledge of the advantages and utility of solar energy, as well as the other forms of renewable energies, their use is yet very limited to a few public and private projects.

3.1. PUBLIC PROJECTS

THE REGIONAL SOLAR PROGRAMME

Until now, there's been only one single large-impact public investment project in the field of solar energy, the Regional Solar Programme, better known by the French/Portuguese acronym of PRS. This project was executed by CILSS between 1994 and 1996 and was financed by the Development European Fund. The PRS was implemented in the Eastern region on the behalf of the Ministry of Energy, Industry and Natural Resources and has benefited in majority the Muslim communities.

The two main principles that guided the establishment of PRS have contributed to major changes in national policies, mainly in the field of potable water supply in remote rural communities. Those principles was:

The implementation of the concept of responsibility in the concerned communities in regard to the common hydraulic infra-structures of potable water supply, aiming to reduce recurrent costs related with the management of these infra-structures and the renovation of some components of the system.

The dissemination of use of photovoltaic energy (pumping systems, communitarian lighting, etc).

The project have equipped 31 centres with simplified potable water pumping solar systems as well as 31 communitarian lighting systems in the mosques and permanents centres of education.

The total power installed by PRS is of 36,4 kW. The PV panels are from SIEMENS (module M50-S; power: 50 Wp) and inverters from SOLARTRONIC (type SA-1500; power: 1,5 kW/3x65; frequency: 7-63 Hz). The batteries are from VARTA and pumps are made by GRUNDFOS (type SP 5A-7; power: 500 W; debit: 2-19 m3/h).

The second phase of the PRS project is in the preparation, which will aim the followings objectives:

The development and management of supply system of potable water that provides a long lifetime of installations according to the institutional, conceptual and organizational plans;

The optimisation and adaptation of the 1st phase systems to the national strategy;

The installation of new systems of supply of potable water that correspond to both low cost and affordable demand of the rural population.

HEALTH

The Ministry of Health have been using PV-based systems in the health centres and dispensaries located in remote areas to provide energy to the conservation of medicines and vaccins, as well as for night lighting.

It is estimated at about 1,5 kW the total power installed.

TELECOMMUNICATIONS & OTHERS

National Telecommunications Company has also made use of PV-based systems, mainly as source of energy in his relay stations. About 2,5 kW of those systems has been installed. The technology is from both BP SOLAR and TUDOR and the batteries are from OLDAM.

National Navy is also using solar energy technology in his radio stations and in lighthouses, but in small scale.

3.2. PRIVATE PROJECTS

As the Government and public institutions are taking action in the solar energy sector, the private sector has also began using this technology.

Entities such as Catholic Church, Non-Government Organizations and individual have made large use of PV-based systems in their missions and projects disseminated in the country, namely for water pumping, lighting, communitarian TV and battery charging.

PERSPECTIVES

As it is stated in the Letter of the Government Policy for Energy Sector, because of the low country electrification rate and in order to guarantee minimal conditions of quality in the life of the populations, it must be considered, at least for while, the creation and diffusion of solar equipments for collective use, as well as to motivate peoples to use solar technology as way to improve quality in the family life and also to the creation of a small network and market of these equipments.

For everything that has been said, it is estimate that the overall power installed in Guinea-Bissau based on solar technology is about 43 kWp. This number may increase significatively due to the followings raisons:

The implementation of the National Rural Intervention and Electrification Program which studies of feasibility has been lead by the High Authority for Energy and Water Supply. Mainly, this program preconises the electrification of about 88 rural communities based on solar technology systems, having at the same time a strong component of environment protection. It is planned to benefit about 100.000 peoples;

The proliferation in the internal market of private enterprises specialized in trade and execution of technologies of valorisation of renewable energies, mainly the photovoltaic one;

The increasing public demand on solar panels as way to cover the deficit created by the low availability of public power supply as well as to reduce the high costs of running and maintaining of private diesel generators.

Solar energy for remote areas in Benin

By Mr. Daniel ASSOGBA
Direction of energy (Benin)

The population of Benin Republic is about 5 millions inhabitants for a surface of 112 622 km2. 70% of the population are in rural areas.

The structure of energy consumption is as follow at 1996:

Wood and other field wastes	72 %
Hydrocarbon	26 %
Electricity	2 %

The use of solar photovoltaic energy as a primary source it weak in spite of the solar insulation which varies between 3.9 kWh/ m2 day in the south to 6.2 kWh/ m2 day in the north of the country. The electrification rate is about 18%. Many remote communities and sites can't never have electricity because of funding problems, the large distance between national grid and the weakness of their consumption. However, those last years have seen some solar photovoltaic applications for rural communities to bring to them well-being and progress under auspices of the government. It is called "solar-villages". There were others applications in telecommunications, village hydraulic and public health.

I/ "SOLAR-VILLAGES"

The government project called "Improvement of well-being in rural areas" funding by the government and rural communities for respectively 90 % and 10%.

The use of photovoltaic systems is summarized per application to:
- water pumping installations;
- elementary health centre;
- leisure centres(lighting, audio-visual equipment);
- community(schools, public-paths) and resident lighting.

The criteria of selection of a village as "solar-village" are:
- population of the village lower than 1500 inhabitants;
- village far from national grid;
- no-existence of electrification plan in medium term;
- existence of drilling with good characteristics;
- existence of school, health centre, leisure centre, market, town hall......;
- existence of funding institutions;
- good level of organisation of the inhabitants.

The solar village is managing by a local committee elected by the villagers. Maintenance and repair may be paid by the communities themselves with incomes from water sale,leisure centres and individual lighting. Equipment photovoltaic systems for each village type is as follow:

Drink- water pumping	1050 Wc
Capacity of the tank	12m3
Number of fountain	3
Photovoltaic array for leisure center	400 w
Photovoltaic array for health center	600 W

Photovoltaic array for School	300 Wc
Photovoltaic array for town hall	100 Wc
Number of public lighting (10)	100 Wc
Number of portable lamps (50)	350 Wc
Individual kits (15)	750 Wc

We have now eleven solar-villages. There is a program at short term funding by Islamic Development Bank. The studies were performed. Tenders were invited and the completion date of the plan will be November 2001. A sum of 240 kWc of photovoltaic systems will be set up in 24 villages.

There are some problems with solar villages.
Failure of solar panels during periods of excessive heath.
Battery problems: decreasing performance up to failure and lack of maintenance.
The capacities of drink-water pump installations are too low.
The portable lamps with batteries are not very reliable.
The neon lamps suffer from black internal deposits
The converters frequently fail to function.
There are many problems with the local management committee:

The responsibility of suppliers and users about the replacement of panels or other components of PV installation is not clearly defined, so that maintenance, fails. Cashing of money fails also through all sorts of reasons.

Table that follow present "solar-villages" financing by the government.

Departments	Sub prefectures	Years	Villages	Costs (FCFA)
Atacora	Ouassa-Péhounco	1998	Ouassa-Péhounco	26500000
Borgou	Bembèrèkè	1997	Beroubouay	26500000
	So-Ava	1997	Houédo-Gbadji	23000000
Atlantique	Zê	1995	Sèdjè-Denou	22040000
Plateau	Pobè	1997	Towé	23000000
	Athiémé	1998	Dédékpoé	65595000
Mono	Dogbo	En cours	Ayomi	27019000
Couffo	Aplahoué	1999	Djotto	54925000
	Dassa-zoumè	1992	Soclogbo	54780000
Collines	Savalou	1998	Kpataba	105536500
	Savalou	En cours	Gobada	118459000

II/ OTHERS APPLICATIONS

Telecommunication (150kWc).
In sum,150kWc has been set up for Post and telecommunication Office (OPT) to take the place of many diesel groups in remote countries. Those photovoltaic systems are used to supply radio relay,rural telephone systems and buoying pylons. Other small photovoltaic systems has been set up to supply transmission system in many town halls.

Village Hydraulic (100 kWc).
Direction of Hydraulic has achieved in many villages of Borgou and Atacora,as well as in lake areas of Atlantic smallest networks of water canalisation by photovoltaic pumps.

Public health (50kWc).
Many villages health centres has been equipped with refrigerated storage for vaccines and ice supply for their transport,as well as lighting systems for childbirth and consultation rooms.

Resident electricity supply (10 kWc)
Regional Action Centre for Rural Development (CARDER) has achieved electrification of many houses in Borgou area by photovoltaic system for 10 kWc.
We didn't take particulars photovoltaic systems into account.

Conclusion

In Benin solar energy is available.There are many applications for lighting, pumping,cooling, telecommunications. 360 kWc of PV systems are already installed. 240 kWc will be installed at the end of this year.

TECHNICAL DOSSIER FOR THE SUPPLY AND INSTALLATION OF A PHOTOVOLTAIC SYSTEM FOR THE DISPENSARY IN THE VILLAGE OF DJENO

GENERAL DESCRIPTION

The photovoltaic system for the proposed dispensary in Djeno consists of the following components:

- 22 photovoltaic (PV) modules of 50 Wc
- 1 24-V control unit, formed by 2 SIGMA load regulators
- 1 battery, 24 V 400 Ah, formed by 8 Sonnenschein Dryfit Solar Block units 6/200
- 1 hot-galvanized steel supporting structure for modules
- 18 fluorescent lamps, "Reglette" type, 13 W 24 V
- 5 weatherproof fluorescent lamps, 18 W 24 V
- 1 refrigerator, 24 V 100 litres
- 2 junction boxes for PV modules
- 1 set of leads and accessories for wiring

The 2 junction boxes, the leads and the accessories (switches, small junction boxes, fixing of leads, etc.) will be at ELECTRA's expense. For installation, all the directions shown on the attached drawings must be exactly followed. The system has been studied for installation in sites far from the network and each component has been devised for highly reliable running, adaptable to all climatic and environmental conditions. For all technical data of the various components, see attachments.

CHARACTERISTICS OF THE SYSTEM

The system has been designed to supply the following items:

Item	Watts	day hours	night hours
5 fluorescent lamps 18 W 24 V	90	1	3
18 fluorescent lamps 13 W 24 V	234	1	3
1 refrigerator 24 V 100 lit.	60	9	6
Energy consumption Wh/day		864	1332

As described in the table, for each item the hours of operation indicated have been foreseen. The system is formed as shown in the attached drawing "GENERAL ELECTRICAL SCHEME", Dwg. N° DIDSP/1.

CHARACTERISTICS OF THE PHOTOVOLTAIC GENERATOR

The photovoltaic generator is made up of 22 modules, each of 50 Wc power for a total installed power of 1100 Wc.

The 22 PV modules are subdivided into 2 sub-fields:

1 sub-field consists of 12 modules, in 2 parallel lines (12 V), each of 6 modules; the series connection is in the junction box (see Dwg. N° DJDSP/2)
1 sub-field consists of 10 modules, in 2 parallel lines (12 V), each of 5 modules; the series connection is in the junction box (see Dwg. N° DJDSP/2).

All the junction boxes are fixed to the supporting structure.

CONTROL PANEL WITH TWO LOAD REGULATORS

The control panel is as shown in Dwg. N° DJDSP/1. Both load regulators proposed are controlled by a microprocessor with specific software for managing all the following functions:

- control and regulation of battery load
- control of applications
- alarms and signals
- correction of load-end voltage by temperature probe
- measurement of current discharged by PV generator and consumed by applications
- measurement of voltage.

The entire electronic circuit is of solid state type.

Display of operation and of alarms is performed by LEDs.

All the components are contained in a plastic housing with degree of protection IP55 to guarantee the necessary protection against impacts, water, rusting, etc. For lead entry there are clamps to ensure the necessary seal.

SUPPORTS

The supports are of modular type and are as shown in Dwg. N° 00-DD-M-246/4. The supports will be joined to the anchorage units with stainless steel bolts and will have a fixed inclination of 15° in relation to the horizontal axis. All the elements will be of hot-galvanized steel so as to be highly corrosion resistant.

BATTERIES

The batteries are watertight and fixed, of SONNENSCHEIN DRYFIT SOLAR BLOCK type. Characteristics of battery: 24 V, 400 Ah. A battery consists of 8 elements of SB6/200 type, each of 6 V and 200 Ah. The 8 elements are subdivided into 2 batteries, each of 4 elements connected in series, producing 24 V and 400 Ah. The batteries will be housed as shown in Dwg. N° DJDSP/3 and ventilation of the room will be necessary.

WIRING

The wiring used will be of NiVV-K or FG7 type. The section is as shown in the drawings.

LIGHTING

The lighting will have the following characteristics:

TECHNICAL CHARACTERISTICS OF BALLAST

Rated supply voltage	24 V
Max. rated power	13 W or 18 W
Range of working voltage	10-15 V
Admissible ballast current	0.72 A
Ballast no-load consumption	Nil
Ballast performance	> 75%
Ballast frequency	35 Hz
Total number of lamps	8,000

Operating temperature	-10°C - +45°C
Admissible moisture rate	90%
Ballast dimensions	Installed in housing
Polarity inversion protection	Yes
Type of protection	Diode
Protection against short-circuiting	Yes
Type of protection	Fuse
Welding of tube	With preheating
Guarantee	24 months

TECHNICAL CHARACTERISTICS OF TUBE

Brand	Philips or equivalent
Power	13 W or 18 W
Guarantee	6 months

CHARACTERISTICS OF HOUSING

Material	Aluminium
Index of protection	IP40 (IP65 for outdoor installation)
Guarantee	24 months
Protection against corrosion	Yes
Dimensions	25 x 35 x 389 mm

Lighting units should be installed as shown in Dwg. N° DJDSP/3

REFRIGERATOR

The refrigerator used has been designed for a continuous current system. The supply voltage is 24 V, capacity is 115 litres and power is 52 W. To be installed as shown in Dwg. N° DJDSP/3. For other characteristics, see annexes.

3.0 ANNEXES

3.1 DRAWINGS

- Dwg. DJDSP/1 - General wiring diagram
- Dwg. NJDSP/2 - Diagram showing connection of modules
- Dwg. NJDSP/3 - Indicative wiring of lighting and refrigerator system
- Dwg. 00-DD-M-246/4 - Structure for Djeno dispensary

DOCUMENTATION RELATING TO PRODUCTS
- Photovoltaic Modules
- Load Regulator
- Battery
- Refrigerator

TECHNICAL DOSSIER FOR THE SUPPLY AND INSTALLATION OF A PHOTOVOLTAIC SYSTEM FOR THE SCHOOL IN THE VILLAGE OF DJENO

GENERAL DESCRIPTION

The photovoltaic system for the proposed school in Djeno consists of the following components:

- 8 photovoltaic (PV) modules of 50 Wc
- 1 24 V control unit, formed by 1 SIGMA load regulator
- 1 battery, 24 V 200 Ah, formed by 4 Sonnenschein Dryfit Solar Block units 6/200
- 1 hot-galvanized steel supporting structure for modules
- 4 fluorescent lamps, "Reglette" type, 13 W 24 V
- 8 weatherproof fluorescent lamps, 18 W 24 V
- 1 junction box for PV modules
- 1 set of leads and accessories for wiring

The junction box, the leads and the accessories (switches, small junction boxes, fixing of leads, etc.) will be at ELECTRA's expense. For installation, all the directions shown on the attached drawings must be exactly followed.

The system has been studied for installation in sites far from the network and each component has been devised for highly reliable running, adaptable to all climatic and environmental conditions. For all technical data of the various components, see attachments.

CHARACTERISTICS OF THE SYSTEM

The system has been designed to supply the following applications:

Item	Watts	day hours	night hours
8 fluorescent lamps 18 W 24 V	144	1	2
5 fluorescent lamps 13 W 24 V	52	1	3
Energy consumption Wh/day		196	144

As described in the table, for each Item the hours of operation indicated have been foreseen. The system is formed as shown in the attached drawing "GENERAL ELECTRICAL SCHEME", Dwg. N° DIDSP/1.

CHARACTERISTICS OF THE PHOTOVOLTAIC GENERATOR

The photovoltaic generator is made up of 8 modules, each of 50 Wc power for a total installed power of 400 Wc.

The 8 PV modules are subdivided into 2 parallel lines (12 V), each of 4 modules; the series connection is in the junction box (see Dwg. N° DJECO/1)

The junction box is fixed to the supporting structure.

LOAD REGULATOR

The load regulator proposed is controlled by a microprocessor with specific software for managing all the following functions:

- control and regulation of battery load
- control of applications
- alarms and signals
- correction of load-end voltage by temperature probe
- measurement of current discharged by PV generator and consumed by applications
- measurement of voltage.

The entire electronic circuit is of solid state type.

Display of operation and of alarms is performed by LEDs.

All the components are contained in a plastic housing with degree of protection IP55 to guarantee the necessary protection against impacts, water, rusting, etc.
For lead entry there are clamps to ensure the necessary seal.

SUPPORTS

The supports are of modular type and are as shown in Dwg. N° 00-DD-M-246/4.
The supports will be joined to the anchorage units with stainless steel bolts and will have a fixed inclination of 15° in relation to the horizontal axis.
All the elements will be of hot-galvanized steel so as to be highly corrosion resistant.

BATTERY

The battery is watertight and fixed, of SONNENSCHEIN DRYFIT SOLAR BLOCK type.
Characteristics of battery: 24 V, 200 Ah.
The battery consists of 4 elements of SB6/200 type, each of 6 V and 200 Ah, connected in series to obtain 24 V and 200 Ah.
The battery will be housed as shown in Dwg. N° DJDSP/3 and ventilation of the room will be necessary.

WIRING

The wiring used will be of N1VV-K or FG7 type. The section is as shown in the drawings.

LIGHTING

The lighting will have the following characteristics:

TECHNICAL CHARACTERISTICS OF BALLAST

Rated supply voltage	24 V
Max. rated power	13 W or 18 W
Range of working voltage	10-15 V
Admissible ballast current	0.72 A
Ballast no-load consumption	Nil
Ballast performance	> 75%
Ballast frequency	35 Hz
Total number of lamps	8,000
Operating temperature	-10°C - +45°C

Admissible moisture rate	90%
Ballast dimensions	Installed in housing
Polarity inversion protection	Yes
Type of protection	Diode
Protection against short-circuiting	Yes
Type of protection	Fuse
Welding of tube	With preheating
Guarantee	24 months

TECHNICAL CHARACTERISTICS OF TUBE

Brand	Philips or equivalent
Power	13 W or 18 W
Guarantee	6 months

CHARACTERISTICS OF HOUSING

Material	Aluminium
Index of protection	IP40 (IP65 for outdoor installation)
Guarantee	24 months
Protection against corrosion	Yes
Dimensions	25 x 35 x 389 mm

Lighting units should be installed as shown in Dwg. N° DJECO/2

3.0 ANNEXES

3.1 DRAWINGS

- Dwg. DJECO/1 - General wiring diagram
- Dwg. DJECO/2 - Indicative wiring of lighting system
- Dwg. 00-DD-M-247/3 - Structure for Djeno school

3.2 DOCUMENTATION RELATING TO PRODUCTS

- Photovoltaic Modules
- Load Regulator
- Battery

TECHNICAL DOSSIER FOR THE SUPPLY AND
INSTALLATION OF A PHOTOVOLTAIC SYSTEM
FOR THE SCHOOL
IN THE VILLAGE OF DIOSSO

GENERAL DESCRIPTION

The photovoltaic system for the proposed school in Diosso consists of the following components:

- 6 photovoltaic (PV) modules of 50 Wc
- 1 24 V control unit, formed by 1 SIGMA load regulator
- 1 battery, 24 V 200 Ah, formed by 4 Sonnenschein Dryfit Solar Block units 6/200
- 1 hot-galvanized steel supporting structure for modules
- 6 fluorescent lamps, "Reglette" type, 13 W 24 V
- 2 weatherproof fluorescent lamps, 18 W 24 V
- 1 junction box for PV modules
- 1 set of leads and accessories for wiring

The junction box, the leads and the accessories (switches, small junction boxes, fixing of leads, etc.) will be at ELECTRA's expense. For installation, all the directions shown on the attached drawings must be exactly followed.

The system has been studied for installation in sites far from the network and each component has been devised for highly reliable running, adaptable to all climatic and environmental conditions. For all technical data of the various components, see attachments.

CHARACTERISTICS OF THE SYSTEM

The system has been designed to supply the following applications:

Item	Watts	day hours	night hours
2 fluorescent lamps 18 W 24 V	36	1	2
6 fluorescent lamps 13 W 24 V	78	1	3
Energy consumption Wh/day		114	306

As described in the table, for each item the hours of operation indicated have been foreseen.
The system is formed as shown in the attached drawing "GENERAL WIRING SCHEME", Dwg. N° DIOSECO/1.

CHARACTERISTICS OF THE PHOTOVOLTAIC GENERATOR

The photovoltaic generator is made up of 6 modules, each of 50 Wc power for a total installed power of 300 Wc.

The 6 PV modules are subdivided into 2 parallel lines (12 V), each of 3 modules; the series connection is in the junction box (see Dwg. N° DIOSECO/1)

The junction box is fixed to the supporting structure.

LOAD REGULATOR

The load regulator proposed is controlled by a microprocessor with specific software for managing all the following functions:

- control and regulation of battery load
- control of applications
- alarms and signals
- correction of load-end voltage by temperature probe
- measurement of current discharged by PV generator and consumed by applications
- measurement of voltage.

The entire electronic circuit is of solid state type.

Display of operation and of alarms is performed by LEDs.

All the components are contained in a plastic housing with degree of protection IP55 to guarantee the necessary protection against impacts, water, rusting, etc. For lead entry there are clamps to ensure the necessary seal.

SUPPORTS

The supports are of modular type and are as shown in Dwg. N° 00-DD-M-246/1. The supports will be joined to the anchorage units with stainless steel bolts and will have a fixed inclination of 15° in relation to the horizontal axis. All the elements will be of hot-galvanized steel so as to be highly corrosion resistant.

BATTERY

The battery is watertight and fixed, of SONNENSCHEIN DRYFIT SOLAR BLOCK type.
Characteristics of battery: 24 V, 200 Ah.
The battery consists of 4 elements of SB6/200 type, each of 6 V and 200 Ah, connected in series to obtain 24 V and 200 Ah.
The battery will be housed as shown in Dwg. N° DIOSECO/3 and ventilation of the room will be necessary.

WIRING

The wiring used will be of N1VV-K or FG7 type. The section is as shown in the drawings.

LIGHTING

The lighting will have the following characteristics:

TECHNICAL CHARACTERISTICS OF BALLAST

Rated supply voltage	24 V
Max. rated power	13 W or 18 W
Range of working voltage	10-15 V
Admissible ballast current	0.72 A
Ballast no-load consumption	Nil
Ballast performance	> 75%
Ballast frequency	35 Hz
Total number of lamps	8,000
Operating temperature	-10°C - +45°C

Admissible moisture rate	90%
Ballast dimensions	Installed in housing
Polarity inversion protection	Yes
Type of protection	Diode
Protection against short-circuiting	Yes
Type of protection	Fuse
Welding of tube	With preheating
Guarantee	24 months

TECHNICAL CHARACTERISTICS OF TUBE

Brand	Philips or equivalent
Power	13 W or 18 W
Guarantee	6 months

CHARACTERISTICS OF HOUSING

Material	Aluminium
Index of protection	IP40 (IP65 for outdoor installation)
Guarantee	24 months
Protection against corrosion	Yes
Dimensions	25 x 35 x 389 mm

Lighting units should be installed as shown in Dwg. N° DIOSECO/2

3.0 ANNEXES

3.1 DRAWINGS

- Dwg. DIOSECO/1 - General wiring diagram
- Dwg. DIOSECO/2 - Indicative wiring of lighting system
- Dwg. DIOSECO/3 - Wiring diagram of PV modules
- Dwg. 00-DD-M-247/1 - Structure for Diosso school

3.2 DOCUMENTATION RELATING TO PRODUCTS

- Photovoltaic Modules
- Load Regulator
- Battery

TECHNICAL DOSSIER FOR THE SUPPLY AND INSTALLATION OF A PHOTOVOLTAIC SYSTEM FOR THE DISPENSARY IN THE VILLAGE OF DIOSSO

GENERAL DESCRIPTION

The photovoltaic system for the proposed dispensary in Diosso consists of the following components:

- 10 photovoltaic (PV) modules of 50 Wc
- 1 24-V control unit, formed by a SIGMA load regulator
- 1 battery, 24 V 400 Ah, formed by 4 Sonnenschein Dryfit Solar Block units 6/200
- 1 hot-galvanized steel supporting structure for modules
- 5 fluorescent lamps, "Reglette" type, 13 W 24 V
- 2 weatherproof fluorescent lamps, 18 W 24 V
- 1 refrigerator, 24 V 100 litres
- 1 junction box for PV modules
- 1 set of leads and accessories for wiring

The junction box, the leads and the accessories (switches, small junction boxes, fixing of leads, etc.) will be at ELECTRA's expense. For installation, all the directions shown on the attached drawings must be exactly followed.

The system has been studied for installation in sites far from the network and each component has been devised for highly reliable running, adaptable to all climatic and environmental conditions. For all technical data of the various components, see attachments.

CHARACTERISTICS OF THE SYSTEM

The system has been designed to supply the following items:

Item	Watts	day hours	night hours
2 fluorescent lamps 18 W 24 V	36	1	1
5 fluorescent lamps 13 W 24 V	65	1	2
1 refrigerator 24 V 100 lit.	60	9	6
Energy consumption Wh/day		641	526

As described in the table, for each item the hours of operation indicated have been foreseen. The system is formed as shown in the attached drawing "GENERAL WIRING SCHEME", Dwg. N° DIOSDSP/1.

CHARACTERISTICS OF THE PHOTOVOLTAIC GENERATOR

The photovoltaic generator is made up of 10 modules, each of 50 Wc power for a total installed power of 500 Wc.

The 10 PV modules are subdivided into 2 parallel lines (12 V), each of 5 modules; the series connection is in the junction box (see Dwg. N° DIOSDSP/2)

All the junction boxes are fixed to the supporting structure.

LOAD REGULATOR

The load regulator proposed is controlled by a microprocessor with specific software for managing all the following functions:

- control and regulation of battery load
- control of applications
- alarms and signals
- correction of load-end voltage by temperature probe
- measurement of current discharged by PV generator and consumed by applications
- measurement of voltage.

The entire electronic circuit is of solid state type.

Display of operation and of alarms is performed by LEDs.

All the components are contained in a plastic housing with degree of protection IP55 to guarantee the necessary protection against impacts, water, rusting, etc. For lead entry there are clamps to ensure the necessary seal.

SUPPORTS

The supports are of modular type and are as shown in Dwg. N° 00-DD-M-246/2.
The supports will be joined to the anchorage units with stainless steel bolts and will have a fixed inclination of 15° in relation to the horizontal axis.
All the elements will be of hot-galvanized steel so as to be highly corrosion resistant.

BATTERY

The battery is sealed and fixed, of SONNENSCHEIN DRYFIT SOLAR BLOCK type.
Characteristics of battery: 24 V, 400 Ah.
The battery consists of 4 elements of SB6/200 type, each of 6 V and 200 Ah, connected in series, producing 24 V and 200 Ah.
The battery will be housed as shown in Dwg. N° DIOSDSP/3 and ventilation of the room will be necessary.

WIRING

The wiring used will be of NiVV-K or FG7 type. The section is as shown in the drawings.

LIGHTING

The lighting will have the following characteristics:

TECHNICAL CHARACTERISTICS OF BALLAST

Rated supply voltage	24 V
Max. rated power	13 W or 18 W
Range of working voltage	10-15 V
Admissible ballast current	0.72 A
Ballast no-load consumption	Nil
Ballast performance	> 75%
Ballast frequency	35 Hz
Total number of lamps	8,000

Operating temperature	-10°C - +45°C
Admissible moisture rate	90%
Ballast dimensions	Installed in housing
Polarity inversion protection	Yes
Type of protection	Diode
Protection against short-circuiting	Yes
Type of protection	Fuse
Welding of tube	With preheating
Guarantee	24 months

TECHNICAL CHARACTERISTICS OF TUBE

Brand	Philips or equivalent
Power	13 W or 18 W
Guarantee	6 months

CHARACTERISTICS OF HOUSING

Material	Aluminium.
Index of protection	IP40 (IP65 for outdoor installation)
Guarantee	24 months
Protection against corrosion	Yes
Dimensions	25 x 35 x 389 mm

Lighting units should be installed as shown in Dwg. N° DIOSDSP/3

REFRIGERATOR

The refrigerator used has been designed for a continuous current system.
The supply voltage is 24 V, capacity is 115 litres and power is 52 W.
To be installed as shown in Dwg. N° DIOSDSP/3.
For other characteristics, see annexes.

3.0 ANNEXES

3.1 DRAWINGS

- Dwg. DIOSDSP/1 - General wiring diagram
- Dwg. DIOSDSP/2 - Diagram showing connection of modules
- Dwg. DIOSDSP/3 - Indicative wiring of lighting and refrigerator system
- Dwg. 00-DD-M-246/2 - Structure for Djeno dispensary

DOCUMENTATION RELATING TO PRODUCTS

- Photovoltaic Modules
- Load Regulator
- Battery
- Refrigerator

INSTALLATION MANUAL
AND
INSTALLATION INSTRUCTIONS
FOR RURAL ELECTRIFICATION SYSTEMS
IN THE VILLAGES OF DIOSSO AND DJENO

GENERAL DESCRIPTION

The present technical specification refers to all the photovoltaic systems installed in the villages of Diosso and Djeno. They are systems operating on direct current at the voltage of 12 V or 24 V. They use only direct current fittings. According to the peak power installed in each system, there are several electrical fittings and the quantity of the fittings installed varies according to the typology of the system and the peak power installed.

To simplify the installation of the systems, they may be divided into two types:

a) Photovoltaic systems operating at 12 V

Village of Diosso
system for school head
system for schoolteacher
system for small houses

Village of Djeno
system for Salvation Army church
systems for small houses

b) Photovoltaic systems operating at 24 V

Village of Diosso
system for dispensary
system for school
system for village Chief
system for Doctor
system for Museum

Village of Djeno
system for dispensary
system for school
system for Lassyste Church
system for police station

INSTRUCTIONS FOR ELECTRICAL ASSEMBLY WIRING OF PHOTOVOLTAIC MODULES

12 V PHOTOVOLTAIC SYSTEMS

Considering the operating voltage of this type of system (12 V) the wiring of the modules in parallel has been necessary (see drawings of module wiring).
It is necessary to use a type of lead that will stand up to UV rays and bad weather.
It is very important to distinguish the two polarities (+ and -) by using leads with different colours and always respecting the same colour for the same polarity.
After having installed the wiring of the modules to the junction box, as indicated in the drawings, the precision of the wiring must be checked with the following measures:

The open-circuit voltage in the junction box should be around 20 V direct current
The short-circuit voltage in the junction box between the + and the - should be in proportion to the short-circuit current measured in each module. The short-circuit current of each module must be measured between the + and the - of each module. Its value will be at the maximum 3.2 A (direct current) with the greatest amount of sunshine.

24 V PHOTOVOLTAIC SYSTEMS

Considering the operating voltage of this type of system (24 V) the wiring of the two groups of modules - each of 12 V - in parallel has been necessary, and the wiring in series of the two groups in the junction box: for the series of the two groups the voltage of 24 V direct current has been obtained.
It is necessary to use a type of lead that will stand up to UV rays and bad weather.
It is very important to distinguish the two polarities (+ and -) by using leads with different colours and always respecting the same colour for the same polarity.
After having installed the wiring of the modules to the junction box, as indicated in the drawings, the precision of the wiring must be checked with the following measures:

For each group of modules in parallel at 12 V

The open-circuit voltage in the junction box should be around 20 V direct current
The short-circuit voltage in the junction box between the + and the - should be in proportion to the short-circuit current measured in each module. The short-circuit current of each module must be measured between the + and the - of each module. Its value will be at the maximum 3.2 A (direct current) with the greatest amount of sunshine.

For connection in series of the 24 V modules in the junction box

The open-circuit voltage in the junction box should be around 40 V direct current
Considering the wiring in series (24 V) of the two 12 V groups, the short-circuit current measured in the junction box between the + and the - must be of the same value as that measured for each 12 V group.

N.B.
It is necessary to take great care to respect the polarity and the section of the wires (harness). In these systems a positive pole (+) should always be connected to another positive pole, and likewise a negative pole should always be connected to another negative pole. In all wiring great care must be taken to respect the section of the wires shown in the drawings.

WIRING OF THE BATTERY

12 V PHOTOVOLTAIC SYSTEMS

The following 12 V systems:
systems for small houses
systems for schoolteacher (Diosso)

consist of two batteries of VARTA SOLAR type, 12 V and 100 Ah (C100), connected in parallel for a total of 12 V and 200 Ah (C100).

The other systems:

systems for school Head (Diosso)

systems for Salvation Army Church (Djeno)

use batteries of VARTA OPZS type of 2 V and different capacity.
For these systems it is necessary to connect up 6 elements in series, for a total of 12 V.

For filling the elements with electrolyte, reference must be made to technical specification n° 32-SG-E-192.

24 V PHOTOVOLTAIC SYSTEMS

Distinctions must also be drawn for these types of systems:

24 V systems with hermetic batteries

systems of the Diosso and Djeno dispensaries
systems of the Diosso and Djeno schools.

These batteries are of the Sonnenschein Dryfit Solar Block type of 6 V and 200 Ah, and have to be connected in series of 4 elements, to obtain 24 V and 200 Ah.
Only in the system for the Djeno dispensary is it necessary to connect in parallel 2 series each of 4 elements in series.

24 V systems with reduced maintenance fixed lead batteries

Village of Diosso
system for the village Chief
system for the Doctor
system for the Museum

Village of Djeno
system for the Lassyste Church
system for the police station.

These systems use batteries of VARTA OPZS type of 2 V and different capacity.
For these systems it is necessary to connect up 6 elements in series, for a total of 12 V. For filling the elements with electrolyte, reference must be made to technical specification n° 32-SG-E-192.

WIRING OF LOAD REGULATOR

For safety's sake and so as not to damage the regulator, we have used a type of regulator that can operate automatically at 12 V or 24 V. In this way only the type of the regulator has to be identified (ALPHA, GAMMA or SIGMA), as described in the technical specification for each system.

This wiring can be distinguished in the following operations:

a) Connection of battery with the regulator

Remove regulator fuse
Fix on the regulator the + and - leads in the direction of the battery and check that the polarities are correct
Connect the + lead of the battery (coming from the regulator) with the + pole of the battery
Connect the - lead of the battery (coming from the regulator) with the - pole of the battery

Connection of modules with the load regulator

Connect the + and - leads, coming from the modules, onto the regulator, and check that the polarities are correct

N.B.: CONNECT ONLY PHOTOVOLTAIC MODULES AS ENERGY SOURCE.

Connection of electrical applications

This operation will be described after describing the wiring for the supply lines of the electrical applications (lighting, refrigerators, etc.) in the paragraphs below.

For other information, refer to the annexes.

WIRING OF LIGHTING SYSTEM AND REFRIGERATOR

For all the installations an indicative wiring scheme has been foreseen. It is very important to verify all the drawings. The following indications must be closely respected:

Use the types and sections of leads as indicated

First place the leads and carry out the entire wiring in the junction boxes and in the switches

Distinguish the polarities of the lead always using the same polarity with the same colour of the conductor

Make sure of having correctly connected the leads, without causing short-circuits

Place the lights in the preferred position

Connect up all the electrical applications and check that the polarities are correct

Check that all the switches are in the STOP position

Once more check the polarities of all the connections

Connect the terminals of the supply lines of the electrical applications on the regulator and check that the polarities are correct.

BRINGING INTO OPERATION

Before operating the system, observe the following indications:

Check all polarities

Check the clamping of the leads

Check that the placement of the battery leads is correct

Disconnect on the regulator one polarity (+) of the modules and one polarity (+) of the electrical applications

Insert the regulator fuse and wait until the LED on the left flashes (2 minutes afterwards at the latest)

Again connect the + polarity of the modules on the regulator

Again connect the + polarity of the electrical applications

One at a time, try the operation of each application. If there are any applications not working, make sure that all the leads are properly connected, that the polarities are respected, and that the fuse is good (not open).

The system is now under way.

SUPPLY AND INSTALLATION OF A PHOTOVOLTAIC SYSTEM FOR A WATER PUMPING SYSTEM IN THE VILLAGE OF DIOSSO TECHNICAL SPECIFICATIONS AND INSTALLATION INSTRUCTIONS

GENERAL DESCRIPTION

The system consists of the following components:

- 232 photovoltaic (PV) modules each of 45 Wc, for a total of approximately 10440
- 1 battery charging regulation unit for the 110 V PV modules
- 1 battery, 110 V 220 Ah, formed by 55 elements of VARTA 40PzS220 type
- 1 hot-galvanized steel supporting structure for modules
- 1 control unit for the pumping system
- 1 inverter 110 Vdc/220 Vac, 50 Hz, 2500 VA peak
- 1 inverter 110 Vdc/220 Vac, 50 Hz, 5500 VA peak
- 2 submersible pumps CAPRARI type E4XA/16, 220 Vac, 50 Hz, for drilling
- 2 submersible pumps CAPRARI type HVX5/2M, 220 Vac, 50 Hz, for sending water from the reservoir to the water tower
- 2 junction boxes for PV modules
- 1 set of leads and accessories for wiring
- 1 set of hydraulic accessories

For installation, the indications provided in the attached drawings must be strictly followed.

The system has been devised for pumping water from the borehole and up to the water tower (see Dwg. 32-DD-E-322). Operation is governed by the control system so as to pump and lift the largest quantity of water to use all the energy produced by the PV modules.
The software installed in the microprocessor has been studied for the gradual utilization of the electrical loads to try to follow the course of energy produced by the PV generator.
The distance between the hole and the water tower (2100 m) has determined the use of a reservoir located near the borehole.

CHARACTERISTICS OF THE SYSTEM

CHARACTERISTICS OF THE PHOTOVOLTAIC GENERATOR

The photovoltaic generator is made up of 232 modules, each of 45 Wc power for a total installed power of 10440 Wc.

The 232 PV modules are subdivided into 6 sub-fields:
5 sub-fields consist of 5 series of modules, each of 8 PV modules, series connected; the junction box contains the connection in parallel of the 5 series (see Dwgs. 32-DD-E-323, 32-DD-E-330, 32-DD-E-327 and 32-DD-E-325).
1 sub-field consists of 4 series of modules, each of 8 PV modules, series connected; the junction box contains the connection in parallel of the 4 series (see Dwgs. 32-DD-E-323, 32-DD-E-330, 32-DD-E-327 and 32-DD-E-325).

All the junction boxes are fixed to the supporting structure (see Dwgs. 32-DD-E-327, 32-DD-E-

328, 33-DD-E-329).

LOAD REGULATION UNIT

The control unit is as described in the annex "REGULATION AND CONTROL UNIT". The unit controls the 6 sub-fields by a microprocessor with software to operate all the following functions:
- control and regulation of battery load
- alarms and signals
- correction of the end-of-load voltage by a temperature probe

The whole electronic circuit is solid state. Display of functioning and of the alarms is by means of luminous LEDs.

All the components are contained in a metal cabinet with IP55 degree of protection to guarantee the necessary protection against impacts, water, rust, etc. The layout of the circuit is included in the annex.

CONTROL SYSTEM

The control system is contained in a metal cabinet. There are two sections in the front panel:
one for control of the system, including the "STOP" and "GO" buttons for each pump, the "EMERGENCY STOP" button and the switch to choose the type of operation, "MANUAL" or "AUTOMATIC".
one for the signals, containing all the LEDs

Each button and LED is identified by a sign (code).
As already described, the control system has to govern the pumping system consisting of two pumps, supplied by inverts. The operating principle is based on permitting the best use of the energy generated by the PV modules.
The signals and the most important characteristics which determine the operating routing of the system are as follows:

The voltage of the battery
The water level in the reservoir, governed by two floats in the reservoir. The control system is supplied at 110 V DC and is directly connected to the battery. For the control of each inverter there is a connection within the control system of each inverter. With the leads in place, the inverters are totally controlled in real time. All technical directions are set out in the annex "CONTROL AND SUPPLY SYSTEM FOR PUMP UNIT".

Inverters
The direct current (DC) power produced by the battery and by the PV generator is transformed into alternating current (AC) by the inverter. The system includes the following two inverters:
- 1 inverter of 110 Vdc/230 Vac, 1000 VA fixed, 2500 VA peak, single phase, 50 Hz for supplying the submersible pump of 550 W in the borehole
- 1 inverter of 110 Vdc/230 Vac, 1500 VA fixed, 5500 VA peak, single phase, 50 Hz for supplying the vertical axis pump of 1500 W

Each inverter has the characteristics detailed in the annex "CONTROL AND SUPPLY SYSTEM FOR THE PUMP UNIT". They are supplied directly by the battery and their start-up is governed by the control system. Connection by way of an obligatory junction box is foreseen between each inverter and the control system. Each inverter is contained in a metal cabinet. The front panel contains the measuring instruments for the AC output and for the output voltage.

2.5 SUPPORTS

The supports are of modular type. Typical ones are as shown in Dwg. N° 00-DD-M-213.
The supports will be joined to the anchorage units with stainless steel bolts and will have a fixed inclination of 15° in relation to the horizontal axis.
All the elements will be of hot-galvanized steel so as to be highly corrosion resistant.

BATTERY

The battery consists of 55 elements of 2 V and 220 Ah (c10h), of VARTA 40PzS 220 type.
The rated voltage of the battery is 110 V and its total capacity is 220 Ah in 10 hours.
The battery is of limited maintenance type.
The positive plates are of small pipes lined with a lead-selenium alloy grille, with a content of SI<1%.
The negative plates are of Petri grille of lead-calcium alloy. The electrolyte is diluted sulphuric acid.
The container is of transparent plastic.
All technical details are contained in the annexes.

WIRING

The wiring used will be of NiVV-K or FG7 type. The section is as shown in the annexed drawings.

ANNEXES

3.1 DRAWINGS

Dwg. 32-DD-E-322
Dwg. 32-DD-E-322
Dwg. 32-DD-E-322 - INDICATIVE DIAGRAM OF PUMPING SYSTEM
Dwg. 32-DD-E-323 - GENERAL DIAGRAM OF PUMPING SYSTEM
Dwg. 32-DD-E-324 - WIRING DIAGRAM
Dwg. 32-DD-E-325 - WIRING ROUTE
Dwg. 32-DD-E-326 - ROOM FOR BATTERY AND ELECTRICAL PANEL
Dwg. 32-DD-E-327 - SUPPORTING STRUCTURES AND JUNCTION BOX
Dwg. 32-DD-E-328 - SUPPORTING STRUCTURES AND JUNCTION BOX
Dwg. 32-DD-E-329 - TYPICAL INSTALLATION SCHEME OF JUNCTION BOX
Dwg. 32-DD-E-330 - WIRING IN PV MODULES
Dwg. 32-DD-E-331 - LAYOUT
Dwg. 32-DD-M-251 - DIOSSO PUMPING SYSTEM
Dwg. 32-DD-M-213 - MODULE SUPPORT STRUCTURES

DOCUMENTATION RELATING TO PRODUCTS

- Load Regulation Unit
- Control and Supply System for Pumping Unit
- Photovoltaic Modules
- Battery
- Pumps

TECHNICAL SPECIFICATION OF CONTROL AND SUPPLY SYSTEM FOR PUMPING UNIT
TECHNICAL DESCRIPTION AND MANUAL FOR USE

1 DESCRIPTION

The system comprises the following equipment:

- 1 control system
- 1 inverter, 110 Vdc/220 Vac, single-phase, 50 Hz, to supply submersible pump in borehole
- submersible pump for borehole, Caprari type, EAXA/16 of 550 W, 220 V ac, 50 Hz, single phase
- 1 inverter, 110 Vdc/220 Vac, single-phase, 50 Hz, to supply pump to lift water from reservoir to water tower
- surface pump for lifting water, Caprari type, EAXA/16 of 1500 W, 220 V ac, 50 Hz, single phase.

The two inverters are supplied directly by the battery and their operation (GO AND STOP) is governed by the control system. The system controls the start-up and stopping of the inverters according to fixed parameters. The software is intended to optimise the use of the energy supplied by the PV modules. All the apparatuses necessary for the automatic and manual operation of the system are contained in the front panel of the control system.

2 CONTROL SYSTEM

The system is outlined in the following diagram:

PV MODULES		
LOAD REGULATOR	CONTROL SYSTEM	
BATTERY	INVERTER 1	INVERTER 2
	PUMP 1 (BOREHOLE)	PUMP 2 (LIFTING)

The type of operation is as follows.

The PV modules charge the battery which provides power to feed the pumps. The system controls the operation of the inverters for the starting up of the pumps. Given that the power supplied by the PV modules is variable during the day, under normal working conditions, the power provided by the modules will be sufficient to supply the applications and to charge the battery. After checking the operating parameters, the control system starts up the system automatically, as established by the software. The layout of the circuit is shown in Dwg. SSTPM01, and Dwg. SSTPMP02 shows the arrangement of the control organs, located in the front panel. Dwg. SSTPM03 shows the arrangement of the signalling LEDs located in the front panel.

CONTROL SOFTWARE FOR AUTOMATIC OPERATION

The system always controls the value of the voltage of the battery and of the other parameters, the water levels in the reservoir, the value of the current consumed by the pumps, etc.

The symbols used for the voltage thresholds are as follows:

- Vb = battery voltage
- Vok = 125.75 V, the value of the battery voltage foreseen for start-up of the system.
- Voff = 120.25 V, the value of the battery voltage foreseen for the stoppage of the normal operation of the system
- Vmin = 103.75 V, the value of the battery voltage foreseen for the stoppage of the system due to the discharged battery alarm.

The values of the voltage indicated are referred to the temperature of 25°, and change according to the temperature, by a coefficient of 5mV°C x battery element (the battery is made up of 55 elements each of 2 V, for a total of 110 V).

Each time that during the programme routine a battery voltage value is recorded equal to one of the mentioned thresholds, before carrying out the corresponding control, it is necessary to wait for 5 minutes. This method has been used to avoid any unstable operation of the system.

The whole of the following description refers to the operation of the system in the "AUTOMATIC" mode.

With the switch of the front panel in the "1 AUTOMATIC" position, the system starts up and the yellow LED goes on.

The red LEDS "1 MIN PUMP 1" and "1 MIN PUMP 2" will light up and also the LED "RESERVOIR FULL" or "RESERVOIR EMPTY" will light up (according to the water level in the reservoir).

In this way the system starts up and the programme will check the value of Vb:

If Vb < Vok, the system remains in wait.
When Vb > Vok, after 5 minutes in this condition, the LED "START-UP ROUTINE" and the reservoir water level is checked.

If the reservoir is not full, "INVERTER 1" and the borehole pump (PUMP 1) are activated and the LED "PUMP 1 ON" will remain on until the reservoir is filled, when PUMP 1 and the LED "PUMP 1 ON" stop and the LED "RESERVOIR FULL" goes on.

From this moment on INVERTER 1 and PUMP 2 for lifting the water will be activated and the LED "PUMP 2 ON" will be on. At the same time an electronic timer to measure 30 minutes will go on.

If before the 30 minutes have ended the reservoir is found "NOT FULL", PUMP 2 is stopped and the LED "PUMP 2 ON" will be off. In this case the system again fills the reservoir, according to the routine already mentioned.

If throughout the 30 minutes the reservoir is not found "NOT FULL", "PUMP 2" remains on until the end of the 30 minutes.

At the end of the 30 minutes the "START-UP ROUTINE" ends and the LED goes out. PUMP 2 remains in operation and the LED "PUMP " ON" will be on.

When the "NORMAL OPERATION" cycle starts, the corresponding LED goes on. PUMP 1 in the borehole will start and the LED "PUMP 1 ON" will go on. The duration of the "NORMAL OPERATION" cycle is usually 5 hours; this time is measured by an electronic timer.

In this condition the 2 pumps are in operation and, if the quantity of water drawn from the borehole is the same as the water lifted, and Vb remains > Vmin, the 2 pumps will remain in operation throughout the 5 hours.

If the quantity of water moved by the 2 pumps is not the same, it can be checked whether the reservoir remains EMPTY or becomes FULL, in which case the programme stops PUMP 1 or PUMP 2 until the conditions are again such as to restart the pump which had been stopped.

In this way it is quite clear how important it is to have the same quantity of water for the two pumps.

If at the end of the 5 hours the condition Vb > Vmin still remains, the operation of the system will remain the same. If at the end of the 5 hours the condition Vb > Vmin remains, there will be a "RESET" of the programme to start the routine again from the starting-point, after having checked that Vb > Vok.

If at the end of the 5 hours the condition Vb > Voff remains, the 2 pumps will remain in operation until such time as Vb > Voff, after which another electronic timer lasting for 30 minutes will start up. PUMP 2 will be stopped and PUMP 1 will be in operation (the LED "PUMP 2 ON" and the LED "NORMAL OPERATION" are stopped, and the LED "ROUTINE STOP" will be on) to complete the filling of the reservoir until the end of the 30 minutes.

If at the end of the 5 hours the condition Vb > Voff still remains, the times is again switched on for 30 minutes and during this time PUMP 2 is stopped (LED "PUMP 2 ON" and LED "NORMAL OPERATION" stopped, LED "ROUTINE STOP" on), PUMP 1 remains in operation until filling of the reservoir has been completed or for the duration of the timer, i.e. 30 minutes.

In this condition the system remains in wait for the new START, perhaps the following day.

Throughout all the conditions mentioned, voltage control is always kept active and the programme is ready for the stopping of the system when the condition Vb < Vmin holds.
The programme has been designed to optimise the use of the power produced by the PV modules.

4 NORMAL OPERATION AND EMERGENCY STOP

In the front panel of the control system, there is a red button "EMERGENCY STOP". If this button is pressed right down, all the apparatuses controlled by the system, i.e. the inverters and the pumps, will stop.
The EMERGENCY STOP must be pressed only in case of emergency.
To disconnect the EMERGENCY STOP, the button must be turned in the direction indicated on the button.
If the EMERGENCY STOP is pressed during AUTOMATIC operation, after disconnection with the button, the system will restart from the initial point of the programme.
To start the "MANUAL" operating cycle, the switch most be in position "pos. 2 MANUAL" (the green LED "MANUAL" will go on.
To put PUMP 1 on, the green button "PUMP 1 WORKING" must be pressed, and to stop it the red knob "STOP PUMP 1 has to be pressed.

The same thing to switch on PUMP 2.

5 TERMINALS

The system includes one terminal for supply by the battery and for the reservoir water level probes. The terminal is located in the bottom of the locker (see Dwgs. SSTPMP01 and SSTPMP01/A). The details of the terminals are as follows:

M3: min level probe (PUMP 1 FLOAT)
M4: min level probe (PUMP 1 FLOAT)

M1: POSITIVE POLE of battery
M2: NEGATIVE POLE of battery

M5: max level probe (PUMP 2 FLOAT)
M6: max level probe (PUMP 2 FLOAT)

The control system is connected with the two inverters by leads already made up and complete with junctions.
The two leads are interchangeable but in the wiring it is necessary to connect INVERTER 1 where INVERTER 1 is indicated (to power the borehole pump) and INVERTER 2 where INVERTER is indicated (to power the lifting pump).

N.B. - THE CONTACT NORMALLY OPEN FOR THE CONDITION OF ABSENCE OF WATER MUST BE USED FOR THE LEVEL PROBES.

6 INVERTERS

The system comprises the following inverters:

- 1 inverter, 110 Vdc/220 Vac (INVERTER 1), 1000 VA fixed, 2500 VA peak, single-phase, 50 Hz, to supply the 550 W submersible pump in borehole

- 1 inverter, 110 Vdc/220 Vac (INVERTER 2), 1500 VA fixed, 5500 VA peak, single-phase, 50 Hz, to supply the vertical axis pump to lift the water, having a power of 1500 W.

For a general scheme of the inverter, see Dwg. SSTPMP04. The terminal is indicated on Dwg. SSTPMP04/A.

The electrical characteristics are as follows:

- Rated voltage	110 Vdc
- Max operating voltage	150 Vdc
- Min operating voltage	90 Vdc
- Rated output voltage	220 Vac, single-phase
- Frequency	50 Hz
- Max output current (INVERTER 1)	25 Aac
- Max output current (INVERTER 2)	12 Aac

The two inverters are switched on automatically by the control system. The connections to be made for the wiring are as follows:
- M1: battery POSITIVE POLE
- M2: battery NEGATIVE POLE

- M3 and M4: output alternating current 220 Vac, to supply the pump.

Before connecting the battery it is necessary to turn OFF the switch with fuse F1/F2.

After having connected the battery, press knob P1 (PRECHARGE) for 15 seconds, and then turn ON the switch F1/F2.

It is then also possible to switch on switch I1 of the outlet line at 220 Vac.

The terminal and the switches are arranged in the lower part of the cabinet.

Each inverter with the lead of the control system is located at the back.

7 CHARACTERISTICS OF INVERTERS

With reference to Dwg. SSTPMP04/A, the letter codes have the following meanings:

P1 is the PRECHARGE power

F1 and F2 = switch with fuses of battery supply

F3 and F4 = switch with fuses of supply unit

I1 is the supply switch for the application at 220 Vac

1 (+) and 2 (-) is the terminal for connection of the battery

3 and 4 is the output terminal for the application at 220 Vac.

The technology used for operation of the inverter is of PWM type. The configuration of the power elements is of H ("BRIDGE") type, with IGBT.

PROTECTIONS ON ALTERNATING CURRENT SIDE

Control of the output voltage is carried out by an electronic circuit which automatically stops the inverter if the voltage exceeds the max outlet value (250 Vac).
The same circuit controls the output current and stops the inverter if the current exceeds the fixed value.
The two controls have a hysteresis time (lag) of 30 seconds, after which the inverter is stopped automatically.
The protection for temperature is arranged on the IGBT and it comes into instant action if the temperature exceeds 75°C.
After the automatic stop of the inverter, to start it again it is necessary to RESET the inverter, in the 2 following ways:

turn the switch (F3/F4) OFF and after waiting for about 30 seconds, turn the switch to activate the inverter again.
place the 3-position switch in the front panel of the control system on "0" and then position the same switch in position "1" or "2", according to the type of operation chosen.

7.2 PROTECTIONS ON DIRECT CURRENT SIDE

The protections used are the following:

- Protection for consumption of max current. The coming into play of this protection causes the stoppage of the inverter and to restart it, refer to the procedure outlined in point 7.1.
- Protection for min and max supply voltage. If this protection comes into play causes the inverter to stop, and restarting is automatic if the voltage again comes within the admissible values
- Short-circuit protection on supply side, with semiconductor fuse arranged on the positive pole at the entrance of the IGBT. After this protection has come into play, before replacing the fuse the integrity of the IGBT has to be checked.
- If the IGBT are damaged the fuse has to be replaced.

INVERTER START-UP TESTS

To perform the start-up test of the inverters, all connections must have been made as shown in the drawings. The control system and the 2 pumps must also be connected.

The following action should be taken:
Turn OFF switches F1-F2, F3-F4 and also I1
In the control system terminal, make a short-circuit of contacts 3 and 4 (PUMP 1 FLOAT) and between contacts 5 and 6 (PUMP 2 FLOAT), to simulate the water levels in the reservoir
Turn ON switch F3-F4
Press button P1 (PRECHARGE) for about 15 seconds.
Turn ON switch F1-F2
Turn ON switch I1 for supplying the pump
In the control system panel, activate position "2" "MANUAL" and start up the inverters with the "PUMP 1 START" and the "PUMP 2 START". They are to be activated before the inverters and after the pumps.
To stop the inverters, the "PUMP 1 STOP" and "PUMP 2 STOP" buttons should be used.

At the end of the tests it is necessary to re-establish the correct wiring of the contacts 3-4 and 5-6 of the control system terminal. Remove the short-circuits.

8 START-UP OF SYSTEM

Before starting up the system it is necessary to check that all the wiring has been placed correctly.
Then it must be checked that the voltage is between 110 and 132 V.
The switch in the front panel of the control system must be placed in position "0".
Place switch I1 of the control system in the ON position (Dwg. SSTPMP01).
Go ahead with "MANUAL" operating test and place the switch in position 2 "MANUAL". The green LED is on and with the button "PUMP 1 START" INVERTER 1 and PUMP 1 may be switched on. After pump start-up, wait a few seconds and then stop PUMP 1 with the red button "PUMP 1 STOP".
Repeat the test for INVERTER 2 and PUMP 2.
After having checked the proper working of the inverters and the pumps, again activate one pump at a time and press the red button (EMERGENCY STOP) to check the emergency stoppage of the apparatuses already activated.
Place the switch on the front panel of the control system in position "0".
Now carry out the operating test in "AUTOMATIC"; place the control system switch in position "1" "AUTOMATIC".
The system will start the operating routine as described in paragraph 3.

TECHNICAL SPECIFICATION OF
CHARGE REGULATION UNIT
TECHNICAL DESCRIPTION AND MANUAL FOR USE

1 GENERAL

The board is formed by a regulation and control circuit for a photovoltaic system having a rated voltage of 110 V. The system can automatically control the photovoltaic generator, divided into 6 "subfields", and recharge the battery according to a fixed routine. The system also includes all signals to determine the state of operation of the system. The signals take the form of LEDs of various colours.

2 DESCRIPTION OF COMPONENTS

The regulation unit consists of a cabinet in which all the circuit components are arranged. The dimensions of the cabinet are as follows: 800 x 585 x 300 mm. The degree of protection is IP55. Inside the cabinet are 3 regulators of RP2 type for control of the 6 PV subfields, for charging the battery as a function of the temperature. The power switches are of solid state type and each entry of the subfields is protected by 25 A switches. The battery output is protected by a 125 A switch. The switches are places inside the cabinet, and the terminal is in the lower part.

3 SIGNALS

The signals take the form of LEDs of different colours:

- LED PV1 - red - alight = subfield PV1 "ON"
- LED PV2 - red - alight = subfield PV2 "ON"
- LED PV3 - red - alight = subfield PV3 "ON"
- LED PV4 - red - alight = subfield PV4 "ON"
- LED PV5 - red - alight = subfield PV5 "ON"
- LED PV6 - red - alight = subfield PV6 "ON"
- LED Vmax - red - alight = max voltage alarm
- LED BATok - green - alight = battery charge voltage
- LED Vmin1 - red - alight = prealarm of battery discharged
- LED Vmin2 - red - alight = alarm of battery discharged

4 ALARMS

With automatic operation, the alarms for controlling the subfields and the battery give rise to the following actions:

- Vmax alarm: all the PV subfields are disconnected "OFF"
- Vmin1 alarm: all the PV subfields are connected "ON"
- Vmin2 alarm: all the PV subfields are connected "ON"

The conditions of alarm during manual operation are only signalled by the LEDs without any intervention.

5 TECHNICAL CHARACTERISTICS

The regulation unit comprises 3 charge regulators of RP2 type and the topographic layout of each regulator is indicated in Dwg. SSTPMP05. Dwgs. SSTPMP07 and 09 show the three regulators, indicated as RP2-1, RP2-2 and RP2-3. Each regulator controls 2 subfields:

- Regulator RP2-1 controls subfields PV1 and PV2
- Regulator RP2-2 controls subfields PV3 and PV4
- Regulator RP2-3 controls subfields PV5 and PV6.

Regulation of the charge takes place in accordance with preset thresholds, having the following values for each subfield (reference to the voltage is made in relation to the voltage of one battery element, that is 2 V per element, at 25°C. The battery used is formed of 55 elements for a total of 110 V):

PV1 2.40 V (cut) - 2.35 V (connection); RP2-1, hysteresis 6 min.
PV2 2.35 V (cut) - 2.30 V (connection); RP2-1, hysteresis 6 min.

PV3 2.30 V (cut) - 2.25 V (connection); RP2-2, hysteresis 3 min.
PV4 2.25 V (cut) - 2.20 V (connection); RP2-2, hysteresis 3 min.

PV5 2.20 V (cut) - 2.15 V (connection); RP2-3, hysteresis 1 min.
PV6 2.15 V (cut) - 2.10 V (connection); RP2-3, hysteresis 1 min.

ALARM Vmax: 2.50 V
END ALARM: 2.4 V

PREALARM BATTERY DISCHARGED Vmin1: 1.95 V
END PREALARM BATTERY DISCHARGED Vmin2: 2.15 V

ALARM BATTERY DISCHARGED Vmin2: 1.85 V
END ALARM BATTERY DISCHARGED Vmin2: 2.15 V

The values indicated are referred to 1 element; the values corresponding to 55 elements are as follows:

PV1 132 V (cut) - 129.25 V (connection); RP2-1, hysteresis 6 min.
PV2 129.25 V (cut) - 126.5 V (connection); RP2-1, hysteresis 6 min.

PV3 126.5 V (cut) - 123.75 V (connection); RP2-2, hysteresis 3 min.
PV4 123.75 V (cut) - 121 V (connection); RP2-2, hysteresis 3 min.

PV5 121 V (cut) - 118.25 V (connection); RP2-3, hysteresis 1 min.
PV6 118.25 V (cut) - 115.5 V (connection); RP2-3, hysteresis 1 min.

ALARM Vmax: 137.5 V
END ALARM: 132 V

PREALARM BATTERY DISCHARGED Vmin1: 107.25 V
END PREALARM BATTERY DISCHARGED Vmin2: 118.25 V

ALARM BATTERY DISCHARGED Vmin2: 101.75 V
END ALARM BATTERY DISCHARGED Vmin2: 118.25 V

6 AUTOMATIC AND MANUAL OPERATION

With reference to Dwgs. SSTPMP05 and 09, in each RP2 circuit there is a dipswitch SW1, with 4 microswitches.

Below is a description of the dipswitches of each RP2 regulator.

- DIPSWITCH OF REGULATOR RP2-1:

- 1: pos. ON = PV1 ON / pos. OFF = PV1 OFF
- 2: pos. ON = PV2 ON / pos. OFF = PV2 OFF
- 3: pos. ON = ALARM Vmin OFF / pos. OFF ALARM Vmin ON
- 4: pos. ON = RP2-1 MANUAL / pos. OFF = RP2-1 AUTOMATIC

- DIPSWITCH OF REGULATOR RP2-2:

- 1: pos. ON = PV3 ON / pos. OFF = PV3 OFF
- 2: pos. ON = PV4 ON / pos. OFF = PV4 OFF
- 3: NOT ACTIVE
- 4: pos. ON = RP2-2 MANUAL / pos. OFF = RP2-2 AUTOMATIC

- DIPSWITCH OF REGULATOR RP2-3:

- 1: pos. ON = PV5 ON / pos. OFF = PV5 OFF
- 2: pos. ON = PV6 ON / pos. OFF = PV6 OFF
- 3: NOT ACTIVE
- 4: pos. ON = RP2-3 MANUAL / pos. OFF = RP2-3 AUTOMATIC

Note carefully that only the circuit of regulator RP2-1 controls the Vmin alarm. In the same circuit there is also a contact having a crepuscular (twilight) function, which is not used.

For AUTOMATIC operation all the microswitches of the three regulators must be in the OFF position.

For MANUAL operation, the regulator does not control anything at all, that is, the voltage thresholds are left in the operator's control. In this condition the voltage of the battery has to be properly checked to avoid damaging it with overly high loads or with overly great discharges.

With MANUAL operation it is advisable to follow the indications below:

Check that all the microswitches are in the OFF position.

Starting from regulator RP1, put microswitch 4 on ON.

Put microswitches 1 and 2 on ON- The LEDs PV1 and PV2 are alight and the subfields PV1 and PV2 are connected to the battery. The voltage will increase in value (be careful not to go past the max value).

After the test, again put the microswitches in position OFF.

After this, the same test can be performed with regulators RP2-2 and RP2-3.

N.B.: FOR AUTOMATIC OPERATION OF THE REGULATION UNIT, ALL MICROSWITCHES MUST BE IN THE "OFF" POSITION.

7 INSTALLATION

Install the board in the room and connecting the earth cable to the terminal strip where the yellow-green contact is located.
Put all the switches of the subfields and of the battery in the OFF position.
Make all the connections indicated:
N.B.: THE POLARITY MUST ALWAYS BE RESPECTED. AN ACT OF CARELESSNESS COULD SERIOUSLY DAMAGE THE WHOLE SYSTEM.
Before connecting the subfields it is advisable to open all the switches of the junction box.
The following are the connections to be made:

- CONTACTS IN THE TERMIMAL STRIP

N° 1 = "-" (NEGATIVE) BATTERY
N° 2 = "+" (POSITIVE) BATTERY
N° 3 = "-" (NEGATIVE) SUBFIELD PV1
N° 4 = "+" (POSITIVE) SUBFIELD PV1
N° 5 = "-" (NEGATIVE) SUBFIELD PV2
N° 6 = "+" (POSITIVE) SUBFIELD PV2
N° 7 = "-" (NEGATIVE) SUBFIELD PV3
N° 8 = "+" (POSITIVE) SUBFIELD PV3
N° 9 = "-" (NEGATIVE) SUBFIELD PV4
N° 10 = "+" (POSITIVE) SUBFIELD PV4
N° 11 = "-" (NEGATIVE) SUBFIELD PV5
N° 12 = "+" (POSITIVE) SUBFIELD PV5
N° 13 = "-" (NEGATIVE) SUBFIELD PV6
N° 14 = "+" (POSITIVE) SUBFIELD PV6
N° 15 = "-" (NEGATIVE) S1 - TEMPERATURE PROBE 1
N° 16 = "+" (POSITIVE) S1 - TEMPERATURE PROBE 1
N° 17 = "-" (NEGATIVE) S2 - TEMPERATURE PROBE 2
N° 18 = "+" (POSITIVE) S2 - TEMPERATURE PROBE 2
N° 19 = "-" (NEGATIVE) S3 - TEMPERATURE PROBE 3
N° 20 = "+" (POSITIVE) S3 - TEMPERATURE PROBE 3
N° 21 = CREPUSCULAR (DO NOT USE)
N° 22 = CREPUSCULAR (DO NOT USE)
N° 23 = ALARM Vmin COMMON CONTACT
N° 24 = ALARM Vmin CONTACT N.F.
N° 25 = ALARM Vmin CONTACT N.O.

- SWITCHES

- S1 = SUBFIELD SWITCH PV1
- S2 = SUBFIELD SWITCH PV2
- S3 = SUBFIELD SWITCH PV3
- S4 = SUBFIELD SWITCH PV4
- S5 = SUBFIELD SWITCH PV5
- S6 = SUBFIELD SWITCH PV6
- S7 = BATTERY SWITCH

8 START-UP

After having made all the connections and checking the correct polarity of the leads, leave all the switches on the board disconnected.

Check that all the microswitches of RP2-1, RP2-2 and RP2-3 are in the OFF position.
Close the switches of the junction boxes.
Check the value of the battery voltage (around 110 V).
Close switch S7 of the battery and wait for 60 seconds.

- the LED BAT OK is alight (the LEDs Vmin might also be alight, according to the value of the voltage)
- the other LEDs of the subfields may be alight.

Place the voltmeter on contact 1 and 2 ("-" and "+" of the battery).

Close switch S6 and check that the value of the voltage increases; after this slowly close the other switches S5, S4, S3, S2 and S1.
The voltage will increase up to the value of the end of battery charge and corresponding to the preset thresholds the regulator will cut out the relative subfield: this condition is signalled by the LEDs. With the voltmeter, the correct value of the voltage can be checked.

THE ENERGY SECTOR

By Ibrahima DABO
Department of Energy
Ministry of Mining,
Energy and Hydraulic

Senegal at a glance

Area: 196 722 sq.km
Population: 9 600 000 (60% living in rural areas)
Growth rate / year: 2.7%
Administrative Division:
- 10 « Régions »
- 30 « Départements »
- 90 « Arrondissements »
- 320 « Communautés Rurales »

Main Cities
- Dakar: (2 000 000 habitants)
- Thies: (250 000 habitants)
- Kaolack: (230 000 habitants)
- Ziguinchor: (210 000 habitants)
- Saint Louis: (150 000 habitants)

Energy Policy

Senegal energy policy is part of a global strategy defined by the Government. Its overall objective is to achieve sustainable economic growth while promoting social development. It focuses on three basic aspects, namely:

- Economic: rationalising energy supply, production, distribution and consumption conditions in conformity with the country's long term interests ;
- Social: providing marginalized people in urban and rural areas access to modern sources of energy ;
- Environmental: preserving basic ecological balances and promoting a rational management of rural estates in forest zones exploited for energy production purposes.

The main objectives of the energy policy may be summarised as follows:
- Ensuring adapted, sustainable, efficient and low-cost energy supply for consumers ;
- Reducing dependency on imports for energy requirement ;
- Assisting in protecting the environment.

Organisation of the Energy Sector

The organisation of the energy sector in Senegal is as follows:

National Energy Commission
This Commission defines energy policies orientation under the chairmanship of the Prime Minister.

National Energy Committee
Establishes proposals for the National Energy Commission. This Committee is chaired by the Minister responsible of Energy.

Department of Energy
It is the Secretary of the National Energy Commission and makes the implementation of the Energy Policy.

It is organised as follows:

Planning and Management Division
Energy Policy ;
Energy evaluation and statistics ;
Offer and demand analysis ;
National Energy Fund management

Electricity Division

SENELEC tutelage ;
Urban Electrification ;
Rural Electrification ;
Follow-up of the sub regional projects (OMVS, OMVG, UEMOA, ECOWAS,...)

Energy Saving and NRE Division
Mastery of Energy industrial and tertiary sectors ;

New and Renewable Energy Division
Promotion of new and renewable energy sources ;
Rural Electrification by new and renewable energy systems;
Follow-up of the sub regional projects in new and renewable energy sector (UEMOA, ECOWAS,...)

Hydrocarbons Division
Supply and distribution of hydrocarbons products;
Member of the National Committee of Hydrocarbons;
Participate in the elaboration of the prices of refined petroleum products.

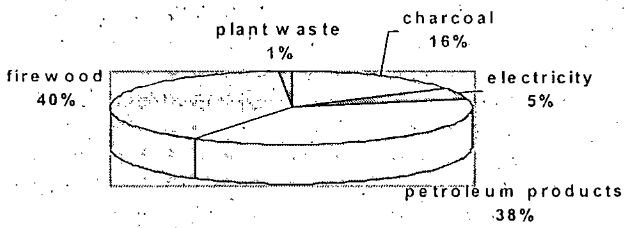
Household Energy Division
Supply of cities in wood energy ;
Butanisation;
Improve stoves and alternatives fuels.

This division is also member of « Cell of household fuels » with other Departments of other Ministries:
Ecological Follow-up Centre ;
Direction of Trade ;
Ministry responsible of women's affairs ;

The Energy Sector in Senegal

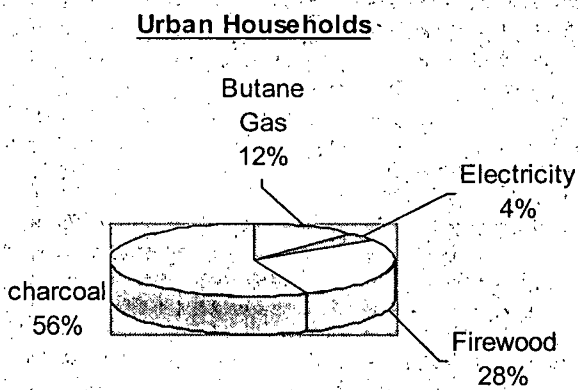
The Energy sector in Senegal can be divided into two sub-sectors:

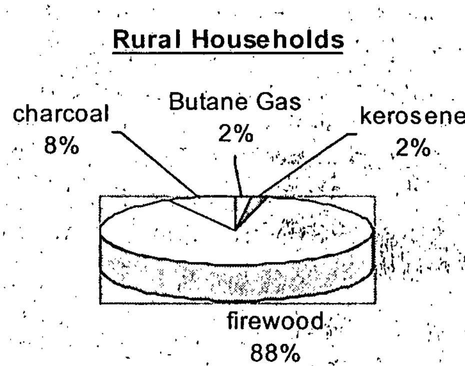
- The « traditional » Energy Sub-Sector dominated by firewood and charcoal mainly used for food cooking, and accounting for 60% of the energy balance ;
- The « modern » energy sub-sector which includes oil fuels (35% of the energy balance) that are almost imported and heat-generated electric power (5% of the energy balance).



In Senegal, The energy sector is first characterised by a twofold dependency on other countries, i.e. for both technology – most of the capital goods are imported – and hydrocarbons supplies. This dependency entails high costs (in foreign exchange) and prices that affect the competitiveness of certain economic sectors at the international level.

Besides, wood-fuel consumption has severe impacts on the environment. Trees are felled to meet





urban consumer needs and this account for the degradation of natural forest resources and the attendant repercussions in rural development in general.

Households Energy Consumption

In the end, there is a huge gap between the rural and the urban areas. A great number of households in the middle-sized towns and rural areas still do not have access to « modern » sources of energy.

As a result of this constraints, substantial efforts are made to rationalise the conditions of energy supply, production and distribution so as to provide marginalised people with modern energy services and preserve the basic ecological balances. As part of these efforts, institutions are encouraged to the sector's new demands, private resources and actions are pooled and the energy sector is reorganised with emphasis on local fossil resources (oil, natural gas and peat), hydroelectric and renewable sources of energy.

PETROLEUM

Hydrocarbon supplies almost exclusively consist of imported oil products refined by the "Société Africaine de Raffinage". Oil imports (900 000 metric tons/year) weight heavily on the national balance of trade (15% of the country's export earning). Some 60 to 80 thousand metric tons are re-exported every year to neighbouring countries.

PETROSEN promotes the development of the Senegalese sedimentary basin, in particular oil deposit discovered between 1950s to 1960s. It is conducting prospecting and mining operations with international companies within a framework of an oil code particularly attractive to investors.

The "Dôme Flore" offshore deposit (off Casamance) is the first major source of hydrocarbons ever discovered in the country. It includes potential reserves estimated at some 100 million metric ton of heavy oil and 5 million metric ton of light oil. Prospecting operations are under way on the site.

Following the discovery of light oil and natural gas reserves in the Sebikotane areas (near Dakar) about 100 000 metric ton of crude oil and 100 million cubic meter of natural gas are being produced since 1986. The 500 million cubic meter gas deposit discovered in 1993 is currently used for the gas turbines of the National Electricity Company. PETROSEN is conducting with private partners in Thies and Sebikotane high resolution seismic prospecting operations to confirm the existence of important natural gas reserves.

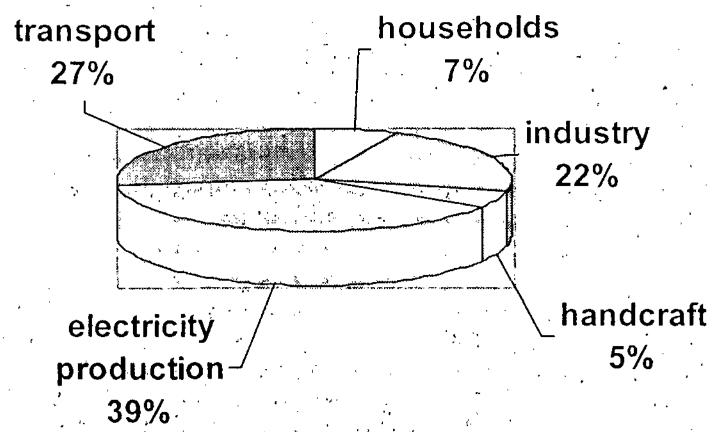
Four major companies (ELF, TOTAL, MOBIL and SHELL) traded petroleum products. They own storage, processing and distribution facilities throughout the country. Petroleum products are mainly used for electric power production (fuel and diesel oil), transportation (diesel oil and petrol) and for household consumption (butane gas and kerosene).

Since 1998, big changes occurred with the liberalisation of the sub-sector by:
- liberalising the importation of petroleum products;
- revising the pricing system;
- opening the transportation system to competition so as to make the sub-sector more profitable and reduce the productive sector's energy bill. Before 1998, only electric power producers could purchase fuel supplies directly on the international market.
- The other fossil energy resources

Senegal sedimentary basin (230 000 sq.km) is part of a larger divergent passive margin basin stretching from Mauritania to Guinea-Bissau.

In 1982, some traces of lignite were discovered in most of the oil drill holes across the country's sedimentary basin. Some research campaigns are being conducted to confirm the findings. Substantial reserves were identified in the early 80s along the coastline between Dakar and Saint Louis. The geological reserves of the basin are estimated at 52 million cubic meters and could be developed to produce fuel for household use.

distribution of oil products consumption



ELECTRICITY

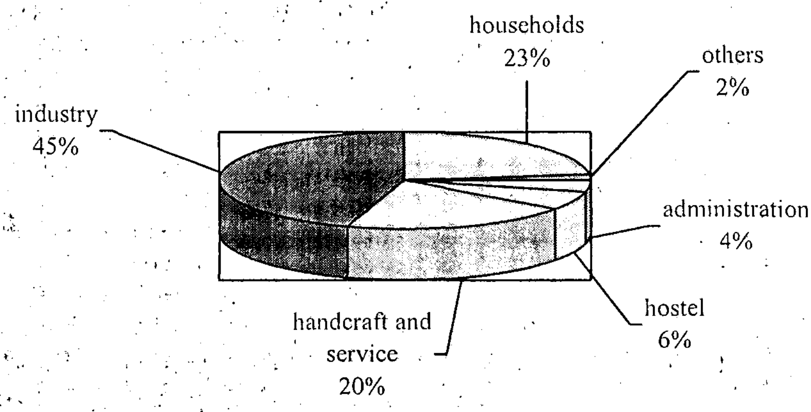
In December 2000, SENELEC owns production equipment (exclusively for heat generated electric power) with a capacity of 422 MW of which 396MW supplies the interconnected grid. In 2000, it produced 1200 GWh against the consumption of about 300 000 tons of petroleum products. The principal "self-producer industries" are ICS (Chemical producing Company), CSS (Sugar Processing Company) and SONACOS (Cooking oil processing plant). They have more than 100 MW production equipment worked by process-generated steam and fuel, cane-trash and groundnut shells respectively. They produce over 100 GWh per annum, a slight part of which is sold to SENELEC.

SENELEC has about 400 000 subscribers in about 550 towns and villages connected to the grid or supplied by autonomous plants. There has been a constant increase in energy sales over the years (approximately 5% per year). The development of electrification has so far been hindered by the obsolescence of production facilities and their low capacity which can no longer meet the ever increasing demand. An important program has therefore been launched to rehabilitate existing plants and the production sector, which is now opened to private entrepreneurship, which allowed the installation of a 50MW power plant in 1999 (under BOOT operation). The Manantali hydroelectric power station (200MW) is expected to be operational by the year 2001 and will provide Senegal with a production capacity of 260 GWh/year.

About rural electrification, its rate is around 7% in 2000. But substantial efforts are being made to significantly speed it up which constitute a prerequisite for any successful balanced development policy. Access to electricity helps in alleviating poverty and illiteracy, improving health services and women's living standards as well as in controlling the rural drift and its pernicious effects on urban management. The voluntarist policy now implemented is based on private as well as public investments and it relies mainly on renewable sources of energy. The target is a rural electrification rate of 15% in 2005 and 40% in 2015. The Senegalese Agency for Rural Electrification (ASER) is now built and is charged to reach these objectives.

Note Before the "Low of Orientation of Electric Sector" in 1998, SENELEC had the monopoly of electric power production, transportation and distribution in Senegal. Actually, it only has the monopoly of transportation (for 10 years over which it will be possible to big consumers to buy directly to Independent Power Producers).

Electricity consumption by sector



WOOD ENERGY

Wood account for 90% of the household energy consumption. It is mainly used for cooking (firewood in rural areas and charcoal in urban areas) and for some handcraft activities. The national consumption is estimated at 330 000 metric ton of charcoal and 1,500,000 metric ton of wood, which represent over 4 million cubic meters of wood. The charcoal demand is addressed through sustained tree felling operations in already weak forest reserves and this find expression in the clearing of 30 000 ha of natural forest every year. Production areas are located in the Tambacounda and Kolda regions, about 400 km away from the capital city. The turnover of this sector amount to over 20 billions CFA francs. About 20 000 individual draw income from this activity. These include: tree fellers, charcoal burners, loggers, truck owners, drivers, whole-sellers and retailers in urban areas. However, the earnings are not equally distributed among the various stakeholders.

Ensuring sustainable wood supplies is a major challenge for the future. This can only materialise through a voluntary substitution process which entails the implementation of the "butanisation" policy, a feasibility study on the use of kerosene as cooking fuel and a stringent control of wood energy consumption with the development of fuel-saving stoves. However, the forest exploitation system also needs to be thoroughly revised with a new forestry code that allows for the involvement and empowerment of rural communities in the management process.

Butanisation

The effort made by the public authorities in regulating butane gas prices and investments by distributors increased the national consumption from less than 5,000 metric tons in 1984 to 15,000 metric tons in 1987 and to more than 80,000 metric tons in 2000. Butane gas is presently the cheapest cooking fuel used in most cities and towns. The rate of gas cookers own is very high: 85% in Dakar, 75% in Thies and 60% in other cities. Savings realised through the promotion of butane gas are estimated at 90,000 metric tons of charcoal per annum, which represents 10,000 ha of preserved natural forest.

RENEWABLE SOURCES OF ENERGY

For the past two decades, Senegal has been implementing a major Research-Development programme on the use of renewable energy sources that helped in assessing their development prospects.

With a high solar potential (global irradiation is estimated at 2,000 kWh/sq.m/year with 3,000 hours of insulation per year) as well as the advanced status of photovoltaic technology, photovoltaic solar systems are now a sustainable solution in rural areas. They are particularly adapted to decentralised consumption pattern and slight energy requirements. Such equipment allows for the delivery of high quality services some priority needs such as potable water supply, lighting, refrigeration, TV, video and audio systems, battery recharging, etc.

Various experiments and programmes have been conducted for the promotion of this technology. About ten solar equipment distributors are trading components with an installed capacity estimated at more than 800 kWp. Thus, 5 power plants, 10 desalinisation units, 80 pumps, about one hundred community systems and some 2,000 household one are currently operating.

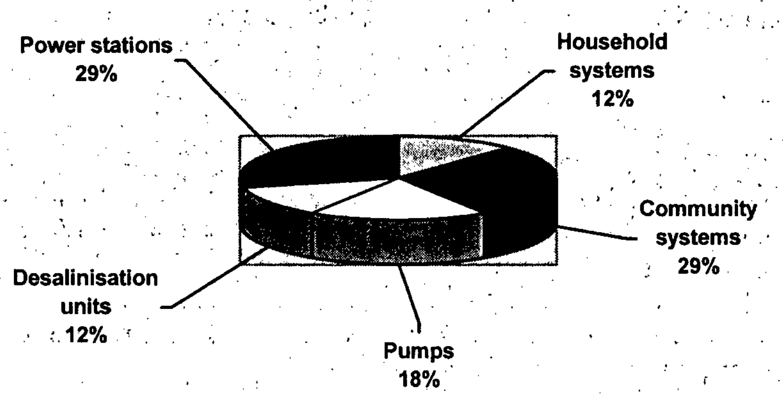
To promote the development of this sector, the government of Senegal has granted costumes duty and tax exemption for solar equipment (kits and photovoltaic lamps and solar water-heaters). The Senegalese authorities are willing to create an institutional, technical and financial environment conducive to private and community initiatives and likely to offer facilities for the maintenance and renewal of installations.

They are also exploring, with private partners, the feasibility of a photovoltaic modules manufacturing plants that would supply the West African Economic and Monetary Union (UEMOA) market.

Solar energy is also used for water heating and drying purposes with solar water-heaters and this practice might be extended to private houses. About 50solar dryers are also used for small-scale processing of agricultural products and foodstuffs.

Wind energy is particularly promising along the coastline (between Dakar and Saint Louis) where the average speed of winds ranges from 3.7 to 6.1 m/s. The ground water in this area is at shallow depths (1 to 10 m) and this allows for the installation of wind-driven pumping systems. About 150 such units are operating. A training programme is planned for local producers and operators who could then promote a wider dissemination of such equipment. Furthermore, a feasibly study on wind-driven generators is being conducted together with a private partner.

Installed Photovoltaic Capacity



ENERGY SAVING

It has become necessary for the Government of Senegal to take energy-saving measures in view of Senegal's dependence on oil imports, the need to cut down the cost of production factors and the will to preserve the global environment. In this regard, considerable work has been done in the industrial sector since 1986. The energy consumption patterns of forty-seven enterprises among the large-scale consumers were audited and the exercise revealed a potential saving of 15% of their total consumption. Over one hundred projects or initiatives have been implemented through a self-funding programme estimated at 2.5 billion CFA Francs.

The public authorities intend to continue their energy consumption control efforts. Several measures have thus been planned and these include:

- supporting the implementation of highly profitable investment programmes identified in the industrial sector;
- auditing small and medium-scale enterprises and assisting with financial resource mobilisation;
- improving electric power management in public facilities ;
- promoting the use of energy-saving electric equipment (with incentives);
- implementing a consumer information, advisory support and assistance programme.

PV Power Systems Applications

By John M. Ngundam, PhD
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Ecole Polytechnique, Yaounde
Cameroon

PV power systems are increasingly seen as the solution to the problem of extremely low access to electricity in Africa. While this may be true, it can only be a short-term solution to the problem. In 1995, the access rate to electric power in Cameroon (population 15 million) was 36% with 64% of urban households supplied as against only 9.7% in the rural areas where over 70% of the population lives. This situation has not changed in spite of the fact that the country is endowed with rich solar and hydroelectric potentials. Ranked 18th in the world and 2nd in Africa after the Democratic Republic of the Congo, only 4% of its total hydro electric potential is being exploited. The use of solar energy for rural electrification is an option that has not been taken yet.

In Cameroon, access to roads and electricity seem to improve villagers' chances of coming out of poverty. Farmers of cocoa, coffee, rice, oil palms, soybeans, groundnuts corn, beans and other agricultural produce need roads and increasingly electric energy to transform some of their produce into oils (groundnut, corn, palm etc.) and being an equatorial forest region energy is needed for treatment wood. This experience may not be unique to Cameroon.

PV power systems are therefore short-term solutions to the electricity needs of these localities situated off the grid lines. However, the planning of the systems must be done with an eye on the economic potential of each locality and the possibility of expanding and modifying supply systems to meet growing demand as economic conditions improve for these regions.

In this presentation we shall be looking at very low and high voltage applications of PV systems as stand-alones, hybrids or grid solar generation methods that could provide higher capacities and voltages. The new methods may not necessarily mean the elimination of small systems but rather the design should have an eye on the eventual connection of stand-alones to the grid system.

LOW VOLTAGE APPLICATIONS

Common Uses of Photo voltaics

Basic Low Voltage Electric Concepts

Advantages and Disadvantages of Solar Electricity

COMMON USES OF PHOTOVOLTAICS

Replacement for petroleum-fueled generators

Grid Power and even dry cell batteries

Low voltage DC lighting systems and other home uses such as powering televisions, cassette players, radios and other appliances that require low voltage DC supplies.

Other uses such as:

Water pumping

Small cottage industries and institutions: Small businesses and schools use solar electricity to power lights, sewing machines, calculators, light tools, computers, typewriters, and security systems

Telecommunications: Stand-alone photovoltaic systems in remote locations are used to power telecommunications equipment in regions without access to electricity. These include radios, remote repeater stations and weather monitoring Equipment

Health Center Refrigeration and Lighting: Solar electric systems are popular for vaccine refrigeration in rural health centers

BASIC LOW VOLTAGE ELECTRIC CONCEPTS

Term	Symbol	Unit	Definitions
Current	I	Amp (A)	Rate of flow of electrons through a circuit
Direct Current	DC	Amp (A)	Flow of electric charge, which does not change direction with time.
Alternating Current	AC	Amp (A)	Electric current which flows through a conductor in one direction and the3n the other, and continues to switch back and forth over time
Potential Difference	V	Volts (V)	The difference in potential energy between the ends of a conductor governing the rate of flow of current.
Resistance	R	Ohms (Ω)	The property of a conductor which opposes the flow of current through it and converts electrical energy into heat
Electric Power	P	Watts (W)	Rate at which energy is supplied from the power source
Power (Watts) = Voltage (Volts) x Current (Amps) Voltage (Voltages) x Resistance (Ohms). Regular Photovoltaic voltages could range from 12 to 220 Volts			

Advantages and Disadvantages of Solar Electricity

Advantages of Solar Electric Power	Disadvantages of Solar Electric Power
Solar electric systems do not use any form of fuel. Electricity is produced quietly without giving off environmental pollutants Solar electric systems require very little maintenance. Modules have no moving parts and last for over 20 years Although installation costs are high, solar electric systems are economical for many applications. Cost of solar cells are falling and obviously together with other renewable energy sources such as micro hydro are useful where mains electricity	The initial cost of solar electric systems is high especially by rural standards in Africa. Solar electric systems require batteries for energy storage. Batteries require proper maintenance if they must remain reliable. The performance of systems is dependent on the quality of batteries availability Appliances and lamps, which run on low voltage, are not as readily available as those that run on mains power. There is a lack of trained technicians to design and install solar electric systems.

does not exist Solar electric systems could be tailored to meet needs of individual small scale applications Small solar electric systems are safer because of the low voltages.	Solar electric systems cannot be expanded easily in situations where load growth is very dynamic

LOAD ANALYSIS

The high initial cost of installing solar electric systems demand that we take special care in sizing or doing a proper load analysis of the system. Should we miss the opportunity to do this, we definitely may be making a poor job of sizing and choosing the Module(s). These errors will not be limited here because there is likely to be a poor choice of charge controllers, batteries, and inverters where they are required. In fact we could end up burning down appliances because of these initial errors. Others may take up this subject in their lectures but let me stress the point by making an overview of the subject of Load Analysis. This is an important area of systems design in small, stand-alone or grid systems and it should be treated as such (show and comment on over head slides).

HIGH VOLTAGE PV APPLICATIONS

Electricity like roads bring along with them other kinds of social and commercial activities requiring more electricity. In Cameroon, there even cocoa growers looking for electric energy to produce cocoa butter in regions far off the grid system. Clearly, the need for electricity in several areas yet to be supplied by grid electricity go beyond lighting and powering light appliances. The potential for creating jobs in most of the so-called regions off the beaten track exist and the lack of electricity and roads seem to be the only stumbling blocks.

In Africa today, solar electric systems are almost all low (12 to 24) voltage low capacity supply systems. As we have seen above, these systems are used to power DC lighting in homes and to run small appliances. Although system voltages could always be increased to run AC systems at 220 Volts (homes for example) there are limits to how much expansion can be carried out to meet the needs of dynamic load growth.

In the case of rural electrification, individuals in Africa are generally too poor to own their own solar electric systems. Experience with cooperative community water supply systems and health centers in a number of countries on the continent suggest that villages or communities could find it useful to pool their resources to develop renewable energy supplies for their domestic, production and commercial uses.

The composition and structure of the system can only be determined after undertaking a feasibility study to evaluate several different schemes including renewable energy technologies (i.e. stand-alone and hybrids). Each power system type has to be measured against a list of criteria some of which are:

- Suitability for remote locations
- Reliability
- Cost of energy
- Ability to accommodate local growth
- Large peak demands
- Service lifetime

- Availability of skilled technicians locally to run and maintain systems
- Impact of a grid system when and if it eventually passes by
- Potential but profitable economic activities in the medium- to long-term

RURAL ELECTRIFICATION

Rural electrification with solar electric systems require high voltages and capacities than the 12- or 24-Volts small-scale applications generally seen on individual or small institutional levels. Electrification schemes should go further than poverty alleviation to include further development of rural Africa in the long-term. Therefore, solar electricity in combination with other renewable supplies at far higher power voltages and capacities should be considered. Surely the requirements for each village may be different. However, the guideline for determining different community needs is provided immediately above.

COMMERCIAL AND SOCIAL ACTIVITIES

Commercial sites quickly appear in villages that use diesel generators and tend to grow as people abandon far off places in the bush to concentrate in villages so electrified. The demand for electricity has generally not matched available supply. Globalisation coupled with the rapid advances of knowledge-based economies can make a formidable impact even in rural Africa as well. Computers will definitely find their way into villages as long as electricity is available. Low cost versions of AutoCard could easily find their way into villages with electricity. Technical school graduates in the fields of designing dresses and woodwork could find profitable employment if only reliable electricity were available. Contrary to what may be considered, electricity demand, in cases where it exists, could be a 24-hour affair. Solar arrays even with battery backup are just inadequate. These levels of capacities and voltages cannot be supplied by solar arrays alone. The disadvantages or limitations of solar electric systems we mentioned above apply at this level too.

Social activities such as nightlife (dancing spots particularly, the odd cinema theatre etc.) seem to be on the rise. So also is the demand for electricity. Even so, in Cameroon, we have seen an acceleration of small halls projecting popular films on videocassette in several villages were video electricity is available. Villages no more go to bed too early. Their social life is definitely changing. At least, for those who can afford it, nightlife in villages seem to be getting more interesting.

SMALL SCALE INDUSTRIES

Several Rural and other communities that are not in the route of grids of many countries in Africa, if I should take the case of Cameroon, do require electricity at voltages as high as 220 Volts to run saw mills, rice, cocoa, corn and other grain husking processes. Yet others need high voltages and capacities to run oil (palm, groundnut, cotton seed, corn and soybean) presses. Reliance on Solar Photovoltaic arrays alone is very inadequate.

STEMMING THE TIDE OF RURAL EXODUS

Experience also shows that All the activities listed above create jobs and rather than villages suffering a net population outflow to the cities, actually experience a net inflow. Access to electricity is definitely one of the major factors of development of rural Africa. Continuing development cannot be based on solar electric from PV systems alone because of the disadvantages we have talked about.

STATE OF THE ART OF SOLAR ELECTRIC ENERGY APPLICATION

Humanity is going to be depending very much on renewable energy to supply energy particularly electricity for the needs of the exploding human population. This choice is necessary in order to drastically cut down the dangerous route towards the destruction of our environment. Like other energy forms, solar electric energy is attracting a sizable share of research funds. While there are continuous improvements in PV solar systems, other methods of producing electricity involving solar energy are emerging. Two of them (hybrid and the atmospheric power tower or solar chimney) stand out at the present moment.

PHOTOVOLTAIC ARRAY IN HYBRID AC POWER SYSTEMS

Remote Area Power Supply (RAPS) hybrid power system should be able to solve most of the electrification problems of rural communities in Africa. Such hybrid systems apart from PV arrays could also include wind turbines, micro hydro (where available), biomass and diesel fuel where the community can afford to. Schemes like these should provide enough power with high levels of reliability.

Hybrid systems may actively charge battery banks supplying power to an inverter. As power is drawn from the battery bank its state of charge decreases. Each one of the generating systems in the hybrid structure contributes to recharge the battery. Currently, proprietary microprocessor-based system controllers are used to monitor and control the charging of the battery on a real-time basis. The system controller is also capable of regulating the energy of the photovoltaic array and the other generating plants in the system.

ATMOSHPERIC TOWERS OR SOLAR CHIMNEYS

The solar chimney combines three well-known physical principles, i.e. the greenhouse effect, the chimney effect and the turbine. Incident solar radiation heats the air under a large collector roof, in the middle of which is a vertical tube that is open at the bottom. Hot air enters the tube and creates and upward draft. The draft is converted into mechanical energy by a turbine and then into electricity via a conventional generator. At the moment, it is possible to construct power plants of this type with an output of 100 MW or more, and with them generate electricity in desert areas at a price of about Sterling 0.05/kWh. Its simple technology makes the atmospheric power tower the ideal choice for countries of the Third World; it can be built and operated there at a low cost and using local labour (see overhead slides).

STRATEGIC DEVELOPMENTS IN THE NIGERIA ENERGY SECTOR
A Country Paper on Energy

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INTRODUCTION

Energy is said to be the engine for growth and development in all economies of the world. Nigeria is no exception. Energy, and in particular, oil, has continued to contribute over 70% of Nigeria's revenue (1). National developmental programmes and security have depended, to a large extent, on these revenue earnings. It is also true that all activities for the production of goods and services in the nation's industry, transport, agriculture, health, politics, and education have energy as an indispensable input. Energy, proxied by crude oil, has over the past five years contributed an average of 13.5% to Nigeria's Gross Domestic Product (GDP), representing the highest contributor after crop production (1). The contribution of energy to GDP is expected to be higher when renewable energy, which constitutes about 90% of the energy utilized by the rural population, who make up about 70% of the nation's population (2), is taken into account.

Nature has made energy resources, in the world, unevenly distributed amongst nations. This situation, in addition to other reasons, has made energy, and in particular oil, an instrument for regional and international politics and diplomacy.

Consequently, energy in Nigeria serves not only as a tradable commodity for the earning of national income, but also as in input to the production of all goods and services as well as an instrument for politics, security and diplomacy.

CONVENTIONAL ENERGY

a. Conventional Energy Resources in Nigeria.

Nigeria is endowed with a wide range of conventional energy resources. These include crude oil, natural gas, coal and lignite, tar sands, hydropower and uranium ores. Estimates indicate that the reserve for crude oil stood at 23 billion barrels in 1998, while that for natural gas was put at 4293 billion m 3 at the beginning of 1999 (3). Coal and lignite reserves are estimated at 2.75 billion tones (4), tar sands at 31 billion barrels of oil equivalent (5) and large-scale hydropower at 10,000 MW (6). Estimate for uranium ore deposits is inconclusive. In terms of energy units, tar sands reserve constitute the highest with about 28.3% of the total conventional energy reserve, which is estimated at 14.894 billion tones of oil equivalent (TOE). Natural gas and crude oil reserves represented 24.7% and 21.0% respectively of the total. Hydropower and Coal reserves are in nearly equal proportions of 13.1% and 12.9%, respectively. Table 1 shows the conventional energy resource types and their reserves in both natural and energy units.

b. Institutional Arrangement

There are four Federal Ministries with policy and planning responsibilities on energy matters, and the ministries have parastatals that are involved in the operational activities in energy. These are the Ministry of Petroleum Resources, with the Nigerian National Petroleum Corporation (NNPC) as the operational establishment for the petroleum sub-sector; Ministry of Power and Steel, with National Electric Power Authority (NEPA) as the operational arm for the electricity sub-sector, Ministry of Solid Minerals, with the National Coal Corporation (NCC) as the operational arm for coal, and the Bitumen Committee for tar sands. The Ministry of Science and Technology has the responsibility, amongst others, of planning and policy matters with regards to research and development (R&D) in the field of science and technology, including energy. It has research institutes and agencies like Sheda Science and Technology Complex (SHESTCO), Project Development Agency (PRODA), Nigerian Building and Road Research Institute (NBRRI) as its R&D implementing establishments. In addition to these, there is an office of the Special Adviser to the President on Petroleum and Energy, in the Presidency, charged with advisory responsibility for policy and planning for the energy sector. Since energy and environment go together, it would therefore be mentioned that a Ministry of Environment exists with the mandate on policy and planning with regards to the environment. It has the Federal Environmental Protection Agency (FEPA) as its operational establishment.

It may be stated that each of the sub-sectors, i.e. petroleum, coal and power, developed its policies and planned its programmes in accordance with its vision. This often resulted in operational problems, over concentration of attention and resources in particular sub-sectors(s) and conflicts in the overall sector's energy programmes. There was therefore the need to have a coordinating body, which will bring into being an integrated approach to policy and planning in the energy sector. This need was made even more imperative by the realization that the policies, plans and programmes of other non-energy agencies such as defense, foreign affairs, agriculture, industry as well as of the private sector establishments, which have energy components. It is for this reason that the Energy Commission of Nigeria (ECN) was established with the responsibilities for planning and coordination of national policies in the field of energy in all its ramifications.

c. Conventional Energy Infrastructure.

The exploitation of the bulk of Nigeria's oil reserves is handled mainly by six major multi-national companies in Joint Venture (JV) with the NNPC, whose interest is looked after by the National Petroleum Investments and Management Services (NAPIMS). The six majors include Shell, ELF, Texaco, Mobil-Exxon, Agip and Chevron. JVs control not less than 90% of the total exploration and production activities in the country (7). Some indigenous Nigerian enterprises are also engaged in the upstream oil activities. These include Alfred James Petroleum Ltd, AMNI Int. Petroleum Development Co. Ltd. And Yinka Folawiyo Petroleum (8). It should be mentioned that in addition to JV, production sharing contract (PSC) arrangement is also now being used with regards to the upstream oil operations, and in particular, the deep off shore operations.

The national company responsible for natural gas is the Nigerian Gas Company (NGC), a subsidiary of NNPC. The company owns approximately 1,100 km of various diameters of gas pipeline, located east and west of the Southern part of the River Niger, with a northern extension up to Ajaokuta. The system is capable of transmitting about 1,8000 MMSCF/day of gas (3). Presently, the West African Gas Pipeline Project (WAGPP) is being put in place for the export of Nigerian's natural gas. Four countries represented by their Oil Companies, are involved in the project. These are NNPC for Nigeria, Ghana National Petroleum Corporation for Ghana; Societe Beninoise de Gas for Benin Republic; and Societe Togolaise de Gas for Togo. Chevron and Shell are the two multi-national oil companies involved as partners. The WAGPP has a design capacity of 620 MMSCF/day and originates from the Lagos end of the ESCRAVOS – Lagos Gas Pipeline at Alagba, Lagos (3). The Nigerian Liquefied Natural Gas (NLNG) Company in Bonny, Rivers State has facilities for the liquefaction and export of liquid natural gas. It has a capacity of 5.78 million tones per annum of LNG. The NLNG outfit is a limited liability company owned by NNPC (49%), Shell (25.6%), ELF (15%) and AGIP (10.4%) as shareholders (9).

There are four refineries managed as subsidiaries of the NNPC, with a total installed capacity of 445,000 barrels/day (bpd). The refineries have an average age of 22 years. The old Port Harcourt refinery was commissioned in 1965, with an initial capacity of 35,000 barrels/day, operated and managed by Shell BP. In 1970, ownership was transferred to NNPC. Its capacity was then upgraded in 1971 to 60,000 barrels/day. The New Port Harcourt refinery was commission in 1989 with a capacity of 150,000 barrels/day. The Warri refinery was commissioned in 1978 with an initial capacity of 100,000 bpd. Its capacity was upgraded in 1988 to 125,000 bpd. The Kaduna refinery was commissioned in 1980 with an initial capacity of 100,000 bpd. In 1985, its capacity was upgraded to 110,000 bpd (3). These are shown in table 2.

Petroleum products distribution is the responsibility of the Pipeline and Products Marketing Company (PPMC), a subsidiary of the NNPC. Distribution of products is done via pipelines, bulk road vehicles (BRVs) and depots. There are 23 depots, twenty in-land and three refinery depots, with storage capacities of 1,070,919 m 3 of PMS, 519,000 m 3 of DPK, 826,300 m 3 of AGO and 75,000 m 3 of ATK (11). The depots are connected to the refineries through 5000 km of pipeline and seven strategically located booster pump stations. Distribution of petroleum products from depots to retail outlets is by BRVs of various capacities. Bridging on pipeline breakdown is done using Bras also. There are nine strategic LPG storage depots located in Lagos, Ilorin, Gusau, Kano, Gombe, Makurdi, Enugu, Calabar and Ibadan. There are also ninety LPG filling stations in Nigeria. There are eight major petroleum marketers who operate over 2,500 retail outlets and 12 lube oil blending plants. There are also about 800 registered and unregistered independent petroleum marketers. The major marketers control over 75% of the fuel business and over 95% of the lubricant market (12). Import of petroleum products are through the maritime ports in Lagos, Warri, Port Harcourt and Calabar, with Atlas cove jetty being the major. The Bonny export terminal is dedicated to export of products (13).

The bulk of the present infrastructure for grid connected electric power generation comprise of nine stations. Three of these stations are hydro-based, while the remaining six are thermal stations. The generation infrastructure has a combined total capacity of about 6,000 MW, and is solely owned by NEPA. Detail of the power plants is given in table 3. By 1995, there were 6,000 km of 330kV and 500km of 132kV transmission gridlines, 1780km of 33/11kV lines, 22 numbers of 330/132kV substations, 91 numbers of 132/33kV substations and 563 numbers of 33/11kV substations (18). By the year 2000, there were over 35,743km of 33kV and over 26,498km of 11kV distribution lines. Distribution underground cables were 1,430km in length for 33kV and 2,558km for 11kV (19). The transmission facilities are extended to Niger Republic for export of Power. The transmission and distribution facilities are, at the moment, solely owned by NEPA.

The production facilities for coal are antiquated. Although there are four existing mines, namely Okpara and Onyeama underground mines in Enugu State, Owukpa underground mine in Benue State and Okaba surface mine in Kogi State. Only the Okpara and Okaba mines are presently producing. Reconstruction and modernization of the export facilities at Berth 8 of Port Harcourt jetty started in 1996 and had reached advanced state of completion (10).

d. Supply/Demand Imbalance of Conventional Energy

It may be recalled that the four refineries in Nigeria have a total name plate capacity of 445,000 barrels per day. Nigeria produces about 2.03 million barrels of crude oil per day (3). Domestic demand is, however, estimated to suffice with 300,000 barrels per day, allocated to the refineries by the Government. This implies that an overall capacity utilization of a little under 70% in the refineries would be sufficient to meet the domestic demand for petroleum products. However, since 1994, the capacity utilization of the refineries has consistently remained below 45% as a result of one technical problem or the other. Consequently, supply of petroleum products, from within, began to fall short of demand with concomitant distress to other sectors of the economy. The government had to take urgent steps to control demand through multiple price increases and most importantly, boost supply by the liberalization of petroleum products supply in December 1998. To this effect in addition to the efforts of PPMC, private entrepreneurs were not allowed to import products. With increased volume of products import, as a result of the breakdown of domestic refineries, the facilities at the coastal ports became over stretched and inadequate. However, as crude oil prices began to increase from $9.69/barrel in December 1998, as compared to $9.50/barrel sold to NNPC by Government, costs of importation became unattractive to the private entrepreneurs, since prices of products with the country remained controlled by the Government. The private entrepreneurs therefore ceased to import. The situation returned the monopoly of importation of products back to the PPMC. The state of the refineries continued to detoriate. By the first quarter of 1999, the refineries had an average capacity utilization of 21%. In particular, Warri refinery and Petrochemical Company (WRPC) had the worst availability put at about 10%. Port Harcourt Refinery and Petrochemicals Company (RHRC had availability of 23%, while Kaduna Refinery and Petrochemical Company (KRPC) had 29% (14). Consequently, about 74% of PMS, 56% of DPK and 44% of AGO consumed in Nigeria during the first quarter of 2000 were imported (14), with the PPMC being the sole importer.

Natural gas is sold by the NGC. This was 103 billion cubic feet (BCF) in 1995, 123 BCF in 1997 and 133 BCF in 1998 (3). The quantities sold were mainly to the domestic market since exports of natural gas began only on October 9, 1999 in its liquefied form. Power generation by NEPA accounted for about 70% of the total gas sold (16). Sales of natural gas, at the moment, are far below supply and this situation may continue up to the medium term future.

It may be recalled that NEPA's installed generation capacity is about 6,000MW. However, the generation stations operated at less than 30% of the maximum capacity for a while. This implies that supply from the national grid had been less than 1,800MW, which fell short of the estimated peak demand of 2,500MW. When supply did not fall short of demand, its availability is erratic and the level of accessibility is poor. For instance, it is estimated that power is accessible to 40% of Nigeria's population, who enjoy it for an average period of six hours only per day (17). Poor maintenance and unimplemented grid expansion programmes, due to lack of funds, have been reasons advanced for inadequate supply. Other reasons have been poor management and accountability and vandaliazation of NEPA equipment. Frequent shortfalls and limited grid extension have encouraged captive private power generation whose combined capacity is estimated at 50% of NEPA's installed capacity. This fact, together with other elements of suppressed demand, will make the actual peak demand greater than the often-quoted 2,500MW (22). It has therefore been estimated that an additional capacity of 10,000MW may be needed within the first decade of the millennium (16).

Coal was, for many years in the past, the choice fuel for power generation and for driving locomotive engines. Coal production began as early as in 1916, with an annual production output of 24,511 tonnes. The production peaked in 1959 with an output of 905,397 tonnes per annum. Production of coal ceased during the 1966-1970 civil war. After the hostilities, production commenced and peaked again in 1972 at 323,001 tonnes per annum, thereafter, it began to decline (4). Between 1988 and 1998, coal production generally continued to decline from 82,490 tonnes to 21,940 tonnes per annum. The decline, as from the 1970s, in coal production was mainly due to the loss of its traditional market to newly found and more competitive duel substitutes, e.g. diesel for locomotive engineers, fuel oil and natural gas for power generation. Consequently, the contribution of coal in the nation's energy mix did decline from about 70% in the 1960's to less than 1% between 1988 and 1998.

e. Training

Training in the areas of conventional energy are currently offered at the Petroleum Training Institute, Warri for the oil sub-sector, the National Energy Research Centres at Ife and Zaria, for the nuclear sub-sector; and the NEPA Training School at Lagos, for the power sub-sector. These are in addition to the conventional Universities and Polytechnics where degree and diploma programme in petroleum and chemical Engineering and energy-related sciences are being offered.

STRATEGIC DEVELOPMENTS

a. Restructuring and Privatization

The energy infrastructure and its institutions are mainly owned and controlled by government. Such structures have demanded huge resources from government without the corresponding benefits in the services provided. For instance, Nigeria has for a while now suffered continued crisis in the supply of petroleum products despite the huge national resources, pumped into the NNPC. The same story applies to NEPA. Electricity supplies to consumers have been inadequate, erratic and poorly spread. The rationale behind restructuring and privatization is that it would permit government to concentrate these huge resources on its core functions and responsibilities of providing basic infrastructure as well as ensuring access to key services like education, health, and environmental protection, while enforcing the "rules of the game" so that the market can work efficiently, with provision of adequate security. Consequently, the electricity sector and the downstream oil sector as well as the Nigerian Petroleum Development Company have been slated for restructuring and government equity shall be partially privatized (2). Privatization is also expected to integrate the nation's economy, and in particular the energy sector, into the mainstream of world economic order. To this effect, restructuring of NEPA has begun with the dissolution of its Board and Management, and the appointment of a Technical Board Committee who would carry on the restructuring, in preparation for its privatization.

Environmental Issues

In the exploitation of energy resources, the environment and the community within vicinity tend to suffer, if appropriate measures are not taken. The most important energy related environmental problems emanating from conventional energy are land and water pollution from oil spills, increased greenhouse gases from combustion of fossil fuels in the atmosphere and floods arising from excess water from hydropower dams. A significant contributor to the pollution is the continued flaring of about 60% of associated gas produced in the oil fields. It is however to be noted that government in its drive to eliminate flaring of gas, has put up a number of programmes, penalties and incentives which would encourage the utilization of natural gas. Programmes such as the West African Gas Project, the Nigerian Liquified Gas Project and the National Natural Gas Grid Project are typical examples. The incentives, which are called the Associated Gas Utilization Fiscal Incentives (AGUFI) of 1992, are periodically reviewed. These incentives include higher downstream investment tax allowance of 15%, accelerated capital allowance downstream of 90%, five years tax holiday and custom duties exemption on plant and machinery purchased. It is expected that associated gas flaring must stop by the year 2008, although the government is considering a new date of 2004.

Measures that directly affect the communities themselves are also imperative. It may be noted that the major oil companies have provided schools, hospitals, roads, town halls and water supply to oil producing communities. For example, Shell Nigeria's expenditure on community development has risen from $2 million per year in the 1960s to over $30 million in 1998 (21). Government in its bid to address the community relations' problem, first in 1978, created the Niger Delta Development Board (NDDB). Then there was the Niger Delta Basin Authority, the 1.5% Ecological Fund, OMPADEC, the Popoola Panel on options on the development of the Niger Delta, and recently the Niger Delta Development Commission (NDDC). There is now the 13% derivation, hitherto 3%, of oil revenue for the oil producing areas.

The above not withstanding, there is increasing feeling of frustration and marginalization by the oil producing communities. Their widespread agitations, often with violence, are an indication of dissatisfaction with the interventions. It is possible that the interventions have been largely misdirected and were done without sufficient openness and transparency on how funds were being spent, and perhaps with inadequate consultation with, and involvement of, the direct beneficiaries themselves. Therefore, the bottom-up approach in the selection of projects, openness and transparency in the management of funds would be the guiding principles for the NDDC and the Oil Companies in line with Government's policy directions. It should be mentioned that agitations by the hydropower producing states, for similar attention from Government, have recently been made.

c. Coal Export and Briquetting

It may be recalled that the production facilities of the Nigerian Coal Corporation are old with only two mines in operation. The export facilities have also been under-developed. However, in 1996, the rehabilitation of the infrastructure at Okpara mines had reached about 80% completion, whereas that at the Onyeama mines had got to about 70% level of completion. During the same period, the reconstruction and modernization of the existing loading facilities at Berth 8 of Port Harcourt Jetty were started and carried to an advanced completion stage. Exports of about 13,000 tonnes was done in 1996, the first since the early 1970s (10).

Another strategic development in the coal industry is the approval, by government, of the use of coal briquette as a substitute fuel to fuelwood. This is in line with its efforts to arrest deforestation and desertification. Consequently, Government has provided some funds to NCC for the production and diffusion of coal briquettes.

d. Bitumen Development

Tar sands, estimated at 31 billion barrels of oil equivalent representing the highest contributor, in energy unit, put at about 28.3% of the total conventional energy reserves of the nation, from which bitumen can be obtained became an area of focus recently by Government. Currently, heavy crude from Venezuela is imported into the country for the Kaduna refinery, which is the only refinery with the capability of processing heavy crude oil. Bitumen is used in road construction and in the building industry for roofing purpose. Because of its strategic applications, and the need to be less import dependent, government constituted a "Bitumen Committee" under the Ministry of Solid Minerals to come up with the modalities for the exploitation of the nation's tar sand, which is mainly found in a belt in Edo and Ondo States. Recent developments suggest that exploitation of the Nigerian bitumen may commence in April 2002.

Cooperation and Networking

We may recall that nature has made energy resources, in the world, unevenly distributed amongst its nations. Some countries have excess energy resources while others are deficient. These provide the opportunities for energy networks and possible directions for energy movements. Nigeria for instance has power transmission grid lines extended into Niger Republic, a nation with less power potentials. Similarly, the huge natural gas reserve in Nigeria has permitted the construction of the West African Gas Pipeline Project to deliver gas to Ghana, Togo and Benin Republic, with possible extension to Ivory Coast and Senegal. The philosophy of energy pooling and networking has advantages ranging from economics of scale to energy economy conservation through the equal-incremental-cost principle (for power) whereby careful dispatch of high cost sources will be kept strictly for peaking or reserve duty. It also enables the sharing of spinning and operating reserve requirement for individual nations. These advantages can only be attained when there is cooperation, and the political will, amongst nations. To this effect, the Government of Nigeria has put in place a Ministry of Cooperation and Integration in Africa, in addition to its Ministry of Foreign Affairs, to facilitate such cooperations.

RENEWABLE ENERGY (RE)

Renewable Energy Potentials

Nigeria is also reasonable well endowed with renewable energy resources, whose types and intensity are shown in table 4. The annual average of daily solar radiation intensities, sunshine hours and wind velocities, which range from 3.5 – 7.0 kWh/m 2 -day, 4 – 9 hrs/day and 2-4 m/s, respectively for the country generally increase in magnitude from the coastal forest belt to the northern savannah and arid regions. Wind speeds, however, have high values in the vicinity of the coastline. While the range of average solar radiation intensities and sunshine hours are quite high, the ranges of wind speeds are only moderate. Favourable wind regimes may be expected mainly at the coast and in the northern region. Potentials for small-scale hydropower plants are fairly well distributed nation wide, in the seven river basins of the country.

INSTITUTIONAL ARRANGEMENTS IN THE RE SUB-SECTOR

The primary governmental agency for the development and promotion of renewable energy technologies in the country is the Energy Commission of Nigeria. Its mandate includes strategic energy planning; policy co-ordination and performance monitoring for the entire energy sector; laying down guidelines on the utilization of energy types for specific purposes; developing recommendations on the exploitation of new sources of energy. Renewable energy is therefore a component of its mandate.

ECN has two renewable energy centers under it, namely, National Centre for Energy R&D (NCERD) and the Sokoto Energy Research Centre (SERC) whose mandates are to carry out R&D, manpower development, dissemination and promotion of renewable and alternative energy technologies. There are other agencies and NGOs that have significant renewable energy components in their programmes. These include the Federal Institute of Industrial Research (FIIRO), Project Development Agency (PRODA), Friends of the Environment (FOTE), Solar Energy Society of Nigeria (SESN), to mention a few. The Solar Energy Society of Nigeria is the sole NGO with dedicated mandate in renewable energy. In the industrial sector, there are essentially vendors and distributors of solar PV systems and equipment.

c. SOME RE-TECHNOLOGY DEVELOPMENTS, TRAINING AND PROMOTION

As a consequence of R&D work in renewable energy technologies at the energy research centers, some other research institutes, universities and polytechnics, a number of RE conversion devices have been developed. Some of these include:

(i) Solar Crop Dryers:

Solar crop dryers developed ranged from small experimental cabinet dryers, through demonstration – size forced circulation dryers, to large-scale natural circulation dryers. The latter include a 2-tonne capacity rice dryer developed at the NCERD and a 2-tonne capacity forage dryer constructed by the SERC.

(ii) Solar Manure Dryer:

A natural circulation solar manure dryer for the drying of poultry waste and similar materials are developed at the NCERD. The existing model has a capacity of over 71 kg of wet manure. On a test day with peak solar intensity of 600 W/m2 it reduced the moisture content of the manure from 71% to 35% (wb) in 22 hours.

(iii) Solar Cookers

Both the flat plate and concentrating versions have been designed, constructed and tested at the NCERD and SERC. The flat plate version could cook rice and beans in 45 minutes at solar intensities of about 850W/m2. A major shortcoming of the technology is the need for outdoor cooking during high solar intensity periods of the day.

Solar Water Heaters

Horizontal and vertical tank, natural circulation solar water heaters have been designed and constructed. Family size model with a tank capacity of 70 liters that can generate water at 50-70oC on an averagely sunny day has been developed. An 800-liter capacity model is available at the Usman Danfodio University Teaching Hospital, Sokoto.

Solar Chick Brooders

In place of electricity, kerosene or gas heated chick brooders for the conditioning of brooder space temperatures (at 35 – 25oC) over the first four weeks of life, the NCERD has developed a natural circulation solar-heated chick brooder. 100 and 200 bird capacity models have been constructed and extensively tested. Chick weight gain and mortality rates were better than those reported for kerosene heated brooders.

Bio Digesters

An efficient environmentally clean way of utilizing biological wastes is through their use as feedstock in bio-digesters for the production of biogas and biofertilizer, through an anaerobic process. The biogas has a high calorific value, while the solid effluent is nitrogen rich, pathogen deficient manure. Biodigesters of the fixed and floating dome types have been constructed in the country, especially by the SERD and NCERD. Capacities range from small laboratory prototypes to 30m 3 plants, while cow dung, chicken waste, cassava peelings, pig waste and human waste have been used as feedstock.

Improved Wood and Other Solid Fuel Stoves

Fuelwood and other biomass fuels are estimated to constitute over 50% of the total national energy consumption. The prevalent stove is the 3-stone type or versions of it, with thermal efficiencies of 5-10%. These facts have created multiple environmental problems through contributing to increases deforestation, combustion related health hazards and global warming.

Improved wood and solid fuel stoves of various designs have been constructed at the SERC and NCERD. They include 1, 2, 3, and 4 seater models with all clay bodies, clay insulating refractory and metal frame, or sheet metal cladding lined internally with burnt clay insulation. Some designs are fitted with chimneys. Some of the stoves are appropriate for the combustion of charcoal and coal briquettes. With thermal efficiencies in the range of 15-25%, their use will greatly reduce fuelwood consumption.

Solar-PV Equipment and Systems

Apart from some limited work on materials for solar cell production at Obafemi Awolowo University, Ile-Ife, and thin film growth at the NCERD, Nsukka, most of the studies on Solar-PV in the country have been on components and systems testing, economic viability studies, pilot plant and other application projects. The largest single pilot plant is the 7.2 kW village electrification project at Kwalkwalawa in Sokoto State, put up by the Energy Commission of Nigeria. Other pilot plants established by the Energy Commission are for water pumping, health centre power supply and village lighting and TV viewing..

Wind Power

A number of wind powered water pumps have been installed in some northern states, notably at Goronyo in Katsina State, Kedada in Bauchi State and in Sokoto State. Presently, a 5kW pilot wind turbine/generator is under tests at Sayya Gidan-Gada village in Sokoto State. The performance so far is satisfactory.

Renewable Energy Data

Considerable work has been done in the area of atmospheric physics and in the collection of renewable energy related data. These include solar radiation intensities (global, direct and diffuse) wind speeds and directions, relative humidities, precipitation and ambient temperatures. The Department of Meteorological Services, of the Ministry of Civil Aviation, is the agency charged with responsibility for the collection, storage and dissemination of meteorological data in the country. It collects data for 64 towns, - one third of whose stations have been in existence for over 50 years. The Physics Department, University of Ilorin, runs a Centre for the Study of Atmospheric Physics. Also at least 12 other Research Institutes/Centres and Universities in the country are significantly involved in the collection and analysis of solar and other meteorological data. Finally, the Energy Data Bank being developed by the Energy Commission of Nigeria has provisions for Renewable Energy Data.

RE-Training/Capacity Building

Training in RE Science and Technology takes place at the NCERD and SERD through seminars, workshops, conferences and R&D projects. Some of the R&D works are done in cooperation with academic departments in the Universities that host the Centres. While regular postgraduate work in some universities have RE specializations, the National Board for Technical Education (NBTE) is considering the introduction of RE course in the curricula of the polytechnics. The Solar Energy Society of Nigeria holds an annual conference on RE while some other environmental NGOs occasionally run workshops on RE related environmental issues

RE Information Dissemination

The ECN publishes and distributes booklets and manuals on RE in general and selected technologies in particular, such as on RE Potentials in Nigeria, Solar PV Technology, Biodigesters, Solar Dryers, Improved Woodstoves, etc. Other existing means of information dissemination are proceedings of workshops and conferences, the Journal of the Solar Energy Society of Nigeria and the Renewable Energy Journal published by the SERC.

Pilot Projects

A very important part of the nation's promotional activities is the establishment of pilot and demonstration projects. Notable pilot projects include:

Solar-PV: 7.2kWp Kwalkwalawa village Electrification, Sokoto State
1.8kWp Iheakpu-Awka village Electrification/TV viewing, Enugu State
1.5kWp Nangere Water Pumping Scheme, Yobe State
Wind: 5kW Sayya Gidan-Gada village Electrification, Sokoto State
Solar Dryer: 2-tonne Solar Rice Dryer, Adani, Enugu State
1.5-tonne Solar Forage Dryer, Yauri, Kaduna State
Biodigesters: 30m3 Plant, NAPRI, Zaria, Kaduna State
20m3 Plant (Cow dung) Mayflower Secondary School, Ikenne, Ogun State
10m3 Plant (chicken droppings/cassava peels) Nsukka, Enugu State
Improved Woodstoves: Danjawa 200 stove Pilot Project, Sokoto State
1 00 persons/day Community Woodstove Project, Zaria, Kaduna State.
Chick Brooder: 200-Bird Chick Brooder, Nsukka, Enugu Stat

World Solar Programme

Nigeria participates in the UNESCO World Solar Programme (UNESCO/WSP) aimed at the promotion of market penetration of RE technologies, worldwide (29). It is an initiative of UNESCO approved by the UN General Assembly, and is to be funded from donor and counterpart sources. Nigeria has eight High Priority National Projects approved for the programme, namely:

Integrated Rural Village Energy Supply (Solar Village)
Development and Dissemination of Efficient Biomass Stoves and Ovens and Briquetting Technology
Popularization of Biogas and Biofertilizer Technology

Upgrading the facilities and personnel of Renewable Energy R&D Establishments and Development

of RE Curricula
Training Workshops and Colleges in RE Technologies (Solar-PV and Solar-Thermal)
Rural Health Delivery and Potable Water Supply Using-PV.
Establishment and Operation of Fuel Woodlots.
International Solar Energy Institute
The projects are threatened by inadequate funding. As a result, only projects (a) and (f) have made significant progress.

Solar-PV Installations
Following a survey of activities in solar-PV in the country up to 1999 (30) a total of 316 installations amounting to 238.8kWp, were identified nationwide. Based on installed capacity, the percentage distribution of the installations over various applications were as follows:

	% by capacity
Residential (mostly lighting)	6.9
Village Electrification & TV	3.9
Office/Commercial Lighting & Equip.	3.1
Street, Billboard, etc, Lighting	1.2
All Lighting	15.1
Industrial	0.4
Health Centre/Clinic	8.7
Telecomm & Radio	23.6
Water Pumping	52.2
	1,00.0

Of the 316 installations, there was at least one in 26 out of the 36 states and the FCT. Lagos (23.6%) Yobe (16.3) Kano (8.6%) and Akwa Ibom (8.6) States had the highest number of installations. Financing of the installations came principally from the federal, state and local governments, European Union and Mobil. Private persons funded some installations, especially in the Lagos area.

More recently, Delta and Lagos States had embarked on projects to use Solar-PV for street lighting. No other modern RE technology has anywhere near the usage of number and capacity of installations in the country as Solar-PV.

Commercial Activities in RE
At present, significant commercial activities in RE technology is limited to Solar-PV. A national survey by the Energy Commission (30) revealed a total of 33 companies that were active in Solar-PV by 1999. Most of them were established within the last ten years. All of them were vendors or contractors for the supply and/or installation of Solar-PV equipment and system, with some of them representing foreign manufacturers. There was, and still is, no local manufacture of the major solar-PV system components including modules, controllers, inverters and solar batteries.

The only key system components that are locally produced and such standard electrical components as cables, switchgear, overload protectors and consumer units. The slow growth in the demand for solar-PV systems is largely responsible for the absence of manufacturing activity.

Integrated Rural Village Supply, IRVES
Modern economic activities depend predominantly on petroleum products and electricity. Their extension from the urban to the rural areas suffers serious economic and demand capacity constraints. Rural areas are poor, energy demand levels are low and centers of demand are scattered. Consequently, while 81% of the urban dwellers have access to electricity, only 18% of the rural population is similarly exposed. Furthermore, while kerosene can be bought in some

urban centers at the pump price of N17 per liter, its retail price in rural areas in much higher, being over N60 per liter in some places.

Renewable energy resources such as solar radiation, wind, small-scale hydropower and biomass are, in general, well distributed over the country, including especially the rural areas. The concept of the IRVES programme is to study the energy needs of a rural community for various socio-economic activities, the energy resources available to the community, energy related environmental problems, as well as the skills and trainability of its man power. An energy supply consumption system for the village is then developed, utilizing the available energy resources, which are mostly renewable, to meet the identified needs in a sustainable way. Capacity building programmes and post-project management are provided to enhance sustainability. Key features of the post-project management arrangement are: provisions for community participation in the management and payment, by beneficiaries, for centrally provided energy services, to cover operation and maintenance costs.

The country is implementing such a programme in two selected communities, namely Okopedi in Bende LGA of Abia State, a forest zone community, and Zakka in Safana LGA of Katsina State, an arid zone community. So far, surveys of the two communities have been completed (31&32). Both communities show a high dependence on fuelwood due to scarcity and high cost of petroleum products – especially kerosene, - and absence of electricity. The fuelwood is predominantly sourced outside the village (up to 6 km). There is great opportunity for the replication of this programme in many rural communities.

Alternatives to Fuelwood

The large scale and predominant consumption of fuelwood has been identified as contributing significantly to the environmental problems of soil erosion and desertification. Other serious hazards include the respiratory and visual disorders.

The potential in using modern renewable energy alternatives to traditional fuelwood based technologies has been recognized. The 1992 Presidential Task Force on Alternatives to fuelwood recommended sawdust briquette, solar energy and biogas as viable RE alternatives (2). More importantly, the year 2000 programme on Combating Desertification and Deforestation, under the Ministry of Environment adopted the large scale introduction of biogas technology and solar cookers, (as well as the use of coal briquettes, natural gas and kerosene) in order to reduce the share of fuelwood, among its alternatives from about 92% to 75% in energy terms, by the year 2003 (33). To these technologies must be added solar water heaters and improved wood stoves.

CONCLUSION:

The strategic developments in the Nigerian energy (conventional and renewable) sector have been highlighted. The status of the energy resource endowments, production and supply infrastructures, institutional arrangement for the management of the energy sector, supply-demand imbalances, policies as well as their strategic developments have been provided. Critical amongst the development is the planned restructuring and privatization of the energy sector in the country. This development is expected to usher in higher efficiencies in the sector through the injection of private capital from within and outside the country. Secondly, commercial use of the abundant renewable energy resources has not yet been reasonably accepted in the country. However, efforts are being made to improve on the situation. To this effect, renewable energy is being promoted as an instrument for energizing rural transformation in Nigeria.

Table 1 - Nigeria's Conventional Energy Resources as at 1999

Resource Type	Reserves		% of Total	Source
	Natural Unit	Energy Unit (billion toe)		
Crude oil	23 billion barrels	3.128	21.0	Ref. 3
Natural gas	4293 billion m3 (159 trillion cu. ft	3.679	24.7	Ref. 3
Coal lignite	2.75 billion tones	1.917	12.9	Ref. 4
Tar Sands	31 billion barrels of oil equivalent	4.216	28.3	Ref. 5
Hydropower	10,000 MW	1.954 (100 yrs)	13.1	Ref. 6
Nuclear	Not available	-	-	
	Total	14.894	100	

Note:

1 barrel of oil	=	0.136 TOE
1000m3 of natural gas	=	0.857 TOE
1 tonne of coal	=	0.697 TOE
1000 kWh (primary energy)	=	0.223 TOE

Table 2 - Refineries in Nigeria with Installed Capacities

Refinery	Year Commissioned	Capacity (Barrels/day)			
		1978	1988	1998	2000
Old P/H Refinery	1965	35,000	60,000	60,000	60,000
New P/H Refinery	1989	-	-	150,000	150,00
Warri Refinery	1978	100,000	125,000	125,000	125,000
Kaduna Refinery	1980	-	110,000	110,000	110,000
		135,000	295,000	445,000	445,000

Table 3 - NEPA'S Electricity Power Station

S/No	Plant	Year Commissioned	Type/Fuel Used	Installed Capacity (MW)	No. of Turbines
1	Kanji	1968	Hydro	760	8
2	Jebba	1986	Hydro	578	6
3	Shiroro	1990	Hydro	600	4
4	Egbin	1985	Thermal Steam/NG, HpFo		
5	Sapele	i. 1978 ii. 1981	i. Thermal Steam/HPFO,NG ii. Thermal gas Turbine/HPFO,NG	i. 720 ii. 300	10
6	Ijora	1978	Thermal gas turbine.NG	60	3
7	Delta	1975	Thermal gas turbine/NG	912	20
8	Afam	1975	Thermal gas turbine/NG	711	17
9	Oji		Thermal	30	
				5991	

Table 4 - Renewable Energy Resource Endowments in Nigeria

Type	Estimated Reserves	Source
Large Scale Hydropower	10,000 MW	Ref. 22
Small Scale Hydropower	734 MW	Ref. 23
Solar Radiation	3.5 –7.0kWh/m2-day	Ref. 24
Wind	2 – 4 m/s	Ref. 25
Fuelwood	43.3 x 106 tonnes/yr	Ref. 26
Animal Waste	61 x 106 tonnes/yr	Ref. 27
Crop Residue	83 x 106 tonnes/yr.	Ref. 28

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PV SYSTEM WITH BATTERIES AND INVERTER

By Umberto MOSCHELLA
ICS Consultant

LEVEL 3 FAMILY TOTAL REQUIRED ENERGY/DAY 1932

ARRAY EFFICIECNY 0.85

Array gross energy 1935 / 0.85 = 2,270 Wh

INVERTER EFFICENCY =0.90

Wh / eff.inv=2,490Wh

We state: SYSTEM VOLTAGE: Vsist = 12V

2,490Wh / 12V= 205 Ah

We know from NASA tables: (Peak Sun Hours) PSH = 5

No. MODULE: 2,490 / (50 W X 5 h) = 10 Modules

According to the System Voltage Value (12 V) we put: ALL MODULES PARALLEL

IF WE STATE FOR THE ARRARY VOLTAGE (IN DC) 24V:
THAN:WE HAVE TO PUT 2 MODULES IN SERIES.
10 / 2 =5 MODULES INPARALL

BATTERY LOT FOR 3 DARK DAYS = 2,490 X 3 = 7,470 Wh

MAX DEPTH OF DISCLARGE (DOP MAX) 50% (0.50 coeff)
BATTERIES SIZE 7,470 / 0.50 = 14,940 Wh

BATTERIES CAPACITY 14.940 Wh / 12 V= 1,300 Ah (14,940 / 24V = 650Ah)

if you have Batteries Capacity Unit of 400 Ah, you need 1,300 Ah / 400 Ah =
4 Battery Set.

PRESS RELEASE

The Department of State for Trade, Industry and Employment is organising a 4 day regional training workshop in collaboration with the International Centre for Science and High Technology (ICS) and United Nations Industrial Development Organisation (UNIDO) on solar photovoltaic technology in The Gambia from Monday 21 May 2001 to Thursday 24 May 2001 at the Tafbel Masionettes. The Workshop is funded by UNIDO and Gambia Government.

The objective of the training workshop is to increase the skills and understanding of engineers, technicians and policy makers in the field of solar energy for better service delivery. Africa, which has the highest potential for utilization of solar PV technology, is suffering from inadequate solar PV equipment and skills for the appropriate utilization of the solar resources, hence the significance of the training.

The workshop would draw 30 participants from West African countries including The Gambia. The workshop would end on Thursday 24th May 2001.

Department of State for Trade,
Industry and Employment
Independence Drive
Banjul

ENG 80/216 01/IV/(99)

18th May 2001

The Director
Gambia Radio and Television Services
Kairaba Avenue

REQUEST FOR PRESS COVERAGE

The Department of State for Trade, Industry and Employment is organising a 4 day regional training workshop in collaboration with the International Centre for Science and High Technology (ICS) and United Nations Industrial Development Organisation (UNIDO) on solar photovoltaic technology in The Gambia from Monday 21 May 2001 to Thursday 24 May 2001 at the Tafbel Masionettes starting at 0900 am prompt. The Workshop is funded by UNIDO and Gambia Government.

Grateful if you could please cover the opening ceremony. Attached, please find the programme.

Thank you for your continue cooperation.

Bah F M Saho
For: Permanent Secretary

Objectives of the Training Course on Balance of System and PV Application Technologies

As the demand for energy increases in the developing world as a result of population explosion and demand for more social amenities, the access to modern energy, especially in the rural areas become more and more dwindling. Renewable sources of energy including sun, wind and biomass will be an increasingly important. These forms of energy provide a reliable and in many cases a cost efficient and reliable energy services. Solar photovoltaic energy has proven to be one such reliable, efficient and affordable form of energy especially in the remote areas powering televisions, lighting systems, water pumps, refrigeration, etc.

In order to exploit this resource, it is essential to increase research, development and sensitization, increase market awareness in developing regions, and undertake prudent capital investments to increase viability of PV applications.

The viability of PV applications is however often dependent on the skills available, and planning tools available to the system designer. Hence the need to conduct this training course with the following objectives:

Provide an understanding of PV market developments
Necessary prerequisites in establishing manufacturing capacity.
Develop critical skills in the application of the technology and project development.
To train engineers, scientists/technicians in the field of planning and designing systems.
To expose candidates to examples of successful applications of PV based system.
To help developing countries in improving their awareness of tools related to planning, assessment and government and monitoring of systems.
To initiate contacts and promote co-operation between industries, research institutions and governments.
The selection and optimization of systems and building databases of information

Achievements/Results of the Training Course on Balance of System and PV Application Technologies

The ICS Training on 'Balance of System and Solar PV Application Technologies' was successfully concluded on Thursday 24 May 2001. Lecturers and Participants were drawn from ICS, UNIDO, The Gambia, Italy, Senegal, Guinea Bissau, Guinea Conakry, Mali, Sierra Leone, Ghana, Benin, Niger and Nigeria. Overall, 4 international Lecturers from Italy (2), Mali (1) and Nigeria (1), 2 Gambia lecturers and representatives of UNIDO, ICS and ICS Consultant attended. 11 international participants were drawn from the ECOWAS member countries mentioned above and 11 Gambian participants also attended.

The training course took the form of lectures, discussions, and country presentations on the solar/renewable energy situation in their respective countries. In addition to the lectures, there was a solar energy show organised by the Department of State for Trade, Industry and Employment at the Gambia Renewable Energy Centre (GREC) on Thursday 24th May 2001 and a field trip organised on Thursday afternoon, 24th May 2001, to visit a solar water pumping station at Tanji, near the beach.

The training provided the following opportunities/achievements:

Understanding of PV market developments
Necessary prerequisites in establishing manufacturing capacity.
Developing skills in the application of the technology and project development.
Trained engineers, scientists/technicians in the field of planning and designing systems.

- Exposed candidates to examples of successful applications of PV based system.
- Assisted developing countries in improving their awareness of tools related to planning, assessment and government and monitoring of systems.
- Initiated contacts and promoted co-operation between industries, research institutions and governments.
- Provided of Lecture notes, case studies and basic information on renewable energy systems.
- Approximately 22 delegates from West African countries received training in PV technologies, manufacturing procedures, quality control and field application.

Recommendations and Follow-Up of the Training Course on Balance of System and PV Application Technologies

The issue of technology transfer has never been easy as it deals with changes affecting the lives of people. Hence there is need for continuous training and sensitisation to effect acceptance of the technology. In the case of solar photovoltaic systems, the technology has been known to mankind for some time now. Even in Africa, the technology is accepted by most people. However, there is greater need for more training, both theoretical and practical, to increase the skilled workforce in this field as the demand increases.

The periodic training of technicians and engineers in the field of solar PV technology by ICS is indeed a welcome move. The following recommendations and follow-ups need to be considered for future training:

- More regular with increase in number of participants
- The duration of the course seems short for any practical demonstrations and hands-on training
- ICS may seem ideal for training but the Banjul training, if replicated in the other regions of the developing world at a regular interval, could provide a cheaper option for training many people for longer durations.
- Training materials (lecture notes, etc) need to be more practical and real situation (problem solving) than abstract theory
- Collaboration between ICS and training institutes or Universities for the extension of such training courses in the developing countries.