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INTERNATIONAL WORKSHOP ON

"PV Applications"

27-29 May 2002
Cairo, Egypt

A I N S H A M S U N I V E R S I T Y

International Workshop on
"PV Applications"
Cairo, Egypt 26 – 30 May 2002

CONTRACT NO. 2002/133

Annex: Proceedings [part 2]

Cairo, Egypt

The Electrical Aspect of Solar Energy

Dr. Hassan H. AFIFY

Professor of Solid State Physics
National Research Center, Egypt

Solar energy now holds out much promise to fulfill the growing demand for energy throughout the world. Therefore, the deep understand of the scientific basis and the feasible technologies for the utilization of solar energy are essential to make use of it on a large scale. The lecture aims to give an introduction to the broad field of solar energy addressing in depth to the electrical aspect.

Solar radiation could be converted to electricity directly by photovoltaic solar cells or indirectly by thermodynamic conversion into mechanical and electrical energy. Physics, technology and use of photovoltaic will be covered in details. The criteria for materials used in solar cells fabrication will be discussed from the physics point of view. The manufactured technology of silicon solar cell from polysilicon production, crystal growth, ingot silicon, wafer cleaning, device processing, encapsulation and assembly in modules are lighted on the consideration of the consumed energy and environmental impacts. Solar cell and module performance parameters as well as photovoltaic systems will be covered in this representation.

WORKSHOP ON " PV APPLICATIONS"
27-29 MAY 2002, CAIRO, EGYPT – SPONSORED BY: ICS-UNIDO, ITALY
AND PHOTOENERGY CENTRE OF AIN SHAMS UNIVERSITY

PV SOLAR ENERGY SYSTEMS : COUNTRY STATUS, ECONOMICS AND TECHNICAL ASPECTS

BY

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ABSTRACT :

This paper will cover the following items :

- PV market .
- Economics of PV installations .
- Some technical aspects (typical applications, sizing PV system, ...).
- Current PV solar energy status in Egypt .

PV MARKETS :

Production of solar cells and modules has been growing steadily throughout the 1990"s. The most significant increases have beent in the grid –connected applications, particularly PVs in buildings. This market sector is gaining government assistance in a number of industrial countries, notably Japan, Germany, Switzerland, the Netherlands And USA .

Several government programmes that drive increase are : the USA one million solar roofs initiative, the Japanese 70000 roofs programme and German 100000 roof .programmes which are intended to provide the necessary volume for price reduction.

The other grid-connected sector, central power stations, is more sensitive to the installed system price. In the present circumstances of low oil and gas prices, substantial growth in this sector is not expected until considerable reduction of PV price.

PV systems are now economical – compared to diesel generators- for powers less than 5 KW. Typical applications include water pumping, medical refrigeration, water purification and small village electrification .

PV modules have proven to be the most reliable power source for remote applications – particularly communications – throughout the world. This market is growing at a rate of 20-30% a year. Crystalline silicon solar cells will continue to serve this important sector due to its proven reliability. This sector is not much affected by world energy prices or policy, and thus PV will continue to serve it as the most effective energy source.

PV module shippments (MWp) cover the following : PV power stations, distributed grid- connected systems , PV- diesel hybrids, professional applications, stand alone : rural & domestic, consumer products (calculators , watches, ...) .

Rural electrification is needed as an optimum option for billions of people throughout the world. However, there is a major barrier to growth of this sector which is the fact that these people have little or no money and the cost of PV systems is capital intensive . In order to serve this vast market, in – country manufacturing is required to reduce cost of PV systems .

ECONOMICS OF PV INSTALLATIONS :

It is necessary to calculate the economic value of a PV system so that it can be compared with other methods of power generation (for example, diesel, extending the grid, . . . etc). At present, PV is most competitive where small amounts of energy are required far from the grid .

In an economic evaluation, the following parameters are considered :

- The life-cycle cost .
- Payback period .
- Rate of return .

In developing countries, if appropriate financing mechanism is available, the barrier to wide PV system usage can be largely overcome.

SIZING PV SYSTEMS :

Sizing of PV systems, particularly a stand- alone one, is an important part of its design. Since the capital equipment cost is the major component of the price of PV solar system, oversizing will increase the price of generated power, while undersizing reduces the supply reliability. The sizing requires :

- Knowledge of solar radiation data for the site.
- The load profile.
- The importance of supply continuity .
- Economic constraints.

The sizing procedure recommends the size of PV modules and the battery capacity that will be optimum for the application. Also, it will allow the nominal characteristics of the electronic components to be specified .

CURRENT PV SITUATION IN EGYPT :

Egypt is a high insolation country where sunshine duration is almost 3300 hours/year with an average daily solar irradiation of 6-7KWh/m^2.

Installed capacity and Applications :Many PV systems were installed for R&D purposes and commercial use. The total installed capacity- not grid connected – is estimated to be about 2MWp. Applications are: Telecommunication – Billboards lighting – Borders guard – Rural electrification – water desalination – Water pumping – Home and camping .

PV modules industry : There exist three companies in the Egyptian PV market. Two companies do encapsulation and module assembly, each having a capacity of 300KWp/year.

The third one is marketing complete systems .

Electrical Aspect of Solar Energy

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Electrical Aspect of Solar Energy

- **Solar Radiation.**
- **Electricity from the sun.**
- **Photovoltaic conversion.**
- **Physics Basis.**
- **What are solar cells?**
- **Silicon solar cell technology.**
    - (a) From sand to pure silicon
    - (b) Growth of silicon crystals.
    - (c) Typical cell-fabrication process.
    - (d) Module fabrication.
- **Enviromentally Benign Solar Cell Manufacturing.**
- **What we do in our lab.**

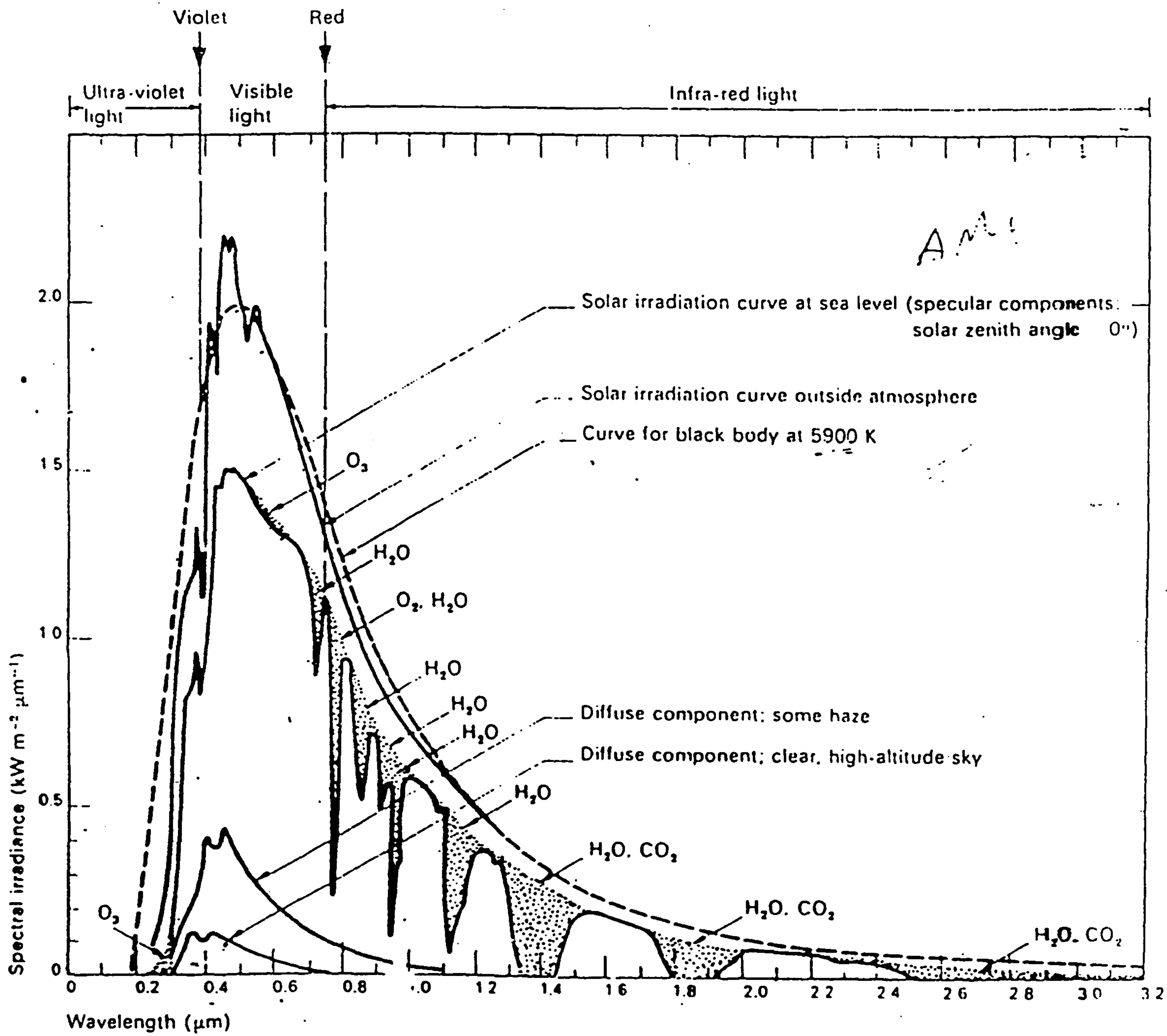


Figure 11. The solar spectrum outside the atmosphere and at ground level

3

Photovoltaic Solar Cells

Photovoltaic Effect:

Phenomenon Involoving:

- Generation of Free Carriers (e & h), which can move when experiencing an electric field.
- Separation of the carriers by some purposely-placed inhomogeneity (e.g. Junction).

Solar Cell:

A Solid State or Semiconductor Device which Produces Useful Electricity in the Form of a DC Voltage and DC Current, when it is Exposed to Light.

Types of Solar Cells:

- Built-In-Field.
- Crystal Structure.

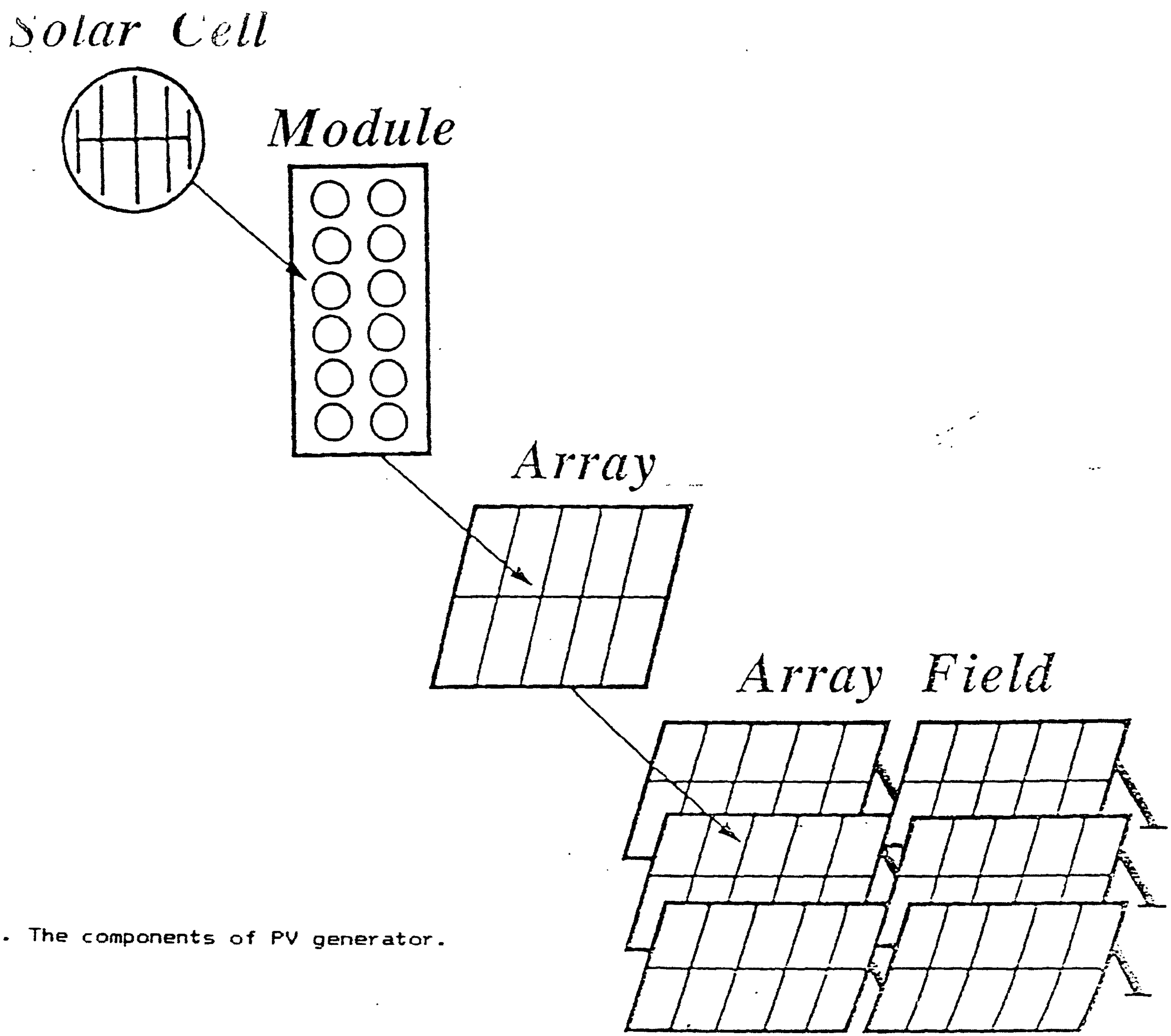
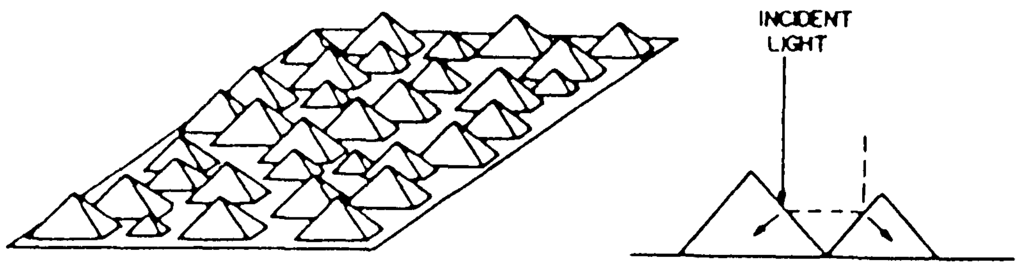


Fig.2.1. The components of PV generator.



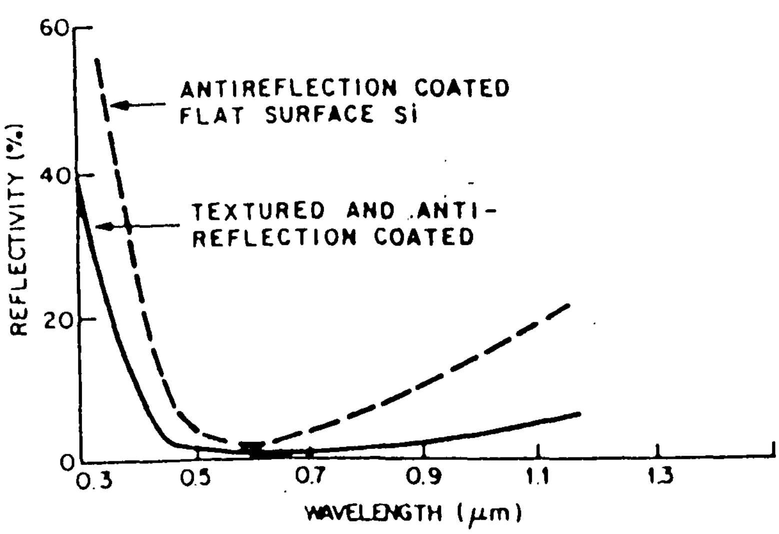


Fig. 3.30 The textured surface and its reflectivity (from P. Hersh and K. Zweibel, *Basic Photovoltaic Principles and Methods*, U.S. Government Printing Office, Washington, DC, 1982. Reprinted with permission)

Loss factors in the solar cell efficiency

1) Loss by long wavelength.

2) Loss by excess energy of the photons.

3) Loss by metal coverage.

4) Loss by reflection.

5) Loss by incomplete absorption due to the limited thickness of the cell.

6) Collection efficiency.

Solar Cell Characteristics

$$V_{oc} = K\,T \ln ((I_L/I_o)+1)$$

$$I_o = 1.5 \times 10^5 \exp (-E_g / KT)$$

$$V_{oc} \propto E_g$$

$$I_{sc} \propto 1/E_g$$

$$FF = (V_m I_m)/(V_{oc} I_{sc})$$

$$\eta = V_m I_m / P_{in} = I_{sc} V_{oc} FF / P_{in}$$

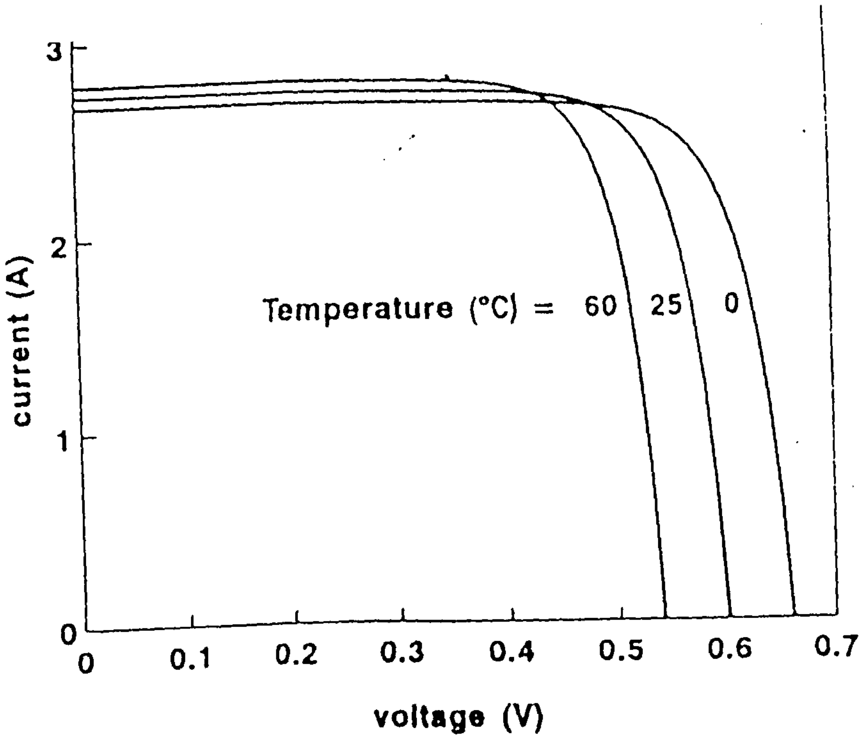


Fig. 3.21 Temperature dependence of the *I–V* characteristic of a solar cell

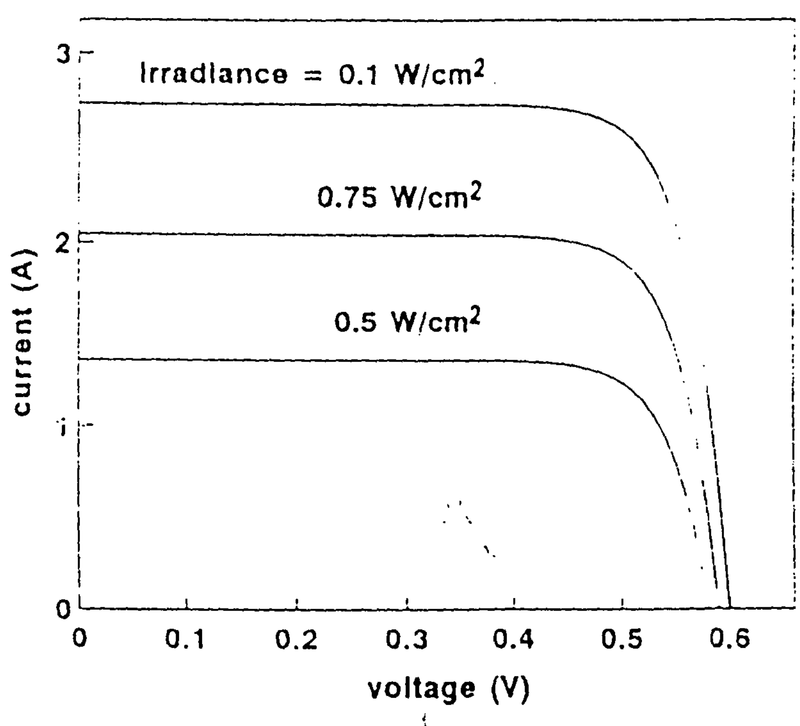


Fig. 3.22 Irradiance dependence of the *I–V* characteristic of a solar cell

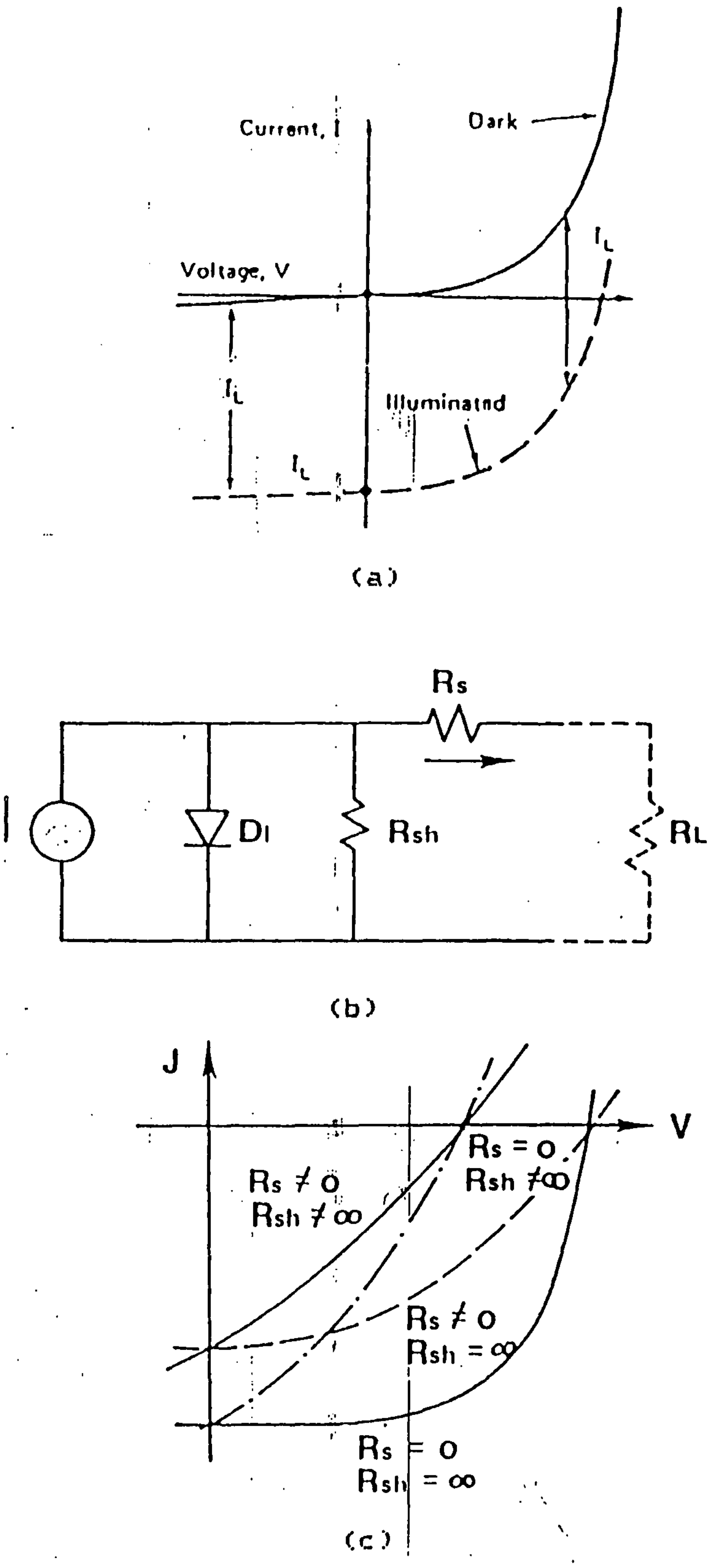


Fig.2.7 (a) Dark and illuminated I-V Characteristic of the solar cell.
(b) Equivalent circuit of the solar cell.
(c) Effect of series resistance R_s and shunt resistance on the output characteristics of the solar cell.

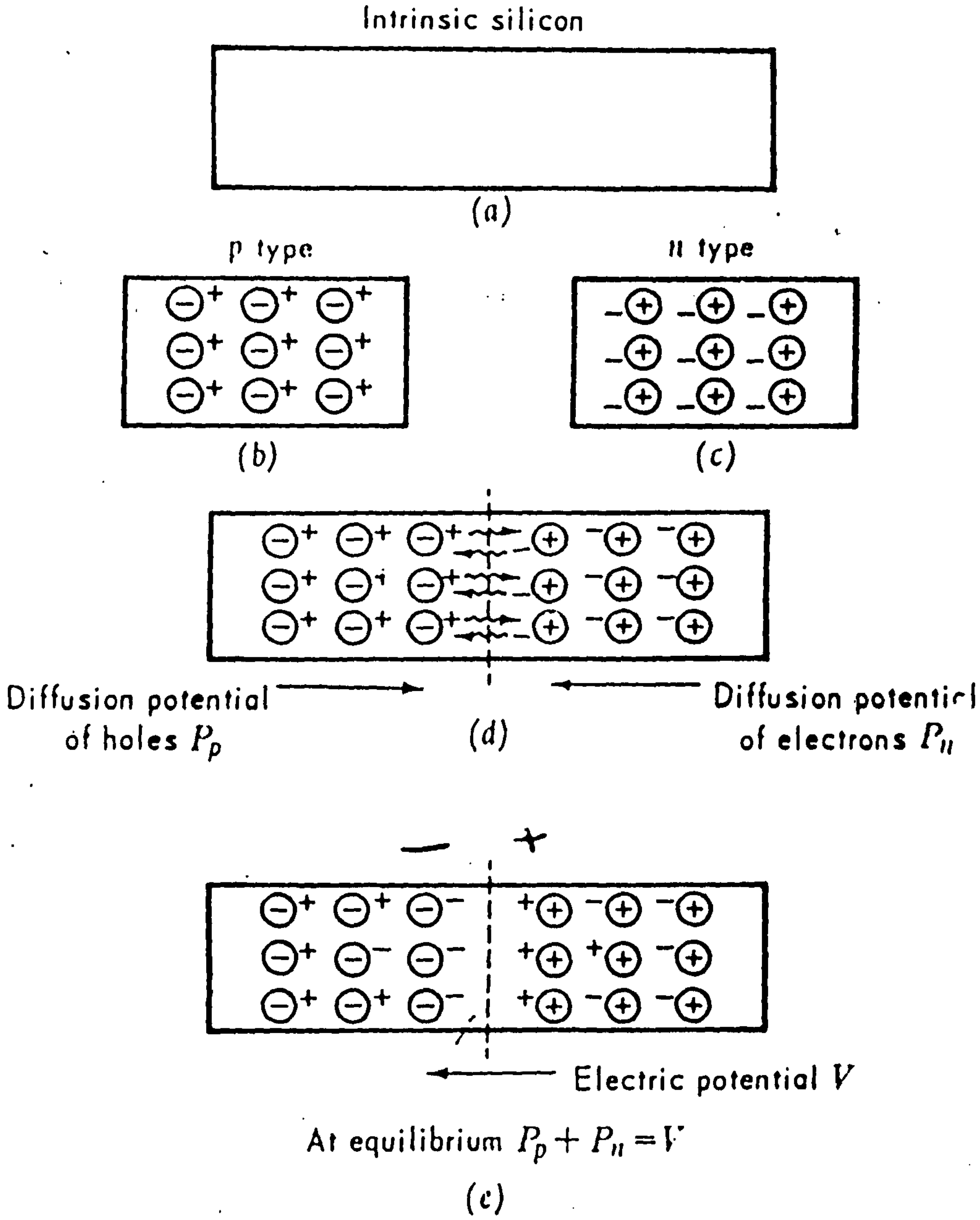


Fig. 1-1. *Conceptual representation of the construction of a p-n junction.*

TABLE I

Material	Energy band gap 300°K (eV)	Mean Absorption Coefficient (cm^{-1})	Electron Diffusion Length (μm)	Hole Diffusion Length (μm)
Si	1.1	200	50 - 200	20 - 100
GaAs	1.45	3.10^3	2 - 10	1 - 5
InP	1.35	3.10^3	5	3
CdTe	1.5	3.10^3	0,5 - 2	0,3 - 1
Cu_2S	1.21	10^4	5	
$CuInSe_2$	1.04	3.10^3		

Types oF Solar Cells:

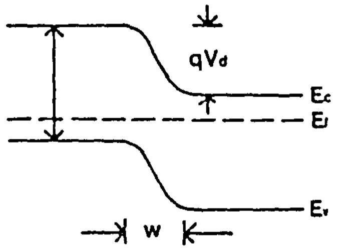
- Single -crystall (Si -GaAs, In-P, Concentrator, Flat Plat)
- Polycrystalline { Thin films (Cu In Se_2, CdS, Cdte ,-------)

  Silicon bulk- Thin Film
- Amorphous (a-Si : H)

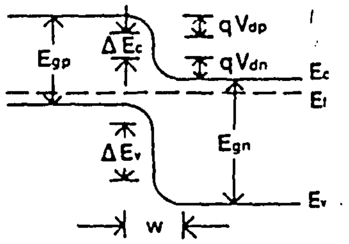
Requirements For Voltovoltaic semiconductor

- Energy gap
- Absorption coefficient
- Doping
- surface recombinatio
- carrier lifetime
- Abundance
- Ease of fabrication

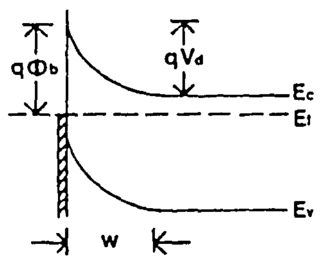
(a) Homojunction



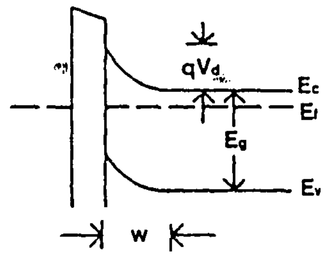
(b) Heterojunction



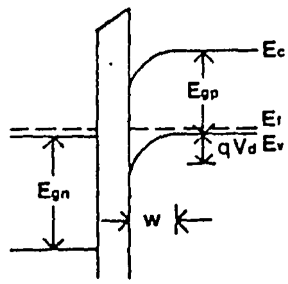
(c) Metal-Semicondutor



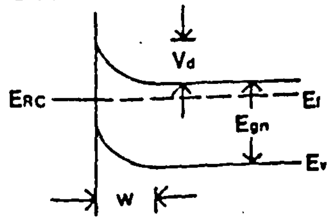
(d) Metal-Insulator-Semiconductor



(e) Semiconductor-Insulator-Semiconductor



(f) Electrolyte-Semiconductor



$\Delta \phi_d \doteq \phi_m - \phi_{sc}.$

Built-In-Field:

a. Homo-Junction
b. Hetero-Junction.
c. Metal – Semiconductor Junction. (Schottky Barrier).
d. Metal – Insulator – Semiconductor (MIS).
e. Semiconductor – Insulator – Semiconductor (SIS).
f. Electrolyte – Semiconductor (Electrochemical).

Efficiency Losses

I. Short Circuit Current Losses:

a. Reflection of incident light:

$$R = ((n-1)^2 + k^2) / ((n+1)^2 + k^2)$$

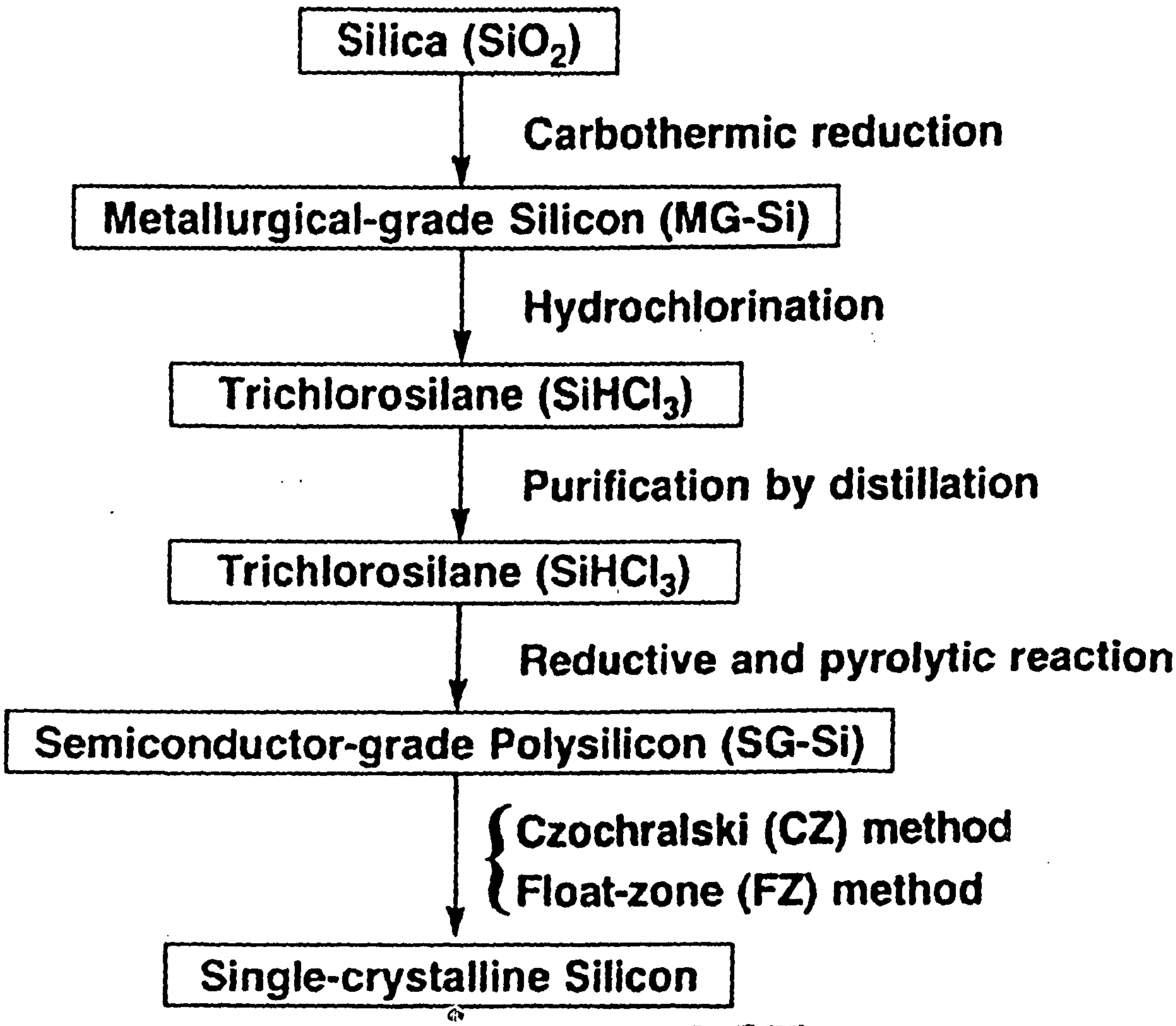
b. Grid contact blocks 5 to 15% of the incident light.
c. Only the election – hole pair generated near p – n junction itself contribute to I_{sc}.

II. Open Circuit Voltage Losses

a. The Presence of Depletion Region Recombination Current Decreases V_{oc}.

Electronic grade Si

Tech...



Sand To MG Si

– the total production 6×10^6 tons a year worldwide.

Quartzite Silica + Coal Coke or Weed Chips $\xrightarrow[\text{arc furnace}]{2000\ ^\circ C}$ **Molten Si at the Bottom + Co Escape ↑**

$$SiO_2 + 2\,C \longrightarrow Si_{98-99\%}\ (liq.) + 2\ Co\ (g)$$

≈ 60% for Al Alloy
≈ 30% for Chemical Products such as Si Resin
≈ 10% for Steel (special)

Only 1% or Less of the Total Product of MG-Si is used for electronic Industry.

For One Ten of MG Si

- 2500 – 2700 Kg Silica
- 600 Kg Charcoal
- 600 – 700 Kg Coal or Coke
- 300 – 500 Kg Wood Chigs
- 13,000 – 15,000 KWk Electric Power are Required.

The cost of Si ≃ 2 \$/Kg MG-Si

Probable Impurities in MG-Si

The major impurities are usually iron and Aluminium. A typical breakdown of impurities in MG-Si is given as follows:

Impurities	**Concentrative Range (parts per million, Atomic)**
Al	1500 -4000
B	40 - 80
Cr	50 - 200
Fe	2000 - 3000
Mn	70 - 100
Ni	30 - 90
P	20 - 50
Ti	160 - 250
V	80 - 200

It is purified until the impurity concentration is less than 0.2 ppma (parts per million atoms). 1 cm^3 of crystalline silicon contains 5×10^{22} atoms. Therefore, the total number of foreign atoms should be less than $.2 \times 10^{-6} \times 5 \times 10^{22} = 10^{16}/cm^3$

MG Si → $SiHCl_3$

Fluidized Bed Reactor is Used (Fig.)

heat
- Removal is essential
- exothermic reaction

$$\text{MG-Si (Powder)} + 3\ HCl\ \text{(Anhydrous)} \xrightarrow[300^\circ C]{\text{~~2000~~}\ ^\circ C} SiHCl_3 + H_2$$

Fe, Al and B Chlorides are Formed in the Reactor, ***Highly Pure*** $SiHCl_3$ is Removed from the these Halides by Fractional Distillation since it Boils at 23°C.

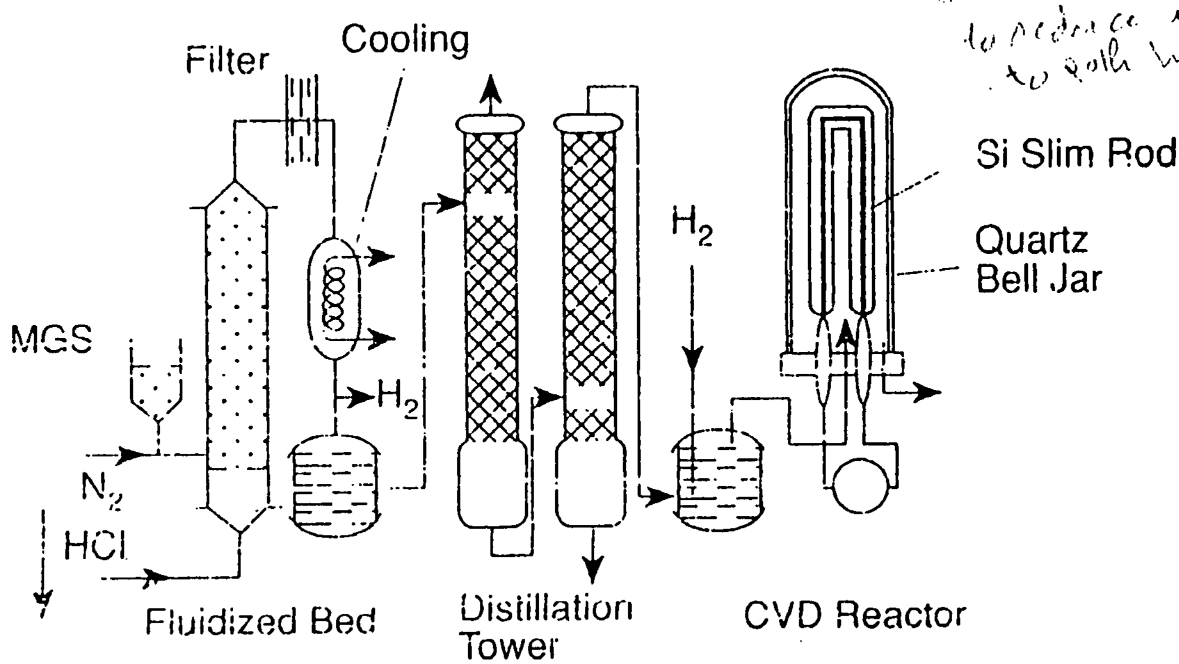
$$\textbf{\textit{Highly Pure}}\ SiHCl_3 \xrightarrow[1100^\circ C]{\text{CVD}} \text{EG-Si}$$

→ Rods (150 - 200 mm dia)

$$SiHCl_3\ (g) + H_2\ (g) \xrightarrow[1100^\circ C]{} Si\ (s) + 3\ HCl\ (g)$$

The Deposition of EG-Si Occurs on a Thin, Heated, High Purity Silicon Rod Referred as ***Slim Rod***.
The Production of Long Diameter Rods Requires Several Hundred Hours.

≃ 200 kwh/kg and the cost is ≃ 80 $/kg.



Schematic of fluidized bed, distillation tower, and chemical vapor deposition (CVD) reactor developed by Siemens for purifying trichlorosilane and converting it into electronic-grade polysilicon

Silicon Single Crystal Growth Technology

Two Techniques have Dominated the Production of Si Single Crystals. One is a Zone – Melting Method Commonly Called the Float – Zone (FZ) Method. The Other is Pulling Method Traditionally Called the Czochrolski (CZ) Mehtod. It is Estimated that 80% of the Single Crystal Silicon is Produced by CZ and the Rest by FZ.

CZ Method
Operation Outline

Growth Sequence:

1. Polysilicon (EG-Si) Chunks are Filled in Quartz Crucible and Melted at 1420°C in an Intert Gas (Ar) or Vacuum Ambient.
2. The Si Melt is Kept at High Temperature (1420°C) for a While in Order to Ensure Complete Melting and Ejection of Tiny Bubbles, Which May Cause Voids or Crystals Defects.
3. A Seed Crystal with the Required Plane is Dipped into the Melt Until it Begins to Melt Itself. The Seed is Then Withdrawn from the Melt.

If the pulling is slow enough, the Si atoms arrange themselves according to the crystallographic structure of the seed. This yield the ingot of single c-Si.

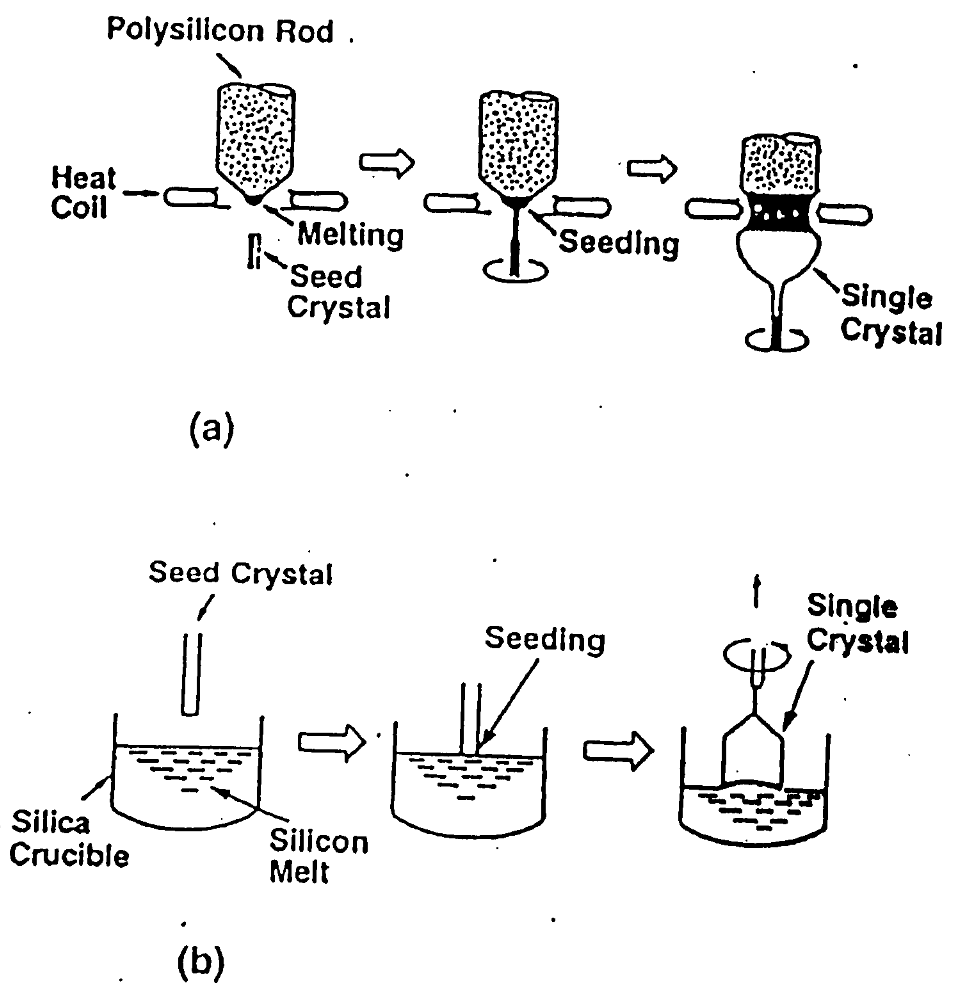
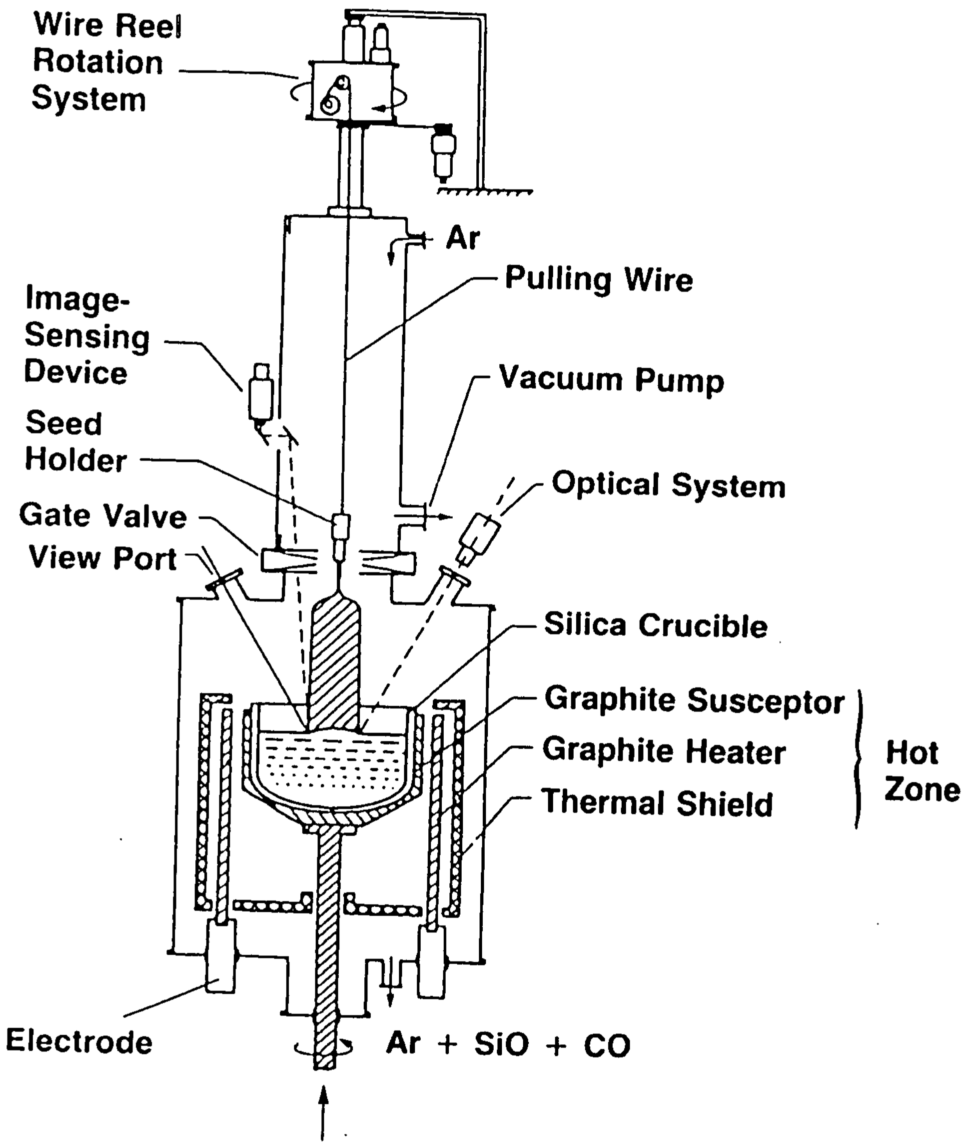


Fig. 1.5 Principles of single crystal growth by (a) float-zone method and (b) Czochralski.

CZ

- The produced pure Si single crystal ingots are typically 1m long, 15 cm φ and 40 Kg in weight
- The growth rate, 0.1 - 0.2 cm/min.
- 930 kWh/m²



Schematic view of typical Czochralski silicon crystal growing system. (After Abe.[24] Reproduced with the permission of Academic Press, Inc.)

4. The Diameter is Increased up to the Target by Decreasing the Pulling Rate and/or the Melt Temperature .

5. During the Entire Crystal Growth Process, Inert Gas (Ar) Flows Downward Through the Pulling Chamber in Order to Carry off Reaction Products Such as SiO and Co.

CZ Disadvantage

Oxygen Contamination

Since Molten Silicon is **Very Reactive**, it Attacks the Quartz Crucible, Converting SiO_2 to SiO:

$$SiO_2\,(S) + Si\,(L) \rightarrow 2\,SiO\,(g)$$

As SiO Bubbles Through the Melt, it Dissociate into Si and Oxygen:

$$2\,SiO \rightarrow 2\,Si + O_2\,(g)$$

The Released Oxygen is Incorporated into the Melt (Concentration $\approx 2 \times 10^{18}\ cm^{-3}$).

Carbon Contamination

The Possible Sources for Carbon are the Starting Material, the Graphite Susceptor, and the Heating Element.

Developments in CZ Method

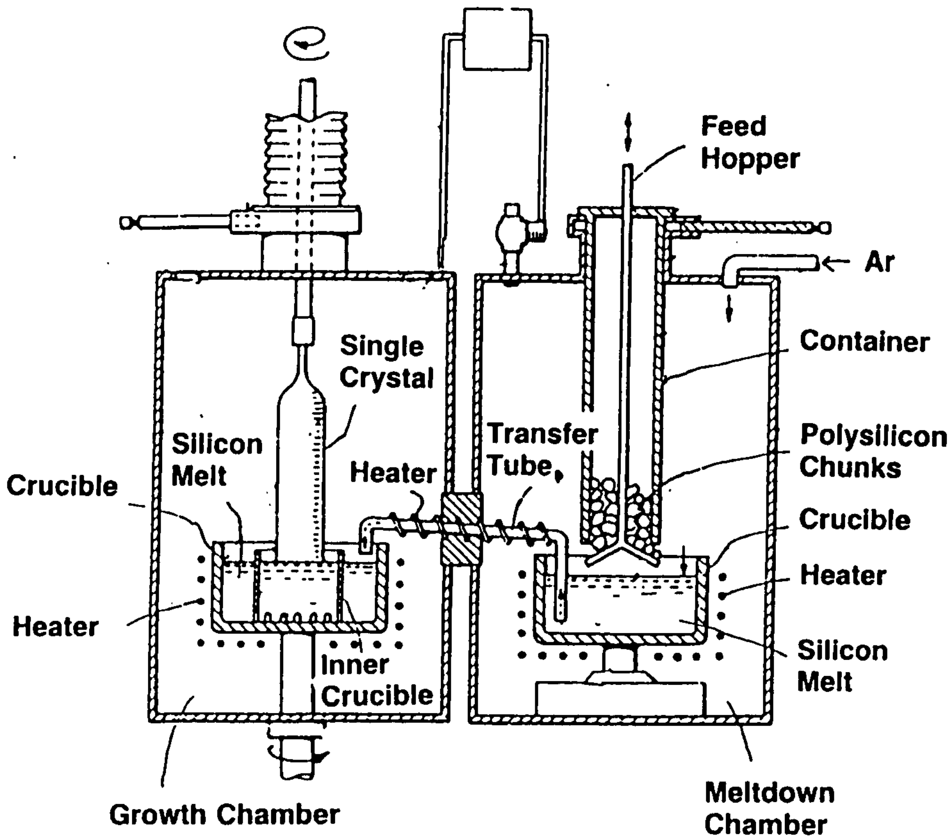
Magnetic Field applied CZ (MCZ)

The CZ is Carried Out Within a ***Strong Horizontal Magnetic Field.*** This Serves ***to Tighten the Thermal Convection Current*** as Each Atom in the Si Melt is Arrested and Upward Mobility is Prevented. The Resulting Si Single Crystal has ***Lower Oxygen Concentration*** and More Homogeneous Impurity Gradient.

Continuous CZ Method (CCZ)

It has been Implemented by ***Mitsubishi Company***. A Continuous Supply of Molten Si is Provided Using a Double Quartz Crucible (Fig.).

Ingot 3.5 m long and 150 kg in weight



Continuous liquid-feed Czochralski growth furnace. (After Lorenzini *et al.*[159])

FZ Method

Operation Outline

A Polycrystalline EG-Si Rod is Mounted Vertically in a Growth Chamber that is Either under Vacuum or Filled with Inert Gas. To Initiate the Crystal Growth, the Rod and Seed are ***Partially Melted using Induction Heating***. The Molten Zone is Passed Along the Length of the Si Rod. In this Process ***Surface Tension Forces*** hold the Molten Zone in Place. Therefore, it is Difficult to Grow Large Diameter Si Crystal. Since the Molten Zone ***is not in Contact with any Crucible***, FZ Crystal has a higher Purity than CZ Crystal. The Oxygen Concentration is $\approx 10^{16}$ cm^{-3}.

- High purity due to low C and O_2 content.
- Growth rate 0.3 - 0.5 cm/min, the typical ingot is 12.5 cm ϕ and 1 m. in length

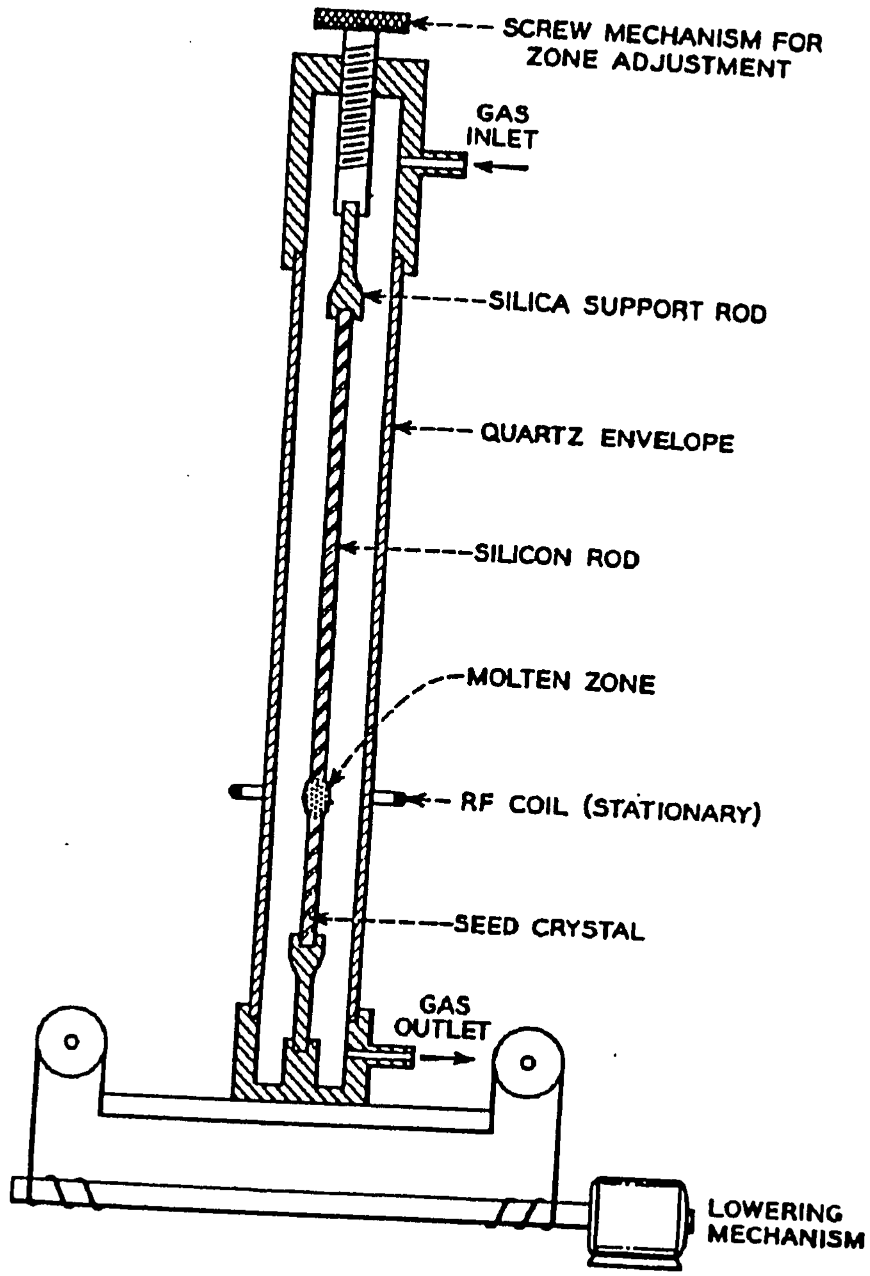


Fig. 18 Apparatus for floating-zone method

Silicon Ribbons Technology

The expense of Slicing and Polishing Wafers has Led to Development of Methods for **<u>The Growth of Si Directly in the Form of Thin Ribbons</u>** by Edge-Defined, Film-Fed Growth (EFG) or by Electronic Web Growth.

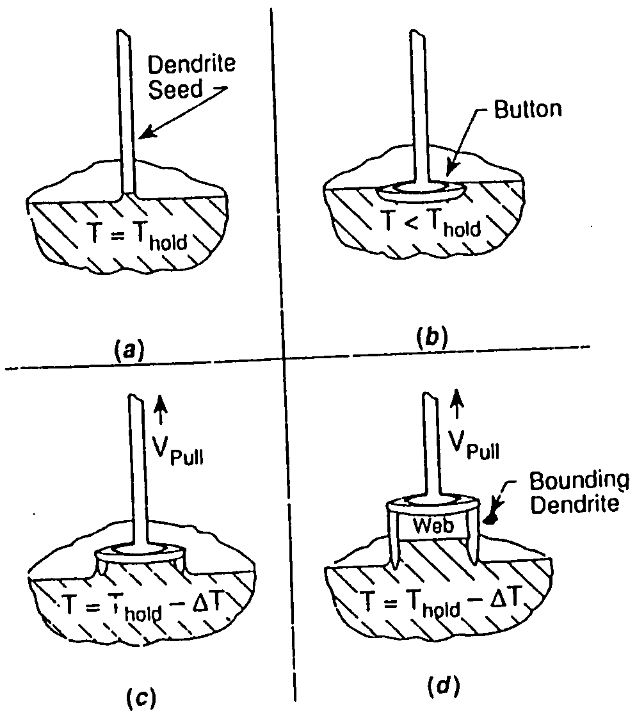
<u>Heat Exchanger Casting</u>

In this Method Crucible Could be Designed to Produce Square or Rectangular Shapes of Si inget (43X43 cm^2 120 Kg weigh) to Overcome The Round Shape Produced by CZ & FZ Methods.

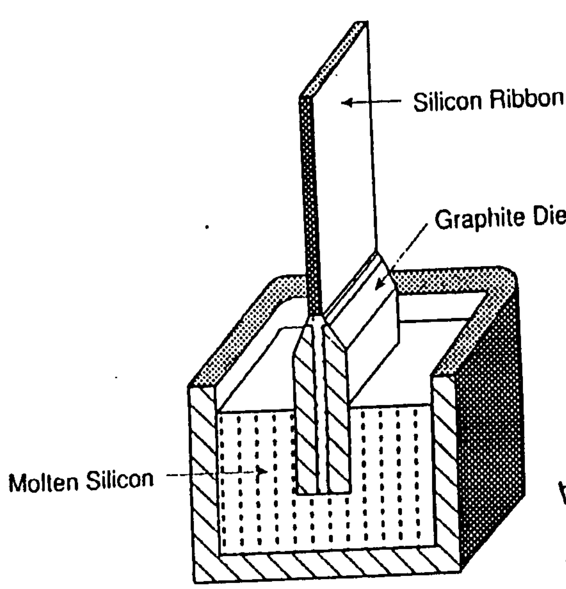
[illegible] It is possible to make Si ingots by pouring molten Si into a crucible and controlling the cooling rate. This cast silicon does not have the same quality as CZ or FZ but it is good enough to make solar cells. The ingot is sliced by the inner diameter saws.

Disadvantage (1) it is very slow ≃ 30 wafers/hour
(2) high loss of Si (the thickness of the kerf = 450 um)

Development 1) Multiblade slurry saw machine.
2) the kerf thickness is 200 um instead of 450 um).
3) ~~Cost reduction~~ from : Energy reduction 440 Kwh/m^2 to 300 Kwh/m^2 76



Schematic representation of the various stages in dendritic-web growth: (*a*) holding, (*b*) buttoning, (*c*) start of growth-dropping dendrites, and (*d*) growth.

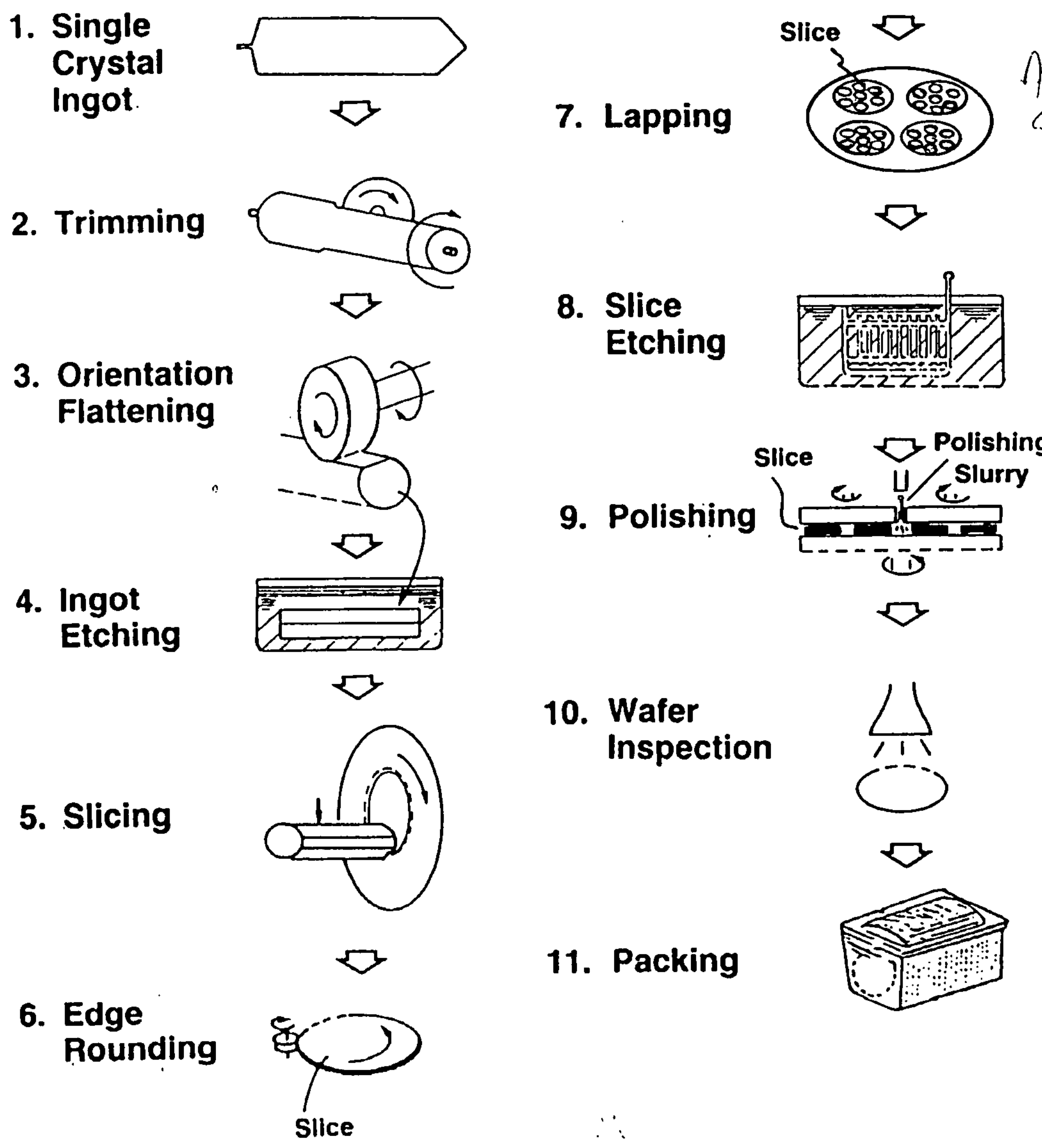


Schematic of "edge defined" meniscus in a ribbon die. (*After Wald [1981]*.)

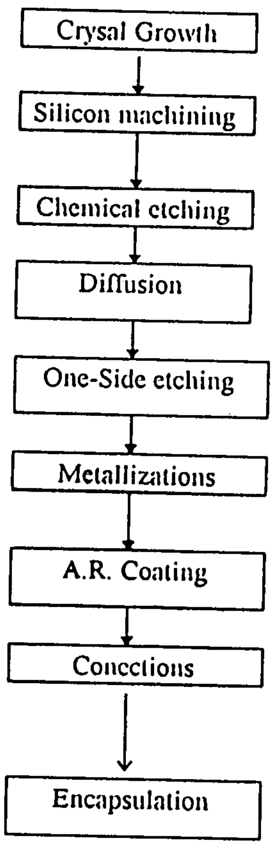
the molten Si ascends by capillarity through a thin slots in a graphite die - The crystallization is initiated with a that is pulled upwards -

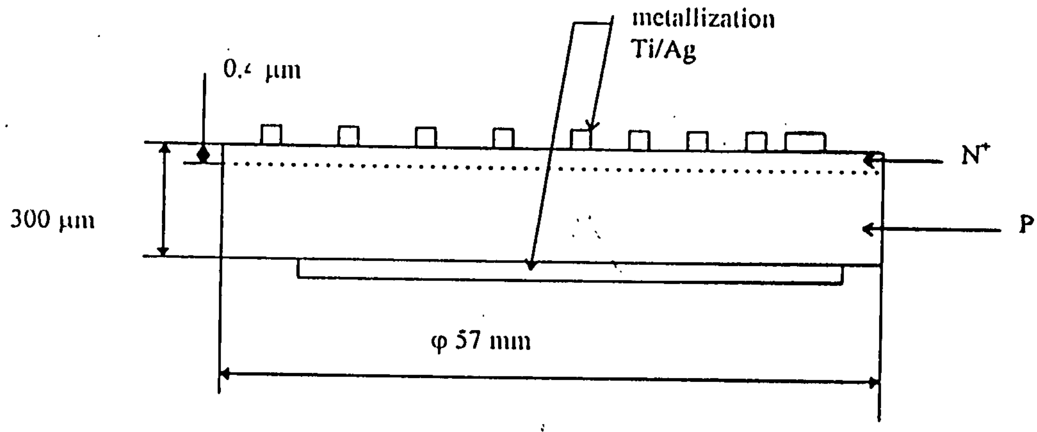
advantages 1) high production rate

Wafer Shaping Process



Si Solar Cell Tech.





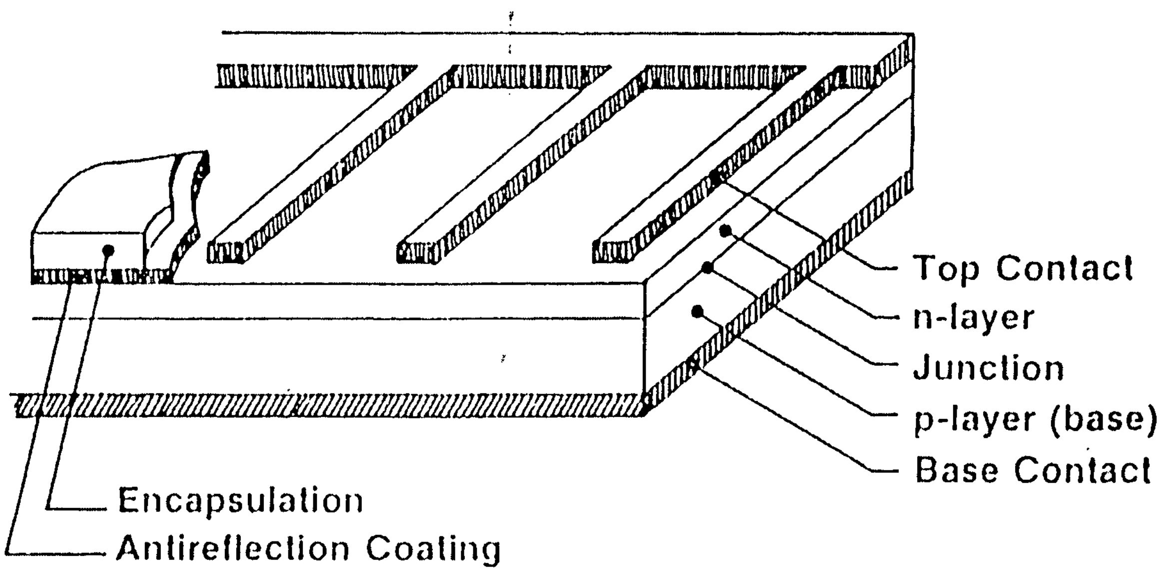


Fig.2.2. The normal configuration of conventional
p-n junction.

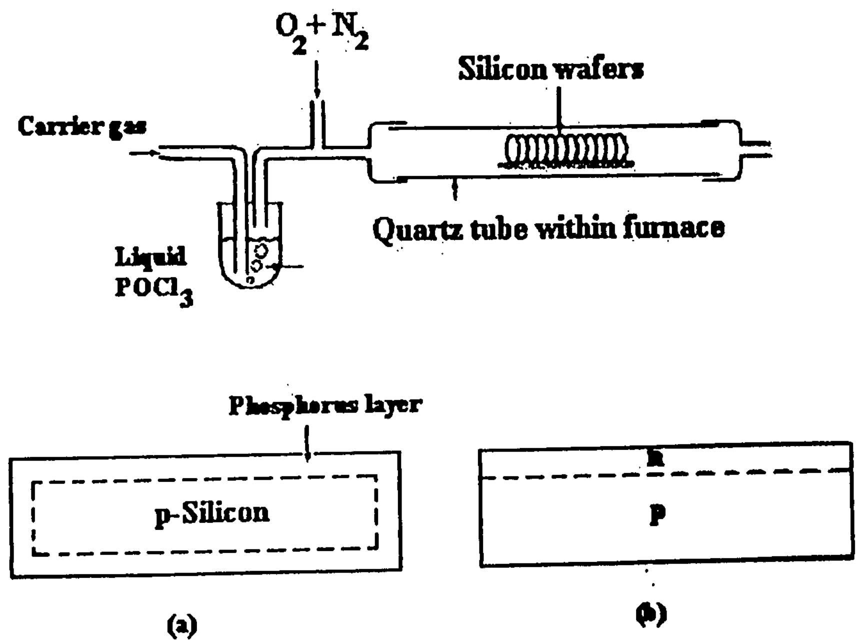


Fig.2.4 Phosphorus diffusion process
A) Immediately after diffusion process.
B) After etching of back and side of wafer

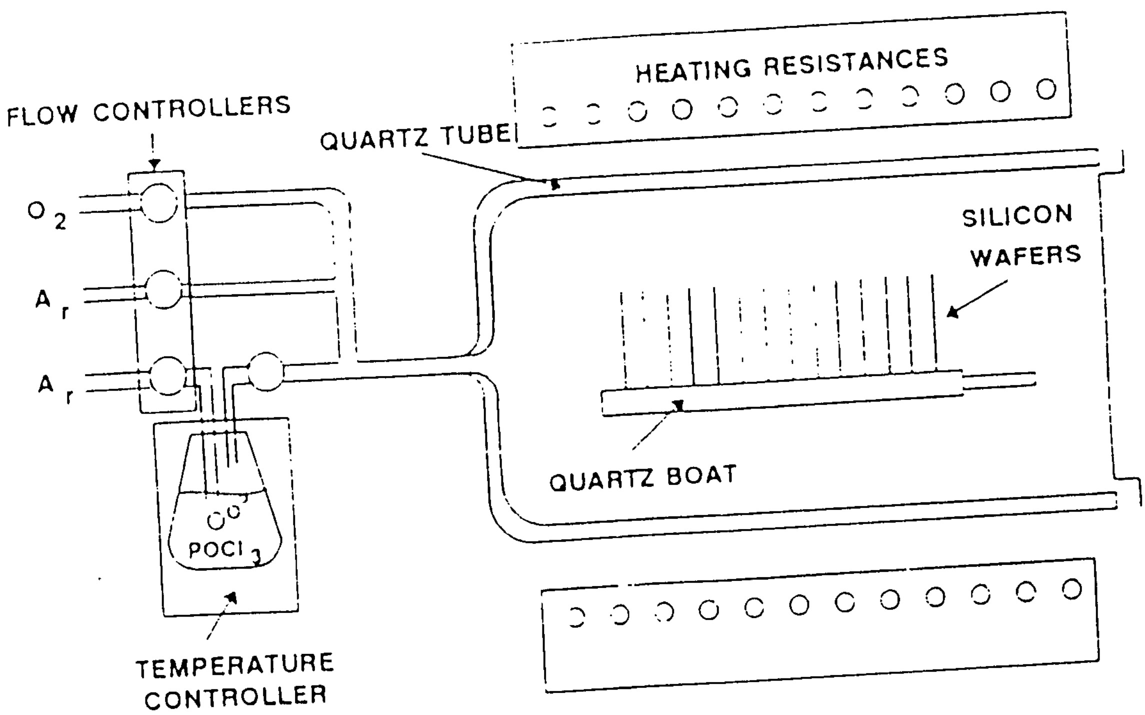
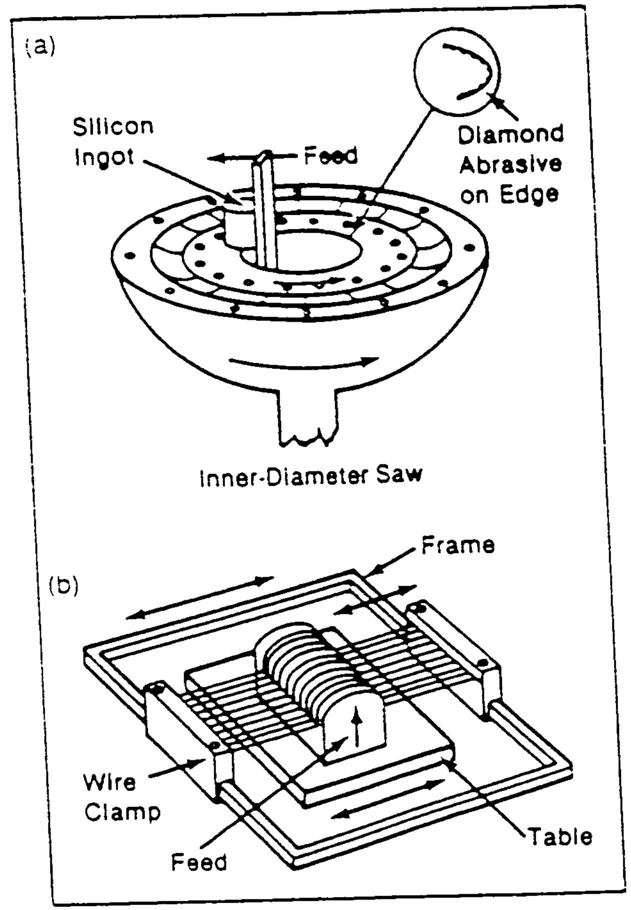


Fig. 3.31 Quartz diffusion furnace



... (from P. Hersh and K. Zweibel.

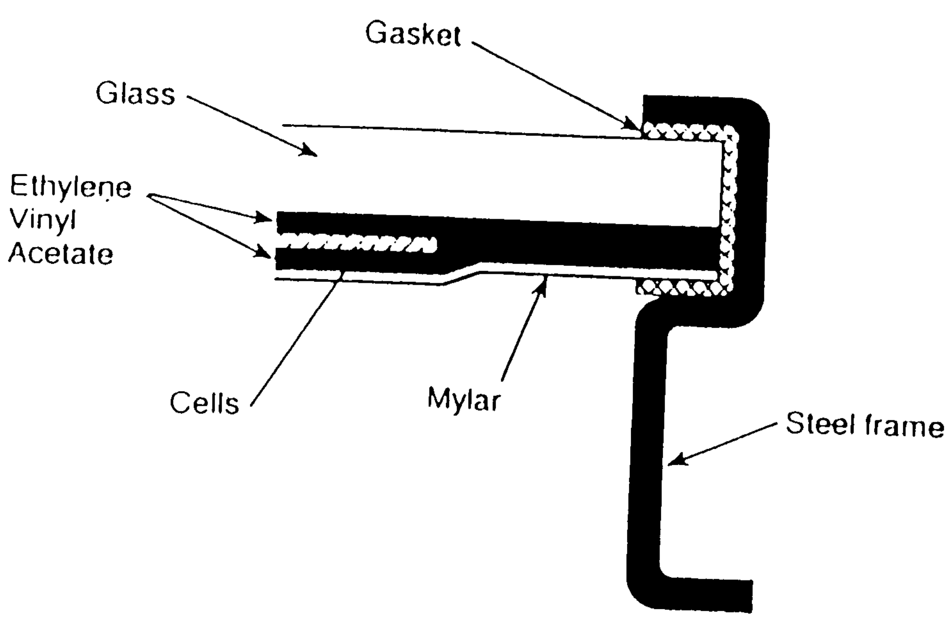


Fig. 3.33 The module cross section (from P. Hersh and K. Zweibel, *Basic Photovoltaic Principles and Methods*, U.S. Government Printing Office, Washington, DC, 1982. Reprinted with permission)

Enviromentally Benign Silicon Solar Cell Manufacturing

The PV industry uses more silicon than IC industry. Therefore, it is important to review the environmental impacts of the rapidly growing silicon PV industry and to find opportunities for improving the energy efficiency and productivity and reducing enviromenatl impacts.

The manufacturing of Sc. Silicon devices requires many steps that are energy intensive and **use large amount** of water and **toxic chemicals**. Now, the IC industry has initiated several programs to promote **environmentally benign manufacturing**, i.e. manufacturing practices **that recover, recycle and reuse materials resources with a minimal consumption of energy**. Such approaches often have the potential for significant cost reduction by reducing the purchase volume of chemicals and by cutting the amount of used chemical that must be discarded.

It is not possible to review here in detail all the steps involved in PV industry. Therefore, we will simply highlight some areas where we think opportunities exist to make the Si-PV industry more environmentally benign.

Poly silicon production

Development of new sources for Solar-grade polysilicon instead of Electronic-grade. This could achieve by two possibilities:-

1- build new factories dedicated to the production of low cost (<10**$**/Kg) Solar-grade polysilicon, and

2- Find new ways to use the rejected silicon that is not currently used, (e-g) purifying the about 30% of Si lost from wafer cutting operations (Kerf loss).

- The production process of EG-Si from trichlorosilane (SiHCl3) distillation and reduction is very energy intensive and **produces large amount of wastes**, including a mix of environmentally damaging chlorimated compounds. Also, 80% of MG-Si used in production of $SiHCl_3$ is wasted.

Low- Temperature, chlorine free process for poly silicon production

The National Renewable **energy** Laboratory (NREL) and Sandi National Laboratory (SNL), with funding from **the initiative for proliferation preventing** (IPP) program, has initiated a joint research program to study new chlorine free methods for producing Solar-grade polysilicon

- MG-Si and absolute alcohol are used as a starting materials.
- 15 to 30 Kwh/Kg are required in contrast to 250 Kwh/ Kg in trichlorosilane ($SiHCl_3$) method.

- The Si yield (polysilicon and the main by- product, silicon sol) is in the 80% to 95% range VS 6% to 20% for $SiHCl_3$ method.
- The eventual cost goal is US $ 10/Kg of solar grade polysilicon.

Sources of Si waste from the Electronic industry

1- In slicing process, the kerf loss is higher (30to 50%) depending on the kerf and wafer thickness.
2- The EG. Top and tails ingot reject pat scrapes and rejected wafers from IC industry are sources for solar grade Si after purification.

Wafer slicing and cleaning

- Wafer slicing is still one of the most expensive process in Si solar cell manufacturing because of the large quantities of consumables (stainless-steel wires and abrasive slurry) and kerf loss. The slurry is composed of SiC and minerals oil-base or glycol-base slurry vehicle. Oil-base slurry is commonly used in PV industry while water-soluble glycol-base slurry commonly used in IC industry.

- The oil –base slurry produces more environmentally damaging wastes and requires more extensive wafer cleaning R & D are needed for the following:-

-Methods for proper disposal or recycling of the SS cutting wires.
-The effective recovery of SiC in the slurry.
-The development of water-base slurries.

Wafer Cleaning and Etching

The cost of chemical waste disposal is high. It is important for the PV industry to find ways to reduce **chemical consumption** and **waste generation through sources reduction, recovery, recycle, ruse and substitution.** Dry cleaning process may be sufficient for PV industry but it is not adequate for the IC industry. For example, **centrifugal shear carbon dioxide cleaning is considered as an alternative to organic solvent and /or hot detergent cleaning methods.** CO_2 gas is non-flammable, non-corrosive, abundant, inexpensive and reusable.

HF acid is used for wafer cleaning dopant oxide removal, and diffusion tube and quartz cleaning. It account for a very large percentage of the total hazardous waste generated by Si solar cell manufacturing. It is possible to reprocess used solution using reverse osmosis.

Optimization Water use and Reuse

The Sc. Industry worldwide spends as much on ultra pure water as wet chemicals for wafer processing. About 30 gallons/sq.inc of wafer is

Low temperature and chlorine free method

(1) $\text{MG-Si} + 3C_2H_5OH \xrightarrow[28^\circ c]{\text{catalyst}} Si(OC_2H_5)_3H + H_2.$

triethoxy Silane

(2) $4Si(OC_2H_5)_3H \xrightarrow{\text{catalyst}} SiH_4 + 3Si(OC_2H_5)_4$

Simultaneous Oxidation and Reduction

tetraethoxysilane

(3) $Si(OC_2H_5)_4 + 2H_2O \xrightarrow{\text{hydrolysis}} SiO_2 + 4C_2H_5OH.$

High Purity

(4) $SiH_4 \xrightarrow[850^\circ c-900^\circ c]{\text{Pyrolysis}} Si + 2H_2$

Silane

pure

Undergo a simple Cycle of purification

needed in the IC industry. The target is to reduce it to 10 gallons/In^2 and 2 gallons/In^2.

Solar Cell Processing

For junction made by diffusion, either a belt furnace or a tube furnace is used. Liquid $POCl_3$ is used as a source of doping. It generates toxic P_2O_5 and Cl_2 and requires cleaning the diffusion tube by HF solution.

Belt furnace are more environmentally benign because they can use water soluble, no-toxic, spin-on or spray on or vapor dopants and do not require HF cleaning. Edge trimming can be done by laser cutting or plasma etching. Antireflection coating can be deposite by vacuum evaporation, plasma deposition, atmospheric pressure CVD and spin-on-liquid. The metal electrodes are soldered with lead free solder (tin/3.590 Ag alloy).

Module Assembly

In soldering process **Flux** is used to act as a deoxidizer and to ensure better adhesion between the solder and solar cell. Conventional flux leave residues on the cell surfaces that need to be cleaned with **(CFC)** chlorofluorocarbon compounds. Which cause zone depletion in the atmosphere.

Recently, water soluble flux and no-clean flux have become widely available. However, it appeared that water rinse of the cell **retained moisture** which causes **module reliability problems**.

Conclusion

As the silicon PV industry continues to rapidly expand, the environmental impact f its manufacturing processes and products will receive increasing attention. It is particularly important for a renewable energy technology to address its environmental impact during manufacturing because one of the primary benefits of renewable energy generation is **its low environmental impact**. We have discussed several alternative approaches in this paper that **are both cost effective and environmentally benign**. However, the manufacturability and reliability of most of these alternative approaches need further investigation. We propose that the silicon PV industry form an association of government laboratories, equipment suppliers, and cell and module manufacturers **to promote more environmentally benign manufacturing approaches**. This association can also coordinate PV industry's interactions with the environmental associations of the integrated-circuits and printed-circuit-board industries mentioned in this paper.

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2- Preparation and Characterization of Some semiconducting Layers Used in Solar Energy Field by Spray Pyrolysis Technique.(M. SC., Faculty of Girls, Ain Shams Univ., awarded in 1994)

3- A Study of The Physical Properties of Sprayed CdS Thin Films.(Ph.D., Faculty of Girls, Ain Shams Univ.,awarded in 1997

4- Study of Some Physical Properties for Zinc Sulfide Thin Films Prepared by Spray Pyrolysis.(M.Sc. , Faculty of Girls, Ain Shams Univ., awarded in 1997)

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WORKSHOP ON " PV APPLICATIONS"
27-29 MAY 2002, CAIRO, EGYPT – SPONSORED BY: ICS-UNIDO, ITALY
AND PHOTOENERGY CENTRE OF AIN SHAMS UNIVERSITY

PV SOLAR ENERGY SYSTEMS :
COUNTRY STATUS, ECONOMICS AND TECHNICAL ASPECTS

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ABSTRACT :
This paper will cover the following items :
- PV world market .
- Economics of PV installations .
- Some technical aspects (typical applications, sizing PV system, ...).
- Current PV solar energy status in Egypt .

1. PV WORLD MARKET:

Production of solar cells and modules has been growing steadily throughout the 1990's. The most significant increases have been in the grid – connected applications, particularly PVs in buildings. This market sector is gaining government assistance in a number of industrial countries, notably Japan, Germany, Switzerland, the Netherlands and USA .

Several government programmes that drive increase are : the USA one million solar roofs initiative, the Japanese 70000 roofs programme and German 100000 roof programmes which are intended to provide the necessary volume for price reduction.

The other grid-connected sector, central power stations, is more sensitive to the installed system price. In the present circumstances of low oil and gas prices, substantial growth in this sector is not expected until considerable reduction of PV price.

PV systems are now economical – compared to diesel generators- for powers less than 5 KW. Typical applications include water pumping, medical refrigeration, water purification and small village electrification .

PV modules have proven to be the most reliable power source for remote applications – particularly communications – throughout the world. This market is growing at a rate of 20-30% a year. Crystalline silicon solar cells will continue to serve this important sector due to its proven reliability. This sector is not much affected by world energy prices or policy, and thus PV will continue to serve it as the most effective energy source.

The PV world market in 2001 is about 275 MWp and it is expected to be about 550 MWp by 2005.

PV module shippments (MWp) cover the following : PV power stations, distributed grid- connected systems , PV- diesel hybrids, professional applications (telecomunication systems, remote monitoring and control, signalling for railways and ocean navigation aids, cathodic protection of remote pipe lines or bridges,...), stand alone : rural & domestic, consumer products (calculators , watches, ...) .

Rural electrification is needed as an optimum option for billions of people throughout the world. However, there is a major barrier to growth of this sector which is the fact that these people have little or no money and the cost of PV systems is capital intensive . In order to serve this vast market, in – country manufacturing is required to reduce cost of PV systems .

1.1. Principal Market Drivers for PV :

The principal market adrivers for solar energy and other RETs include :

- Growth in electricity demand : world energy consumption is expected to grow by 54% from 1995 levels by the year 2015. Electricity demand growth rates of 4 – 5% are common in countries of Asia , Ltin America and Africa .
- Liberalisation of the energy markets : there is a world – wide trend towards energy liberalisation opening the market for private investment in power generation.
- Rural electrification : An estimated 2 billion people world – wide still have no access to electricity. PV provides the most economic solution.

1.2. Price competition

PV systems are not yet the economically preferred sources of power for the much larger grid – connected market, because the electricity market and infrastructure are mature and well developed besides the fact that nonrenewable energy sources are heavily subsidized. It is expected that technology improvments and economics of manufacturing scale will permit unsubsidized PV systems to compete with traditional electricity serivce within next years.

In developing countries, if appropriate financing mechanism is available, the barrier to wide PV systems usage can be largely overcome.

2. ECONOMICS OF PV INSTALLATIONS

It is necessary to calculate the economic value of a PV system so that it can be compared with other methods of power generation (for example, diesel, extending the grid, ... Etc). At present, PV is most competitive where small amounts of energy are required far from the grid.

The economics of PV systems – compared to that of other small power systems – is characterised by :

- Capital cost on equipment is high
- No fuel cost.
- Low maintenance cost.
- Hgih reliability and so low replacment cost.

- Output energy of system depends on lcoation
- Social and environmental benefits.

There are two ways of looking at the value of an electricity generating system:

- The economic approach : is expresses the standpoint of the government which considers its value to the economy as a whole. It therefore looks at costs which exclude taxes and subsidies.
- The financial assessment : it is an evaluation from the buyer's point of view, and therefore taxes, subsidies, interest rate on loans, ... etc., must be taken into account.

In an economic evaluation, life – cycle costing (LCC) is the usual method for determining whether an application is economic or not.

2.1. Life – Cycle Costing (LCC):

In this method, the initial costs and all future costs during the operational life of the PV system are considered. The calculation of LCC requires to know values of the following items :

- Period of analysis (lifetime of longest – lived system under comparison).
- Capital cost (total initial cost of equipment and installing the system).
- Operation and maintenance cost each year.
- Fuel costs (annual fuel cost).
- Replacement cost (cost of replacing each component at the end of its life time).
- Inflation rate (i). The rate of price increase of a component above or belwo general inflation.
- Discount, rate (d) : the rate at which money would increase in vlaue if invested (Typically 8 – 12%).

To make a correct comparison, all future costs (replacement cost, annual payments,....) have to be discounted to their equivalent value (PW or present worth) at time of calcualtion.

- For a single payment : for a single future cost Cr, payable in N years, its present worth is :
  PW = Cr . Pr
  Pr.. is discount factor (from tables : Pr = f(d, i , N))
- For annual payment : for a payment Ca occuring annually for N years :
  PW = Ca . Pa
  Pa..... is comulative discount factor (from tables : Pa = f (d, i, N)).
  The total LCC of a system is the sum of all PW of its items.
- Annulaised life – cycle cost (ALCC) : is the system cost per year, given by
  ALCC = LCC / Pa
- Unit Electricity cost (UEC): This is the most important figure for comparing two systems. The net cost of generating each KWh during the lifetime of each system is given by :
  UEC ($ / KWh) = ALCC ($/ year) / Electricity supplied (KWh/ Year).

2.2. Sizing of PV Systems :

The sizing calculation determines the size of solar array and battery capacity for a specific application and it allows to specify characteristics of electronic component. Sizing of a PV system, especially a stand – alone one, is an important part of its diesign. Oversizing increases the price of generated energy and undersizing a stand – alone system reduces supply reliability.

Sizing of a system requires knowledge of :

- Solar radiation data of site (average KWh/m2 day)
- Load profile.
- Importance of supply continuity

Solar radition data is usually given in form of global daily radiation on a horizontal surface at the site. Since PV panels are usually positioned at a tilt angle to horizontal plane, the energy input to the system must be calculated from the data.

The load data give information about appliances and equipment to be powered : number, nominal power, nominal operating voltage and number of hours of operation per day.

Whe reliability of supply is important the array sizing factor should be chosen sufficiently large so that array can supply enough energy during worst conditions.

3. PV APPLICATIONS AND CURRENT SITUATION IN EGYPT

Egypt is a high insolation country where sunshine duration is almost 3300 hours/ year with an average daily solar irradiation of 6-7 KWh/m^2.

3.1. PV Applications in Egypt :

The total installed capacity-not grid connected-is estimated to be about 2 MWp for:

- R & D and demonstration :

  Water pumping – villages electrification – Refrigeration – Desalination.
- Commercial applications :

  Telecommunication – Billboards lighting – Borders guard – Home and camping.

  It is expected to have large future needs of underground water pumping for reclamation of desert land in the south western part of Egypt. If 1000 acres are to be cultivated yearly, the demand for PV solar energy is about 0.5 MWp/year using modern irrigation systems.

3.2. PV Industry :

- There is no PV wafer or cell manufacturing facility in Egypt.
- There exist three companies in the Egyptian PV market, each having capacity of 300 – 500 KWp/year. Two companies import cells and do encapsulation and module assembly. The Third one is marketing complete systems. Local manufacturing of cells can reduce cost of PV solar system by about 25-30%.

Appendix :

- Tables for values of Pr and Pa
- LCC calculation example
- LCC comparison : PV versus diesel generator.
- Unit electricity cost against load : comparison of PV, diesel and grid extension.

Table . 1. Selected values of present worth factor Pr for a cost in *N* years time

Discount Rate (*d*)	Inflation Rate (*i*)	Factor Pr for given number of years				
		5	10	15	20	30
0.00	0.00	1.00	1.00	1.00	1.00	1.00
	0.05	1.28	1.63	2.08	2.65	4.32
	0.10	1.61	2.59	4.18	6.73	17.45
	0.15	2.01	4.05	8.14	16.37	66.21
	0.20	2.49	6.19	15.41	38.34	237.38
0.05	0.00	0.78	0.61	0.48	0.38	0.23
	0.05	1.00	1.00	1.00	1.00	1.00
	0.10	1.26	1.59	2.01	2.54	4.04
	0.15	1.58	2.48	3.91	6.17	15.32
	0.20	1.95	3.80	7.41	14.45	54.92
0.10	0.00	0.62	0.39	0.24	0.15	0.06
	0.05	0.79	0.63	0.50	0.39	0.25
	0.10	1.00	1.00	1.00	1.00	1.00
	0.15	1.25	1.56	1.95	2.43	3.79
	0.20	1.55	2.39	3.69	5.70	13.60
0.15	0.00	0.50	0.25	0.12	0.06	0.02
	0.05	0.63	0.40	0.26	0.16	0.07
	0.10	0.80	0.64	0.51	0.41	0.26
	0.15	1.00	1.00	1.00	1.00	1.00
	0.20	1.24	1.53	1.89	2.34	3.59
0.20	0.00	0.40	0.16	0.06	0.03	0.00
	0.05	0.51	0.26	0.13	0.07	0.02
	0.10	0.65	0.42	0.27	0.18	0.07
	0.15	0.81	0.65	0.53	0.43	0.28
	0.20	1.00	1.00	1.00	1.00	1.00

Table . 2. Selected values of present worth factors Pa for an annually recurring cost

Discount Rate (*d*)	Inflation Rate (*i*)	Factor Pa for given number of years				
		5	10	15	20	30
0.00	0.00	5.00	10.00	15.00	20.00	30.00
	0.05	5.80	13.21	22.66	34.72	69.76
	0.10	6.72	17.53	34.95	63.00	180.94
	0.15	7.75	23.35	54.72	117.81	499.96
	0.20	8.93	31.15	86.44	224.03	1418.26
0.05	0.00	4.33	7.72	10.38	12.46	15.37
	0.05	5.00	10.00	15.00	20.00	30.00
	0.10	5.76	13.03	22.21	33.78	66.82
	0.15	6.62	17.06	33.51	59.44	164.68
	0.20	7.60	22.41	51.29	107.59	431.39
0.10	0.00	3.79	6.14	7.61	8.51	9.43
	0.05	4.36	7.81	10.55	12.72	15.80
	0.10	5.00	10.00	15.00	20.00	30.00
	0.15	5.72	12.87	21.80	32.95	64.27
	0.20	6.54	16.65	32.26	56.38	151.24
0.15	0.00	3.35	5.02	5.85	6.26	6.57
	0.05	3.84	6.27	7.82	8.80	9.81
	0.10	4.38	7.90	10.71	12.96	16.20
	0.15	5.00	10.00	15.00	20.00	30.00
	0.20	5.69	12.73	21.44	32.22	62.04
0.20	0.00	2.99	4.19	4.68	4.87	4.98
	0.05	3.41	5.16	6.06	6.52	6.87
	0.10	3.88	6.39	8.02	9.07	10.19
	0.15	4.41	7.97	10.85	13.18	16.58
	0.20	5.00	10.00	15.00	20.00	30.00

Table .3. Life-cycle costing calculation sheet

System description: *250 W Stand-alone domestic PV supply*

Parameters

Period of Analysis = *20 years* Excess Inflation $i = 0$ Discount Rate $d = 10\%$

Capital Cost

Hardware:	$ .... 1900 ....
Installation:	$ .... 400 ....
Total:	$ 2300

Operation and Maintenance:

Annual Cost	$ .... 50 .... per year
Discount Factor (Pa)	$ .... 8.51 ....
Present Worth:	$ 425

Fuel

Annual Fuel Costs:	$ .... Nil .... per year
Discount Factor (Pa):	....
Present Worth:	$ Nil

Replacements

Item	*Year*	*Cost*	*Pr*	*PW*
Battery	5	$500	0.62	$310
Battery	10	$500	0.39	$195
Battery	15	$500	0.24	$120
			Total	$ 625

Total Life-cycle Cost	$ 3350
Annualisation Factor (Pa)	...... 8.51 ......
Annualised Life-cycle Costs	$ 394 per year

Table . 4. Life-cycle costing comparison: PV vs diesel generating systems

Period of analysis	20.00	years
Discount Rate	10.00	%
Annualisation Factor	8.51	

PV Calculation

			Lifetime
Load	2.00	kWh/day	
Battery Efficiency	70.00	%	
Demand at Array	2.86	kWh/day	
Days of Battery Storage	5.00	days	
Design Insolation	5.50	kWh/m^2 day	
Array Mismatch Factor	0.90		
Module Price	4.50	S/W_p	
Battery Price	100.00	S/kWh	
Array Size	577	W_p	
Battery Size	10.00	kWh	
Array Cost	2597.40	S	20 yrs
Battery Cost	1000.00	S	5 yrs
Support/Wiring	866	S	20 yrs
Power Control	50.00	S	10 yrs
Capital Cost	4513.20	S	
Installation	902.64	S	
Total Installed Cost	5415.84	S	
O&M Costs	108.32	S/yr	
Life-cycle O&M	922.16	S	
Recurring Costs			
Array	0.00	S	
Battery	1245.86	S	
Support Wiring	0.00	S	
Power Control	19.28	S	
Total Replacements	1265.13	S	
Life-cycle Cost	7603.14	S	
Annualised LCC	893.06	S	
Unit Electricity Cost	1.22	S/kW	

Diesel Calculation

Using 5 KVA Low Speed Diesel Engine

			Lifetime
Load	2.00	kWh/day	
Generator	3000.00	S	20 yrs
Installation	600.00	S	
Installed Capital Cost	3600.00	S	
O&M Costs	360.00	S	
Life-cycle O&M	3064.88	S	
Diesel Price	0.26	S/litre	
Engine Efficiency	25.00	%	
Diesel Consumption	11.00	kWh/litre	
Diesel Usage	0.73	litres/day	
Diesel Cost	69.02	S/year	
Life-cycle Fuel Cost	587.59	S	
Replacement Costs			
Generator	0.00	S	
Total Life-cycle Cost	7252.47	S	
Annualised LCC	851.87	S	
Unit Electricity Cost	1.17	S	

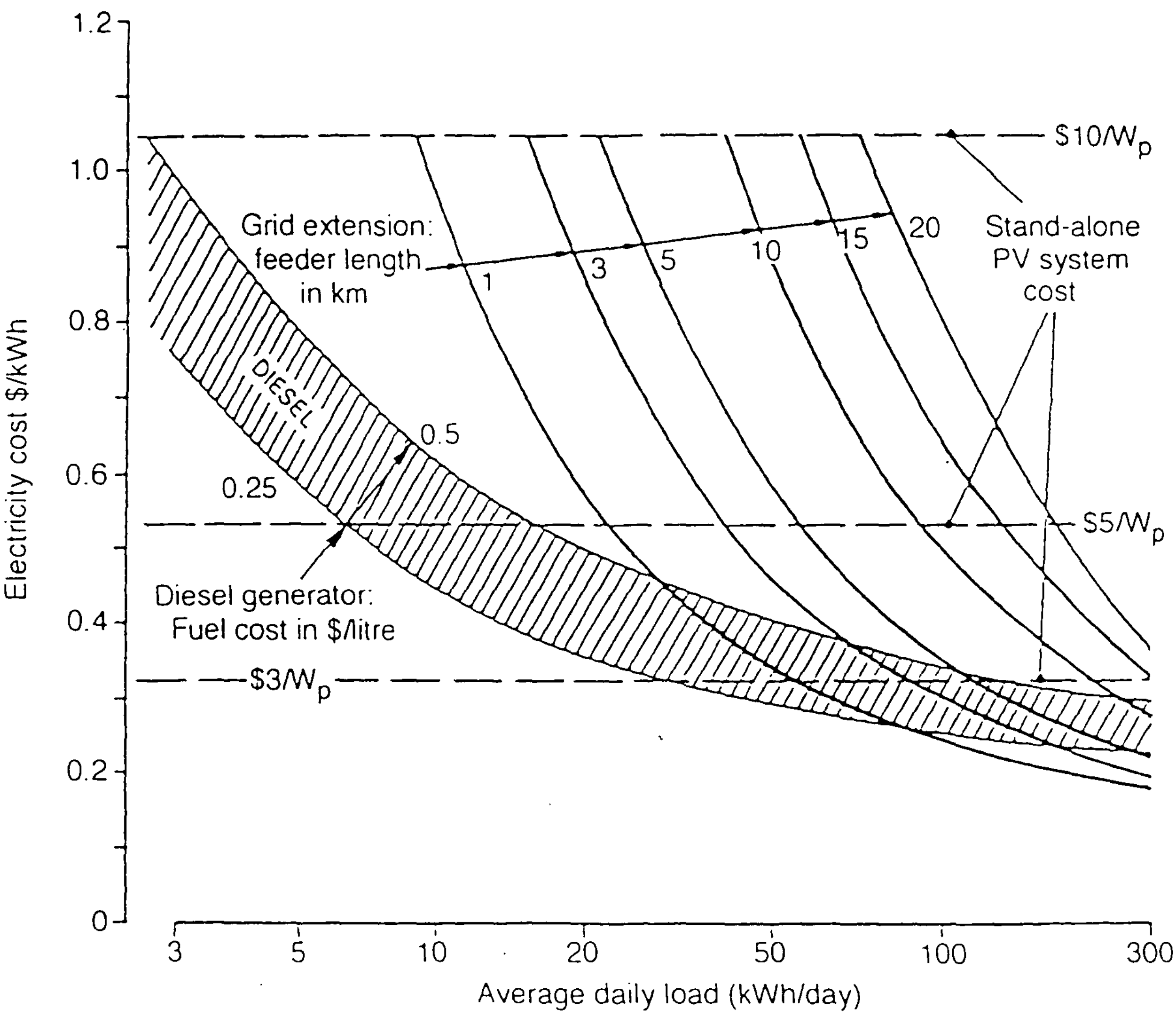

Fig. 1. Unit electricity cost against load. Comparison of PV, diesel and grid extension

PV – Application In Egypt

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Cairo 2002

PV Activities in Egypt
Status & Prospects

Eng. Hassan Hassaballa Rakha
General Manager PV Dept. NREA

1- Abstract

This paper presents the extensive experience of PV applications in Egypt, which are carried out, in parts by the New & Renewable Energy Authority (NREA) and the benefits of renewable energy. It also covers the future prospects of PV applications for sustainable development of rural and isolated areas, and the constrains limiting the spread use of such technology in Egypt.

2- Introduction

Egypt is located in the world's solar belt and has an excellent solar availability. The annual average global solar radiation over Egypt ranges from about 1950 kWh/m2/year on the Mediterranean coast to a more than 2600 kWh/m2/year in upper Egypt. While about 90 % of the Egyptian territory has an average global radiation greater than 2200 kWh/m2/year.

In 1986, the New and Renewable Energy Authority NREA was established in order to carry out the role of the introduction, dissemination, utilization and development of Renewable Energy RE application in Egypt. Energy was considered as an integral part of the national energy planning that targets to cover 3 % of the electric energy demand from renewable resources by the year 2010.

Egypt has got an ambitious plan for village electrification. More than 98 % of the village were electrified from the utility grid. From the rest of the unelectrified villages there are few hundreds of small remote rural communities that was found to best fit for photovoltaic PV solar electrification. Those villages are characterized by low power demand, constant load, dispersed nature of houses, beyond the economical extension of the utility and are not included in the future plan for electrification from the national grid.

Also PV pumping systems and PV solar home are needed for the private sector in the new reclaimed lands and remote areas, but the main difficulty now is the high initial costs of these systems.

3- Benefits of Renewable Energy

- Enhance diversity in energy supply markets, thereby strengthening energy security.
- Represent secure, long-term, environmentally sustainable energy supplies.
- Make a major contribution to the global and reduction of atmospheric emissions.
- Provide commercially attractive options to meet specific user.
- Create significant regional employment opportunities in energy infrastructure manufacturing, installation and maintenance.
- Offer low operating costs and opportunity to manufacture much of the equipment locally.
- Renewable energy can not be exhausted.

4- PREVIOUS EXPERIENCE I N THE FIELD OF PV SOLAR ENERGY FOR RURAL ELECTRIFICATION

Photovoltaic power utilization has been addressed within the Egyptian Ministry of Electricity and Energy MEE as early as 1979. Most of the known PV applications such as water pumping, desalination, clinical refrigerator, ice making plant, village electrification, bill boards etc have been demonstrated and field tested in Egypt. Some commercial PV applications such as telecommunication, navigation aids and billboards are now self-sustainable in Egypt.

Currently, the various PV powered projects are accounted to beyond 2 MWp spread over different parts of Egypt. Contributors in these projects are the national, international institutions and private sector.

5- NREA ACCOMPLISHMENT IN THE FILD OF PHOTOVOLTAIC PROJECTS

NREA has accomplished considerable achievements in introducing PV to the Egyptian Context for various applications starting from pilot projects to field - testing and demonstration through commercialization. The most significant projects are follows :

Water Pumping

- 14 kW_p PV pumping system at Wadi El-Natroun with water production in the range of 80 - 100 m3lday.
- 2.2 kW_p PV portable unit with water production in the range of 20 - 30 m3lday.
- 1.7 kW_p PV pumping unit at Mansoreia Village.

Desalination

- 7 kW_p PV pumping and RO water desalination plant for producing 5 - 7 m^{3}/day of fresh water at High Voltage Research Center I EEA.
- 18.5 kW_p PV desalination RO plant at El-Hamrawein on the Red Sea with a productivity of 60 m3lday.
- 8 kW_p PV I Diesel - powered RO water desalination unit for producing 5 m^3lday of potable water at Abou-Ghosoon on the Red Sea Cost.

Village Electrification

- 28 kW_p PV pilot project for electrification of remote village has been implemented for :
  - Household Lighting.
  - Street Lights.
  - Pumping Units.

Refrigeration

- Installation of a 38 kW PV/Diesel/Battery hybrid power system powered Ice-Making Plant to produce 6 tons per day of flake ice for fish preservation at remote desert lake in Wadi El-Raiyan, El-Fayoum.
- 10 PV-Power Refrigerators for vaccine storage were installed in rural health care facilities.
- 1.2 kW_p refrigerator for keeping medicine in health unit equipment at Mit Abou El-Kom Village.

Communication

- 8 PV powered emergency communication systems.

Signaling & Warning

- A naval warning system placed on Lake Nasser.

Others

- A number of PV - Powered colour television sets.
- A loudspeaker system at Mit Abou El-Kom Mosque.
- Lighting some offices for the organization for Energy Conservation and Planning OECP.

Concultancy Services

- Prepare tender document for PV powered obstruction lighting units with battery storage for High Voltage Transmission Lines (Towers) for Egyptian Electricity Authority EEA.
- Introducing the technical consultancy for acceptance and operation tests and preliminary hand over for Ein El-Skhona Tall Station and Suez Balance with 30 kW_p PV power system for lighting.

6- PV Prospects

PV Solar Electricity to serve rural / isolated areas

Energy has a vital role to play in meeting the basic needs of rural population and improving the standard of living. Increased and improved energy supplies can increase food production, water supply, Health care, Education and communication. It can also support industrial activity in rural areas, providing local employment, reduce migration to urban areas.
Egypt in its national strategy plan is aiming for the development of new communities, remote villages and desert areas.

6.1 Off-grid Remote Communities and Village PV Electrification

Inspite of the ambitious on going Egyptian rural electrification plans through grid extension which covers more than 98 % of the rural villages, there will be still some remote isolated small communities and settlements that are far from the electric grid and consequently will not be attached to it.

More than a hundred of small remote isolated communities which are characterized by poor inhabitants were found to best fit the PV electrification and are not included in the future plan for electrification from the national grid. The structure of those communities in many cases includes 20 house each, 8 persons per family, low power demand (700-800 Wh/day), constant load, and dispersed nature of houses and far from the utility grid. Consequently individual PV household's kit capable of supplying around 700 Wh/day could be an appropriate solution.

The Egyptian government has decided lately to electrify a number of 33 remote villages as a first stage in Sinai using PV power systems. Five **remote communities have** been choosen in south Sinai to be electrified by PV power as a 1st phase. Those five communities will be assessed in terms of the technical reliability and social impact and will feedback the next phases.

First Phase Project Profile

No of houses to be electrified	143
No of public buildings	4
Estimated load energy per house	800 Wh/day

6.2 PV Electricity Supply for Pumping System for Land Reclamation Projects

Currently the government of Egypt is placing high priority on developing New Desert areas in order to decrease the overpopulation around the Nile Valley and Delta creating new societies, new job opportunities, new investment as well as raising the standard of living.

The Egyptian plan of new land reclamation projects considered the use of ground water as a potential supply of irrigation. High level of solar radiation and availability of under ground water characterize the Egyptian desert areas. All those feature encourage the use of renewable energy, which is inexhaustible, clean energy and suitable for use rural areas which are far from the utility grid and difficult sites for the diesel operation.

In regard to the diesel gensets, the disadvantages of the diesel generator set are multiplied; costs of fuel and repairs time required for management of the supply of fuel, breakdowns and of start & stop, operation, a relatively short life time, fume, the disturbances resulting from fumes, noise and vibration.

The Egyptian national plans for new land reclamation include; development of 3.4 million feddans in Toshki, 12.000 feddans at Darb EL Arbean and planting 200.000 feddans in East Oweinat in 10 years time by digging 1500 – 1600 water wells. The estimated power requires for East Oweinat 200 MW for water pumping and water distribution network, small industries for agriculture product and lighting. The existing water wells are 217 and they use diesel generators.

The characteristics of the existing wells at East Oweinate are :

Static Head	: 25 – 30	m
Well Depth	: 250 – 300	m
Well Discharge	: 200 – 250	m^3 / hr.
Diesel Operation	: 16 hr/day	

7- PV Cost Reduction

- New material.
- Higher module efficiency.
- Improved manufacturing technology.
- Mass productions.
- Design quality.

8- PV Barriers

- Relatively higher unit cost of systems.
- Low income levels of rural dwellers.
- Lack of people awareness.
- Lack of coordination of the key players.
- Lack of incentive for market stimulation.
- Lack of local manufacturing capabilities to minimize system cost.
- Lack of setting of rural energy within national plans.

9- Recommendation / PV market development

To make PV a significant energy option for rural / isolated areas progress is needed to reduce costs, increase awareness faster market deployment by removing technical and non – technical barriers.

10- Action needed

The role of the governments:

- Incentives and subsidies (micro – finance schemes) should applied to stimulate demand.
- Given high priorities in the national plan for using PV solar home systems in the rural areas with small loans instead of extending the national grid.
- Holding seminar / workshops on rural energy to encourage the market.
- Encourage the private sector to participate in rural energy.
- Eliminate the taxes on the imported equipment.

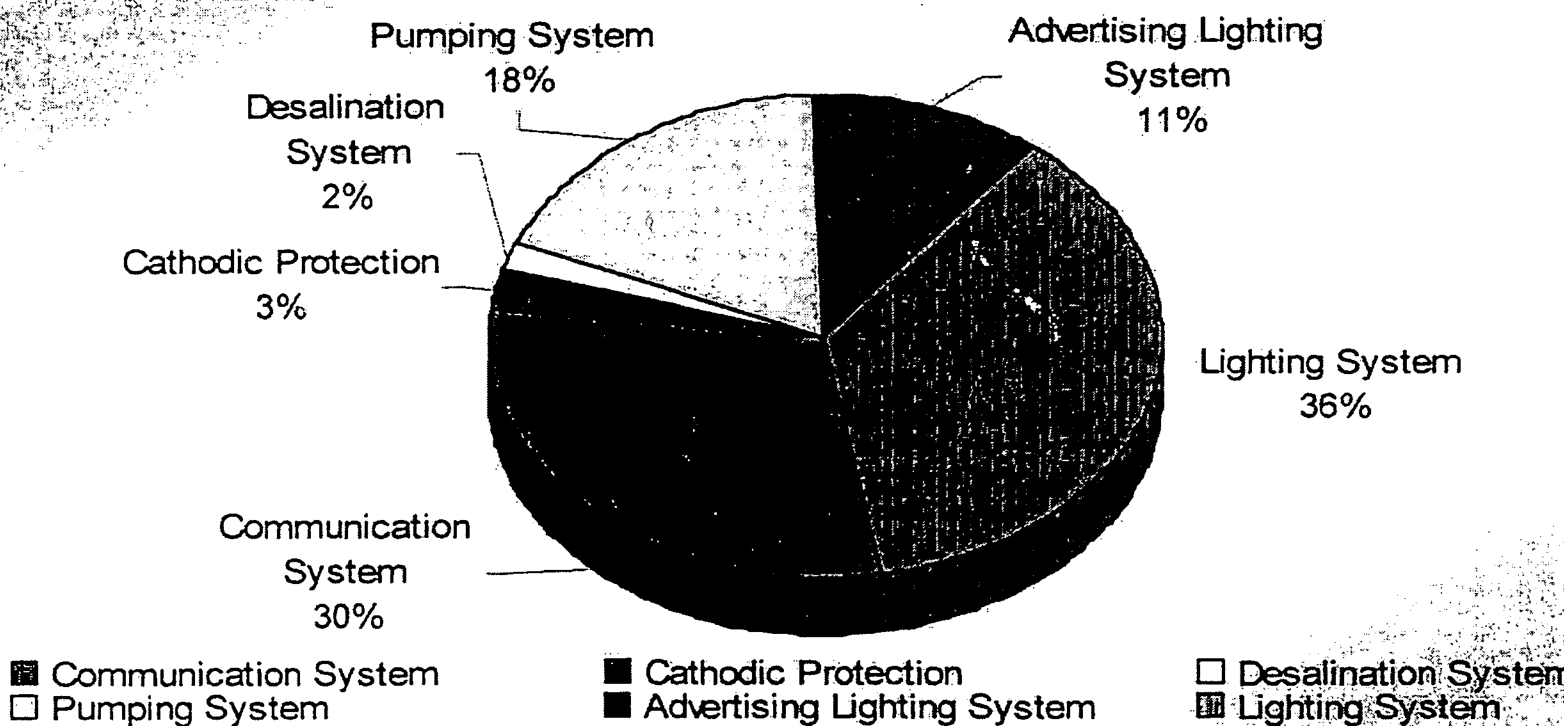
10-1 Technical issues

- Improving productivity and manufacturers of PV to make it more affordable.
- Train local people in technology application and operation.
- Link agriculture and cottage industries to rural energy development.

10-2 Financing agencies

- Adequate funding of GEF and ODA (official development assistance).
- Adequate funding of CDM (clean development mechanism) of Kyoto protocol to the UN framework convention on climate change.
- Leverage new World Bank Village Power Program.

Partitioning by PV Application in Egypt (2000 kw_p)



Ministry of High Education
High Institute of Energy (Aswan)

GROUND WATER PUMPING USING A PV POWERED SYSTEM IN COMPARISON WITH A DIESEL POWERED SYSTEM IN EAST OWINAT AREA

BY

Houssein El-Nazer Abdin

Abstract

Egypt is considered one of the most powerful countries in the Middle East area. There are many strategic and economic projects in Egypt. One of these is East Owinat development project. The area is located in the south west of Egypt.

Referring to geological information, there is the Great Nubian Aquifer with a great amount of water, which can be used in agriculture and consequently industrial and social activities. This means a new society is being established to get out of the crowded River Nile Valley .

As we know, energy is the backbone of the life. Our traditional sources of energy, like hydropower stations, oil, natural gas and coal, are very limited and not enough for the development plane of Egypt.

The East Owinat area is far from the national electric grid. Other sources of energy such as diesel engines are used in ground water pumping for irrigation and other daily uses. These engines are insufficient as well as they cause environmental pollution

For the long run, replacement of the diesel units is very expensive.

Our study is based on the replacement of a diesel engine by a solar PV system for ground water pumping, which is clean, available all time; cheap and does not need significant repair and maintenance

Refer to the geological data, geophysical information we found that the solar energy is very efficient to be used in ground water pumping. The static water head is ranging from 5 meters to more than 120 meters.

As a result of this thesis, it is found that using PV powered system is more efficient and economic than using diesel powered system for ground water pumping, especially at remote areas such as East Owinat, taking into consideration the long life time (20,25,30 years) of the PV modules.

The water cost is strongly affected by the decrease of the PV systems prices, so it is recommended to start manufacturing PV cells and modules locally.

Introduction

In the past (1978-1988) researches , studies were prepared by governmental organizations to evaluate the water resources , lands and resources of different natural wealth in the area. These studies had two stages; the first stage included

1. Area reconnaissance and investigation studies
2. Hydro – Geophysical studies
3. Drilling 21 wells of depth from 22 to 140 meters
4. Ground water pumping test
5. Data recording of environment and weather of this area.

The second stage in which the ground water resources of the Nubian Aquifer, water flow directions, information about the land and weather studies were evaluated. The following tasks were done: -

1. Drilling of wells (8 groups of wells).
2. Ground water pumping tests, it was found that the water is very suitable for Irrigation and drinking.
3. Soil, physical and chemical studies.

Experimental farm to cultivate maize, wheat, oranges, lemon, vegetables and fruit

The analysis and studies of area gave guid to use the solar energy for ground water pumping which will be more efficient than diesel engine.

Characteristics of the selected erea

Its position is latitude: 22° to 24° N, longtitude: 28° to 30° E

The average monthly solar insolation is presented, The main characteristics of the region are summerized in the follwing

1. The area is an open aquifer, so ground water pumps have to be used to get the water.

(5 : 120) meters

2. Static water head is ranging from 28 to 65 meters, it reaches 140 meters in some places.
3. The water is suitable for irrigation, drinking and industrial use.

Procedure

Annual levelized cost using sink fund method .

$$C_L = P_s * F_L$$

$$C_L = P_s * \frac{d(1+d)^n}{(1+d)^n - 1}$$

C_L Annual levelized cost

P_s initial capital cost

F_L levelized cost factor

d discount rate or interest rate

n expected life time in years

Levelized cost factor F_L

Discount	Factor F_L for given numbers of years					
Rate(d)	**5**	**10**	**15**	**20**	**25**	**30**
0.05	**0.231**	**0.1295**	**0.0963**	**0.0802**	**0.0709**	**0.0650**
0.10	**0.264**	**0.163**	**0.131**	**0.117**	**0.110**	**0.106**
0.15	**0.298**	**0.199**	**0.171**	**0.159**	**0.154**	**0.152**
0.20	**0.334**	**0.238**	**0.214**	**0.205**	**0.202**	**0.201**

Calculation of present worth:

For single future payment: for a single payment Ps ($) to be made in the future, the present worth, PW, is calculated by multiplying the payment Ps by a factor Fs, found from table , Fs is defined by the discount ~~rate~~ Factor, the commodity – specific interest rate (relative to general inflation), and the number of years in the future that the payment is to be made,

$$PW = Ps x Fs$$

The formula used to calculate these factors, Fs is:

$$Fs = [(1+i)/(1+d)]^n$$

Where:

Fs factor for given numbers of years

i inflation rate

d discount rate

Calculation of discount factor for a single future payment

Discount Rate(d)	Inflation Rate(i)	Factor Fs for given numbers of years					
		5	10	15	20	25	30
0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
	0.05	1.28	1.63	2.08	2.65	3.48	4.32
	0.10	1.61	2.59	4.18	6.73	10.83	17.45
	0.15	2.01	4.05	8.14	16.37	32.9	66.21
	0.20	2.49	6.19	15.41	38.34	95.39	237.38
0.05	0.00	0.78	0.61	0.48	0.38	0.295	0.23
	0.05	1.00	1.00	1.00	1.00	1.00	1.00
	0.10	1.26	1.59	2.01	2.54	3.20	4.04
	0.15	1.58	2.48	3.91	6.17	9.72	15.32
	0.20	1.95	3.80	7.41	14.45	28.17	54.92
0.10	0.00	0.62	0.39	0.24	0.15	0.92	0.06
	0.05	0.79	0.63	0.50	0.39	0.32	0.25
	0.10	1.00	1.00	1.00	1.00	1.00	1.00
	0.15	1.25	1.56	1.95	2.43	3.04	3.79
	0.20	1.55	2.39	3.69	5.70	8.80	13.60
0.15	0.00	0.50	0.25	0.12	0.06	0.03	0.02
	0.05	0.63	0.40	0.26	0.16	0.102	0.07
	0.10	0.80	0.64	0.51	0.41	0.329	0.26
	0.15	1.00	1.00	1.00	1.00	1.00	1.00
	0.20	1.24	1.53	1.89	2.34	2.897	3.59
0.20	0.00	0.40	0.16	0.06	0.03	0.01	0.00
	0.05	0.51	0.26	0.13	0.07	0.04	0.02
	0.10	0.65	0.42	0.27	0.18	0.113	0.07
	0.15	0.81	0.65	0.53	0.43	0.345	0.28
	0.20	1.00	1.00	1.00	1.00	1.00	1.00

For a recurring annual payment:

: for a payment of Pa occurring annually over a number of years, the net present worth is found by multiplying the annual payment Pa by a factor Fa , from Table according to the discount rate, the commodity – specific interest rate (relative to the general inflation rate) and the number of years for which the payment is to be made.

$$PW = Pa * Fa$$

The actual formula used to calculate these cumulative discount factors, Fa, is

$$Fa = \left[\frac{(1+i)}{(1+d)}\right] \frac{\left(\left[\frac{(1+i)}{(1+d)}\right]^{n} - 1\right)}{\left[\frac{(1+i)}{(1+d)}\right] - 1}$$

Where i is the rate of inflation.

d is the discount rate.

n is the number of years from the present.

Calculation of cumulative discount factor for an annual payment

Discount Rate(d)	Inflation Rate(i)	Factor Fa for given numbers of years					
		5	10	15	20	25	30
0.00	0.00	5.00	10.00	15.00	20.00	25.00	30.00
	0.05	5.80	13.21	22.66	34.72	50.11	69.76
	0.10	6.72	17.53	34.95	63.00	108.18	180.94
	0.15	7.75	23.35	54.72	117.81	244.71	499.96
	0.20	8.93	31.15	86.44	224.03	566.37	1418.26
0.05	0.00	4.33	7.72	10.38	12.46	13.38	15.37
	0.05	5.00	10.00	15.00	20.00	25.00	30.00
	0.10	5.76	13.03	22.21	33.78	48.46	66.82
	0.15	6.62	17.06	33.51	59.44	100.29	164.68
	0.20	7.60	22.41	51.29	107.59	189.19	431.39
0.10	0.00	3.79	6.14	7.61	8.51	9.07	9.43
	0.05	4.36	7.81	10.55	12.72	14.34	15.80
	0.10	5.00	10.00	15.00	20.00	25.00	30.00
	0.15	5.72	12.87	21.80	32.95	46.88	64.27
	0.20	6.54	16.65	32.26	56.38	93.65	151.24
0.15	0.00	3.35	5.02	5.85	6.26	6.46	6.57
	0.05	3.84	6.27	7.82	8.80	9.32	9.81
	0.10	4.38	7.90	10.71	12.96	14.57	16.20
	0.15	5.00	10.00	15.00	20.00	25.00	30.00
	0.20	5.69	12.73	21.44	32.22	43.73	62.04
0.20	0.00	2.99	4.19	4.68	4.87	4.94	4.98
	0.05	3.41	5.16	6.06	6.52	6.75	6.87
	0.10	3.88	6.39	8.02	9.07	9.75	10.19
	0.15	4.41	7.97	10.85	13.18	15.06	16.58
	0.20	5.00	10.00	15.00	20.00	25.00	30.00

Step by step procedure for life cycle cost :

To perform a ful life-cycle costing of solar and diesel powered pumping system. We should follow simple steps as follows: -

Step 1	**Calculate hydraulic energy requirements**
Step 2	**Determine design month conditions**
Step 3	**Size power source and pump**
Step 4	**Calculate capital costs**
Step 5	**Calculate recurrent costs**
Step 6	**Calculate life-cycle costs**

For the next steps the following data are required : -

Economic data

- Period of analysis .
- Discount rate.
- Inflation rate.

Cost for each component

- Capital costs.
- Annual maintenance cost.
- Fuel , labor cost.

Technical data

- Life time for each component.

Capital costs

Recurrent costs

Replacement costs

Maintenance and repair costs

Operation costs

Life-Cycle Costs

Annualized Life – Cycle Cost

Unit water costs

Finally we can convert the annualized life – cycle cost (or LCC) to unit water cost. This tells us the true cost of the water provided in terms of $ / m^3

Practical cost appraisal :

For each pumping system on which we are going to perform a life – cycle cost analysis, we need to identify all the initial and future costs. These can be generally divided into the following six categories, each of which is discussed in more detail as follows:-

1. Initial capital cost.
2. Installation.
3. Operation and maintenance over all life time.
4. Fuel (only for diesels) over whole life time.
5. Replacement of components during life time.
6. Additional income from extra crops in irrigation case.

Cost appraisal of water pumping:

General procedure

To perform a life – cycle cost comparison we must, sum the contributions from the items in the following list:

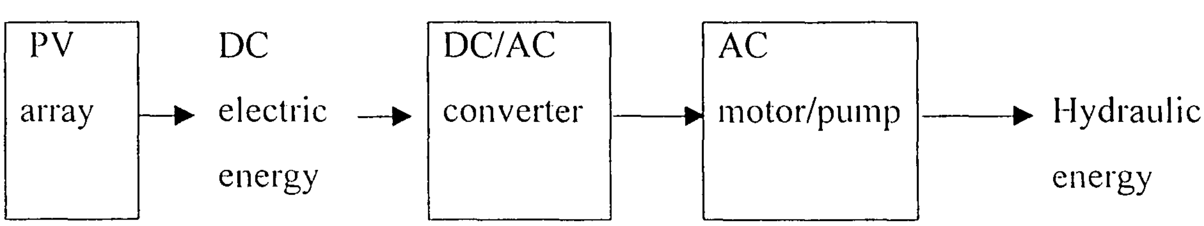
- Initial capital cost.
- Installation.

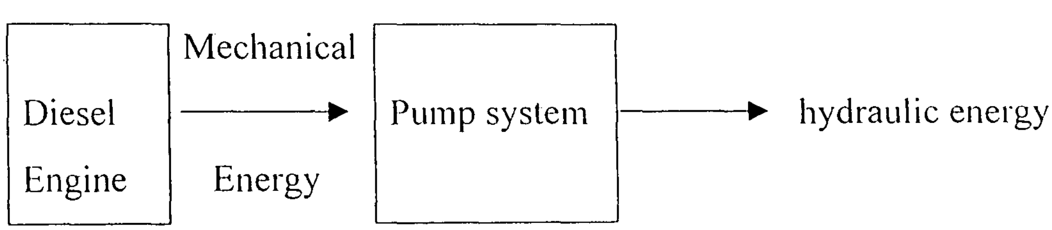
- Operation and maintenance over all life time.
- Fuel (only for diesels) over whole lifetime.
- Replacement of components during life time.

Other items:

Component	Price	Estimated lifetime
Array	1.5 – 5 $ / Wp	System life (20 years)
Support structure (add 4 $ / Wp for tracking array support)	1 – 2 $ / Wp	System life (20 years)
Pipe work / storage		System life (20 years)
Inverter	$1000-$ 20000	10 years
Simple power control	$ 450	10 years
Batteries (if any)	See note below	5 years

The following block diagrams present both the PV powered system & the diesel powered system used in the calculations





Site characteristics:

Site location

the selected area has: -
22° 15′: 23° 30′ latitude-north

27° 30′: 28° 15′ longitude-east

Average temperature is 25 °C.

Solar radiation

solar parameters of the site all over the year.

Table 5.1 Solar radiation

Month At Φ =23°	G_o		G kWh/m^2	K_t G/G_o
	(kWh/m^2)	(kj/m^2)		
Jan	7.1175	25622.8	5.124	0.72
Feb	8.2157	29576.6	5.996	0.73
Mar	9.4090	33872.2	6.868	0.73
Apr	10.4211	37516	7.711	0.74
May	10.8968	39228.2	8.172	0.75
Jun	11.01397	39650	8.369	0.76
Jul	10.9242	39327	8.411	0.77
Aug	10.5586	38010.8	7.812	0.74
Sep	9.7307	35030.5	7.005	0.72
Oct	8.7592	31533	6.131	0.70
Nov	7.3772	26557.8	5.016	0.68
Dec	6.7894	24442	4.480	0.66

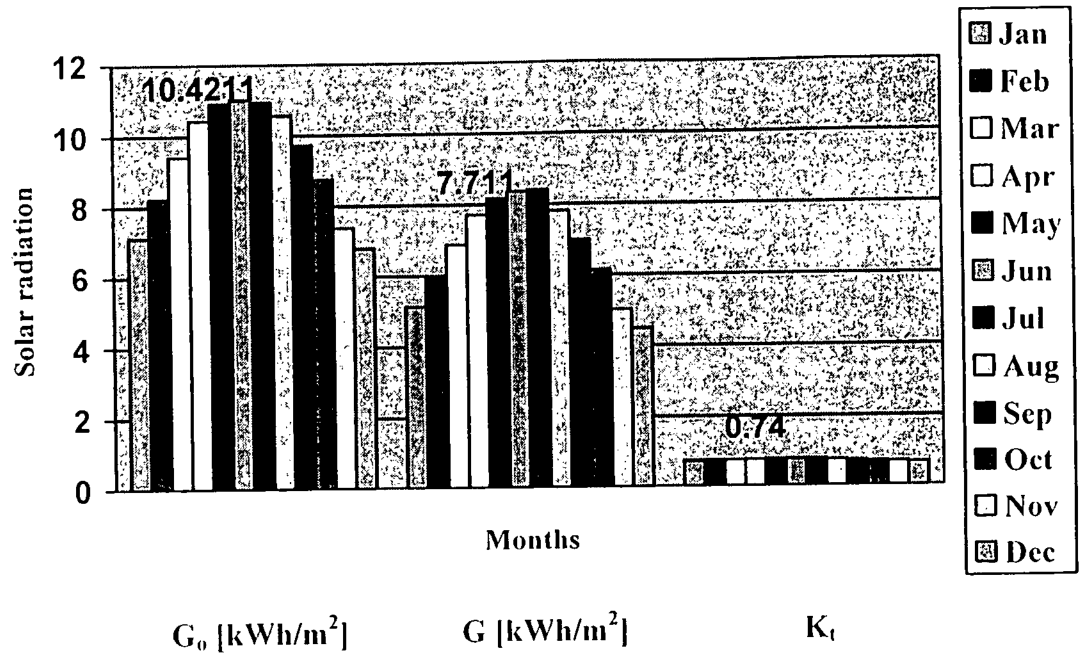
Where: -

Φ Site latitude is 23° N

G_o mean daily extra terrestrial global solar radiation [$kWh/m^2/day$]

G monthly average daily terrestrial radiation on horizontal surface[$kWh/m^2/day$]

K_t relative global radiation on horizontal surface [$K_t=G/G_o$]



Monthly Solar radiation

1 kj/m^2 = 0.2778*10^{-3} kWh/m^2

$K_t = G/G_o$

Water pumping design

In this section, we are going to calculate the hydraulic power for water pumping and hydraulic energy, where the given data are:

$P_{theoretically} = \gamma * Q * H$

$P_{theoretically}$ power of the pump

γ (density * acceleration) factor

$\gamma = \delta * g$

Where

δ is the density [Kg/m^3]

g is the gravity ≈ 980 [m/sec^2]

H is the water head [m].

Q is the Pump discharge [m^3/h$_r$]

$$P_{actual} = \frac{\gamma * Q * H}{C * \eta_o}$$

C constant factor = 1000 in case of electric power (kW)

= 75 in case of mechanical power (HP)

η_o Overall efficiency or total efficiency = $\eta_{motor} * \eta_{pump}$

$\eta_o \approx 0.55$ where $\eta_{motor} \approx 0.65$, $\eta_{pump} \approx 0.85$

Then the hydraulic energy (kWh/day)= $\frac{(9.8 * V * H)}{3600}$

Where V is the water volume (m^3)

H is the water head (m)

The hydraulic energy (kWh/day)= $\frac{(9.8 * V * H)}{3600}$

$$P_{hydraulic} = \frac{V * H}{367}$$

$\eta_{pump.\ motor}$ is the pump motor set efficiency = (35-40)%

$P_{electric} = P_{hydraulic} / \eta_{pump.motor} = P_{hydraulic} / (35\text{-}40)\%$

$P_{electric} = P_{hydraulic} / (35\text{-}40)\%$

PV array sizing:

The needed PV array peak power is calculated taking into consideration the backup batteries capacity (BC).

$$\text{Array peak power} = \text{PV needed output power} * \frac{\left[f_l + \frac{1 - f_l}{\eta_b}\right]}{\eta_a * h_p}$$

f_l is the load factor, fraction of the load to be supplied directly by PV≈0.8

η_b is the battery round trip efficiency ≈0.8

η_a is the array wiring efficiency ≈0.96

h_p is the equivalent hours of peak solar insolation ≈ 7 hours in East Qwinat in our case.

Array peak power = PV needed output power * 0.15625

To determine battery capacity BC=PV needed output $\left[\frac{1 - f_l}{\eta_b (1 - SOC_{min})}\right]$

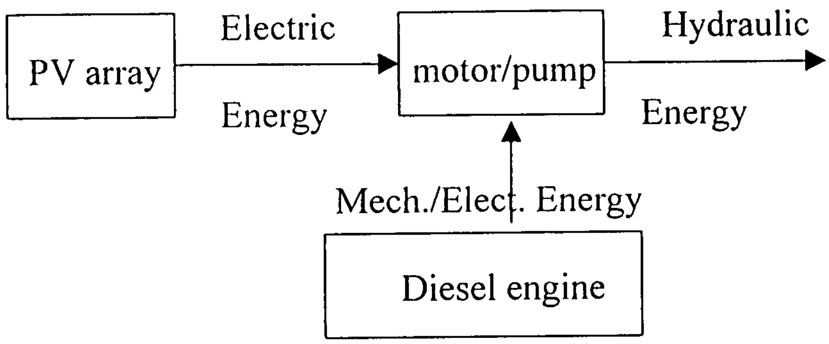
Where SOC_{min} is the minimum battery state of charge = 0.25

BC = PV needed output power * 0.333

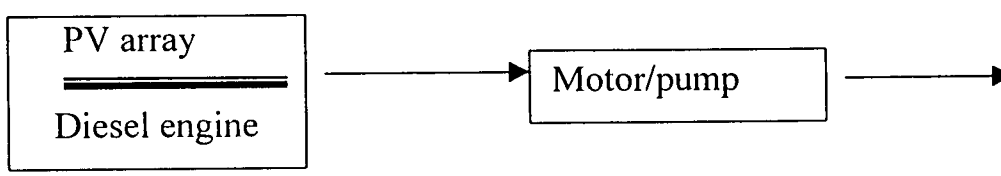
Design options

To use PV systems for water pumping, [illegible] different options are available to be applied: -

a. A stand-alone PV power source to supply the energy needed, with a diesel engine backup unit in emergency cases.



b. PV power source sized to the average yearly energy demand, with a diesel engine unit for peak energy needs above average.



Calculations and results

Sprinkling irrigation

Using the excel application with the following assumptions: -

N=50 faddans

Q=20 m^3/faddan/day — daily discharge of water

H= 40,80,120 m — static water head

The following results are obtained:

a) Case one, H=40m

Total water discharge = 50 * 20 =1000m^3/day

$$\text{Hydraulic energy} = \frac{1000 * 40}{367} = 108.991 \text{ kWh/day}$$

$$\text{PV array output energy needed} = \frac{108.991}{0.35} = 311.405 \text{ kWh/day}$$

Where pumping subsystem efficiency =0.35-0.40

$$\text{Array peak power} = 311.405 * \frac{\left[0.8 + \frac{1-0.8}{0.8}\right]}{0.96 * 7}$$

$$= 311.405 * 0.15625 = 48.657 \text{ kW}_p$$

$$BC=311.405*\frac{1-0.8}{0.8(1-0.25)}=311.405*0.333$$

$$=103.697\ kWh$$

For pumping subsystem power calculations

Assuming 7 hours duty cycle

$$\text{Hydraulic power } P_h=\frac{\text{hydraulic energy}}{7\text{ hours}}$$

$$P_h=\frac{108.991}{7}=15.570\ kW$$

At η_{pump}=0.4 (pump efficiency) then the pumping subsystem power

$$=\frac{15.570}{0.4}=38.925\ kW$$

These results are presented in worksheet .

Dripping irrigation

Using the excel program with the following assumptions: -

N=100 faddans.

Q=15 m^3/faddan/day=daily discharge of water.

H= 40,80,120m=static water head.

The following results are obtained

a) Case one, H=40m

Total water discharge = 100 * 15 =1500m^3/day

$$\text{Hydraulic energy}=\frac{1500*40}{367}=163.487\ kWh/day$$

$$\text{PV array output energy needed}=\frac{163.487}{0.4}=408.719\ kWh/day$$

$$\text{Array peak power}=408.719\frac{\left[0.8+\frac{1-0.8}{0.8}\right]}{0.96*7}$$

$$=408.719*0.15625=63.862\ kW_p$$

$$BC=408.719\frac{1-0.8}{0.8(1-0.25)}=408.719*0.333=136.103\ kWh$$

For pumping subsystem power calculations

Assuming 7 hours duty cycle

$$\text{Hydraulic power } P_h = \frac{\text{hydraulic energy}}{7 \text{ hours}}$$

$$P_h = \frac{163.487}{7} = 23.335 \text{ kW}$$

At $\eta_{pump}=0.4$ then the pumping subsystem power $= \dfrac{23.355}{0.4} = 58.388$ kW

These results are presented in worksheet .

Cost calculation

for i=5% inflation rate

d=10% discount rate,

n (expected life time) =20,25,30 years, for PV arrays, power conditioning and installation.

5 years lifetime for batteries and pumping subsystems

Calculating C_L for PV array, power conditioning, and installation using the prices of year 1990,1995,2000 to get the annual levelized cost C_L for the three prices respectively: -

C_L=Ps*0.117

=Ps*0.110

=Ps*0.106

Calculating the PW for batteries, and the pumping subsystem for five years lifetime then calculating C_L for them.

For d=10%.

n=20,25,30 years. Then F_L=0.117,0.110,0.106

For d=10%, i=5%. Then F_S=0.79 for n=5 years

=0.63 for n=10 years

=0.50 for n=15 years

=0.39 for n=20 years

=0.32 for n=25 years

=0.25 for n=30 years

For PV array, power conditioning and installation :

C_L=Ps*0.117 for n=20 years

C_L=Ps*0.110 for n=25 years

C_L=Ps*0.106 for n=30 years

For battery and pumping subsystem:

PW_{total} =PW + PW1 + PW2 + PW3 + PW4 + PW5 + PW6

Where PW=initial cost or present cost

PW1=PW*0.79 for n= 5 years

PW2=PW*0.63 for n= 10 years

PW3=PW*0.05 for n= 15 years

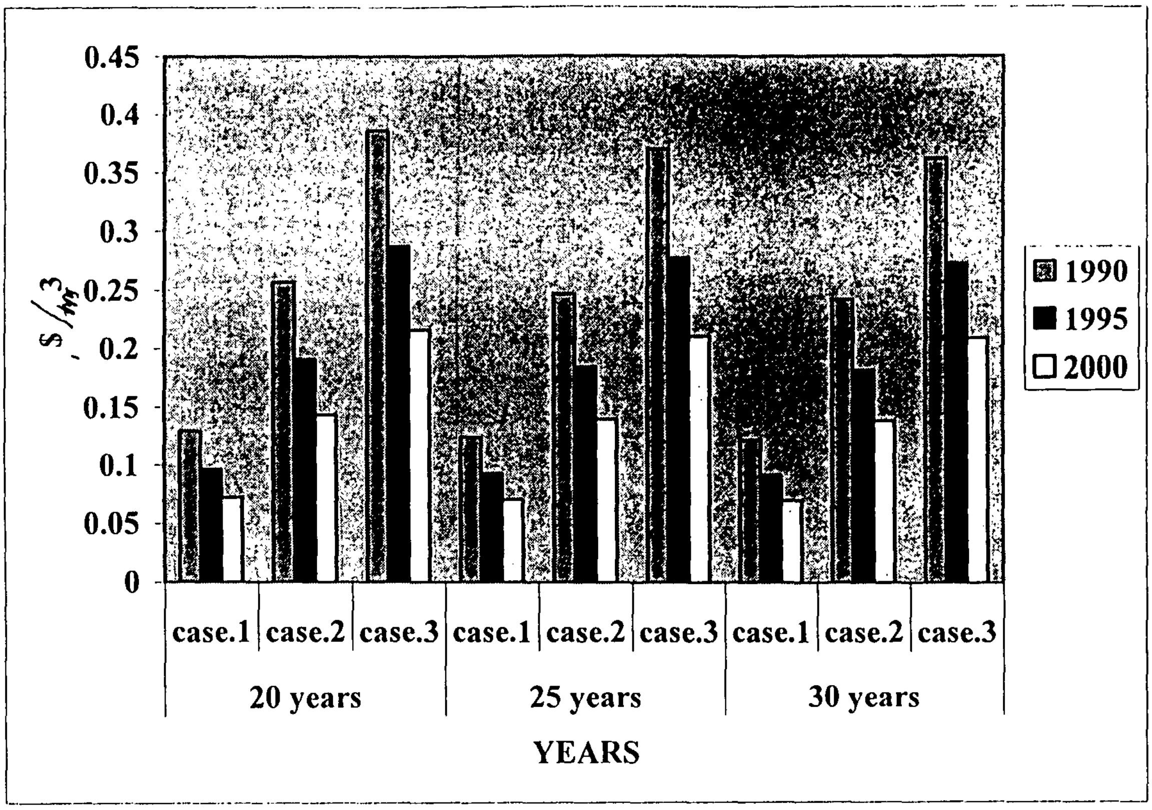
PW4=PW*0.39 for n= 20 years

PW5=PW*0.32 for n= 25 years

PW6=PW*0.25 for n= 30 years

Sprinkling irrigation water cost

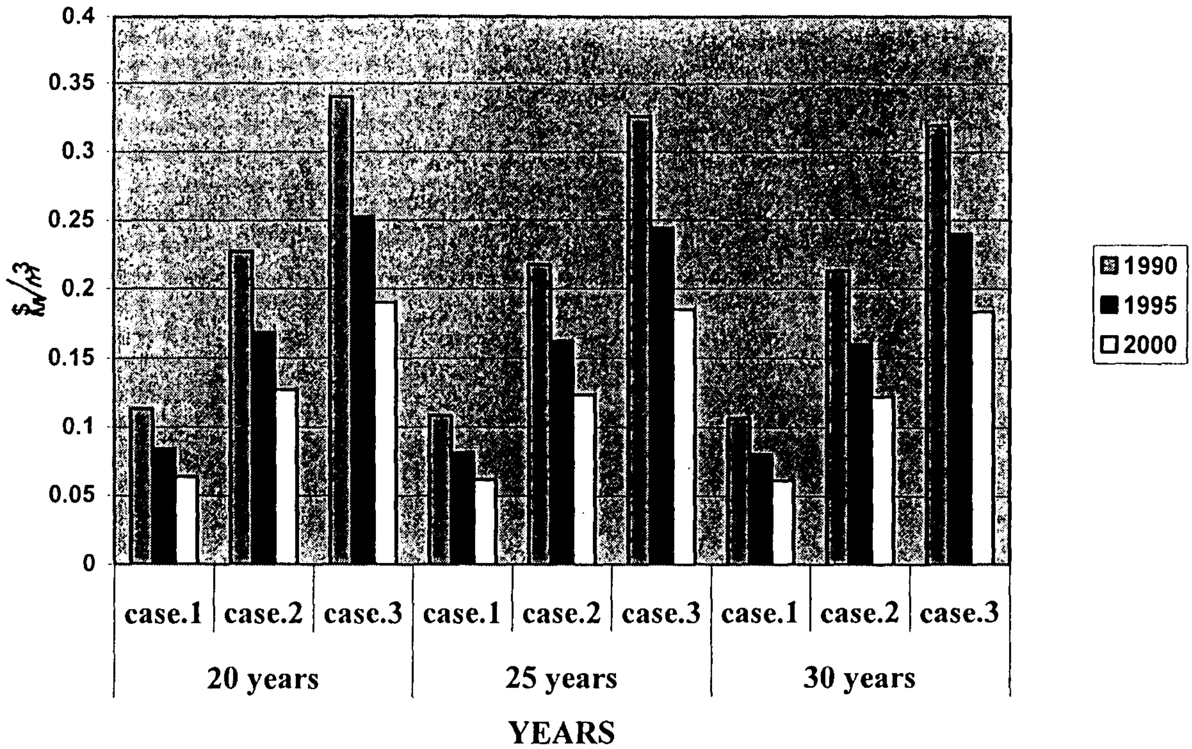
Case number	Year price	Water cost $/m^3		
		20 years	25 years	30 years
Case 1				
H=40m	**1990**	0.12949	0.12408	0.12142
N=50 faddan	**1995**	0.09605	0.09264	0.09112
Q=20m^3/faddan	**2000**	0.07216	0.07018	0.06948
Case 2				
H=80m	**1990**	0.25658	0.24590	0.24065
N=50 faddan	**1995**	0.19038	0.18366	0.18067
Q=20m^3/faddan	**2000**	0.14309	0.13920	0.13783
Case 3				
H=120m	**1990**	0.38607	0.36998	0.36207
N=50 faddan	**1995**	0.28643	0.27630	0.27180
Q=20m^3/faddan	**2000**	0.21525	0.20938	0.20731



Water cost using PV (sprinkling)

Dripping irrigation water cost

Case number	Year price	Water cost $/m^3$		
		20 years	25 years	30 years
Case 1				
H=40m	1990	0.11330	0.108632	0.10635
N=100 faddan	1995	0.08418	0.08125	0.07997
Q=15m^3/faddan	2000	0.06338	0.06170	0.06112
Case 2				
H=80m	1990	0.22668	0.21735	0.21279
N=100 faddan	1995	0.16844	0.16259	0.16002
Q=15m^3/faddan	2000	0.12684	0.12348	0.12233
Case 3				
H=120m	1990	0.33999	0.32598	0.31914
N=100 faddan	1995	0.25263	0.24385	0.23999
Q=15m^3/faddan	2000	0.19023	0.18518	0.18346



Water cost using PV (dripping)

Water cost calculation using diesel engine:

_Diesel engine annualized leveling cost

Sprinkling irrigation

Case one

H=40, N=50 faddan, Q=20 m^3/faddan/day, 300 days irrigation /year, duty cycle=7 hours

Hydraulic energy =108.991 kWh/day

Hydraulic power = $\frac{108.991}{7}$ =15.57 kW/day

For η_{pump}=65%=0.65

Diesel engine power = $\frac{15.57}{0.65}$ =23.95 kW=32.11 HP

For d=10%, i=5%, life time =5 years ,diesel power =23.95 kW

Unit cost = 300 $/kW

Diesel engine price = 300*23.95=7186.22 $ = PW

PW_{5years}=7186.22*0.79=5677.11 $

$PW_{10years}$=7186.22*0.63=4527.32 $

$PW_{15years}$=7186.22*0.50=3593.11 $

$PW_{20years}$=7186.22*0.39=2802.63 $

$PW_{25years}$=7186.22*0.32=2299.59 $

$PW_{total\ 20\ years}$=7186.22+5677.11+4527.32+3593.11=20983.76 $

C_L(20 years)=20983.76*0.117=2455.1$

$PW_{total\ 25\ years}$=23786.39 $

C_L(25 years)=23786.39*0.11=2616.5 $

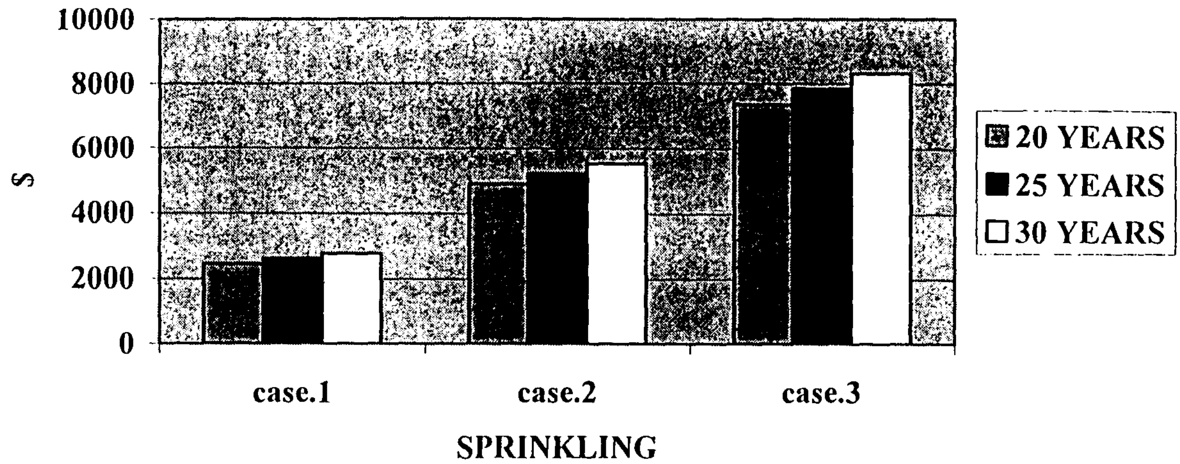
$PW_{total\ 30years}$=26085.98 $

C_L(30 years)=26085.98*0.106=2765.11 $

The above calculations are illustrated in worksheet [illegible] for the three cases (H=40,80,120m) and summerize the different values.

Diesel engine cost (sprinkling irrigation)

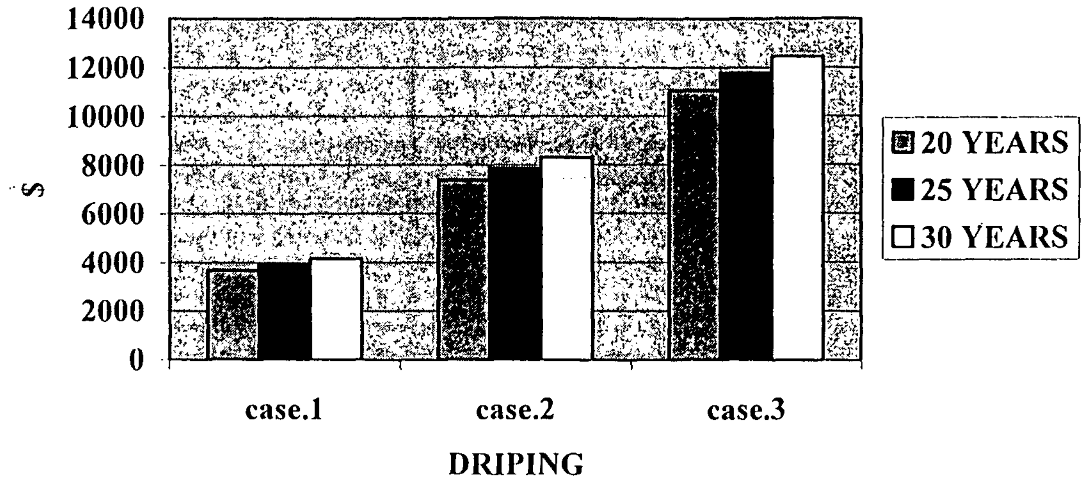
Case number	20 years		25 years		30 years	
	PW$	**$C_L$$**	**PW$**	**$C_L$$**	**PW$**	**$C_L$$**
Case 1 H=40m N=50 faddan Q=20m³/faddan	20983.76	2455.1	23786.39	2616.5	26085.98	2765.11
Case 2 H=80m N=50 faddan Q=20m³/faddan	41970.99	4910.61	47576.7	5233.44	52176.26	5530.68
Case 3 H=120m N=50 faddan Q=20m³/faddan	62951.67	7365.35	71359.6	7849.56	78258.41	8295.39



Diesel C_L cost (Sprinkling irrigation)

Diesel engine cost (dripping irrigation)

Case number	20 years		25 years		30 years	
	PW$	$C_L$$	PW$	$C_L$$	PW$	$C_L$$
Case 1 H=40m N=100 faddan Q=15m³/faddan	31475.74	3682.66	35679.69	3924.77	39129.09	4147.68
Case 2 H=80m N=100 faddan Q=15m³/faddan	62951.48	7365.32	71359.38	7849.53	78258.17	8295.37
Case 3 H=120m N=100 faddan Q=15m³/faddan	94427.6	11048.03	107039.51	11774.35	117387.74	12443.1



Diesel C_L cost(dripping irrigation)

Diesel engine operation cost :

The operation, repair and maintenance costs represent a very important and effective factor in water cost calculation when using diesel powered system .

Sprinkling irrigation

Case one

H=40, N=50 faddan, Q=20 m^3/faddan/day, 300 days irrigation /year, duty cycle=7 hours

Diesel power =23.95 kW=32.11 HP

a- Engine depreciation cost

$$\text{Engine consumption cost/hour}=\frac{initial \cdot cost}{lifetime * (daily \cdot operation \cdot hours / year)}$$

$$=\frac{7186.22}{5*(300*7)}*300*7=1437.24\ \$/year$$

Lifetime=5 years, daily operation hours=7 hours/day, 300 days

b- Operation, maintenance and repair cost

1) Fuel cost/hour=0.2*maximum H.P of the engine *load factor *litter price

= 0.2 *32.1 *0.7 *0.1=0.4494 $/hour

i.e =0.4494 * 300 *7 =943.87 $/year

where load factor =0.7, fuel price =0.1 $/litter

2) Oil lubrication cost/year =0.5 *fuel cost/year

=943.87*0.5=471.94 $/year

3) Repair and maintenance cost / year= engine depreciation cost /year

=1437.24 $/year

Total cost of operation, maintenance and repair = (1)+(2)+(3)

= 943.87 +471.94+1437.24=2853.05 $/year

C - Labor cost /hour

Labor cost /hour= $\frac{4*annual.salary}{operation.hours/year} = \frac{4*(200*12)}{7*300}$ = 4.57 $/hour.

i.e = 9600 $/year

Total running cost =(a)+(b)+(c)=1437.24+2853.05+9600=13890.3 $/year

The same procedure is used to calculate the total running cost for the other tow cases as in worksheet , while present the summery of these results.

d=10%, i=5% life time (period of study)=20 year, 25 year, 30 year

For 20 years F_a=12.72

For 25 years F_a=14.26

For 30 years F_a=15.8

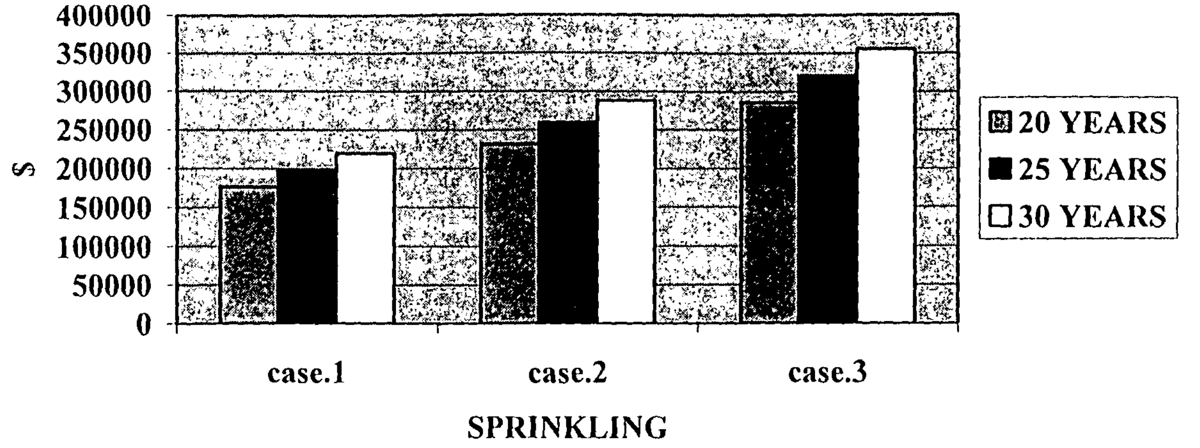
C_L(20years)=13890.3*12.72=176684.6 $/year

C_L(25years)=13890.3*14.26=198075.66 $/years

C_L(30years)=13890.3*15.8=219466.72 $/year

Diesel operation, repair and maintenance C_L cost (sprinkling)

	Case1 $	Case2 $	Case3 $
20 YEARS	176684.6	231265.08	285837.99
25 YEARS	198078.66	259264.16	320444.16
30 YEARS	219466.72	287263.23	355050.33



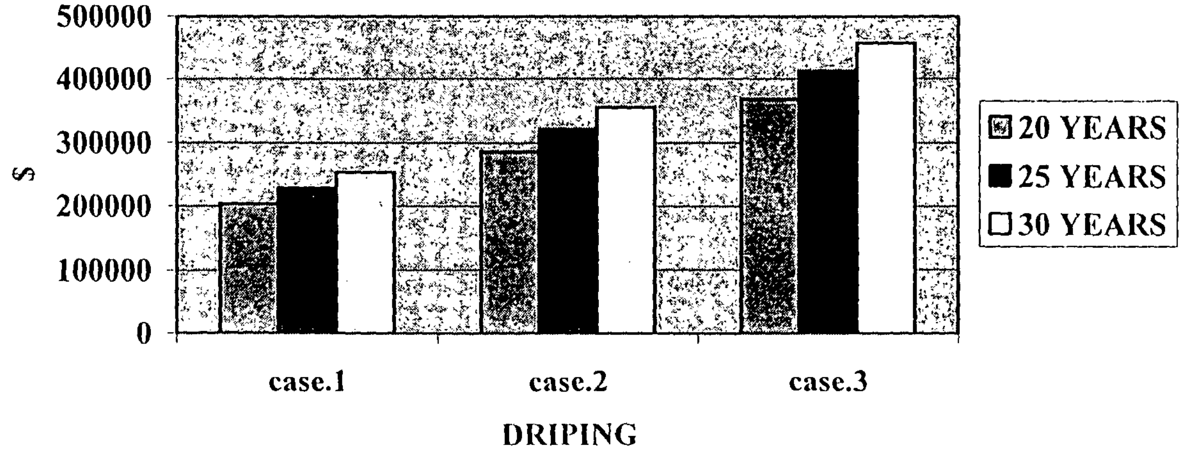
Diesel Operation, Repair And Maintenance C_L cost

Dripping irrigation

Performing the same calculation for dripping irrigation we get C_L after 20,25,30 years as in worksheet .

Diesel operation, repair and maintenance C_L cost (dripping)

	Case1 $	Case2 $	Case3 $
20 YEARS	203974.83	285837.66	367701.16
25 YEARS	228669.9	320443.79	412218.44
30 YEARS	253364.96	355049.92	456735.72



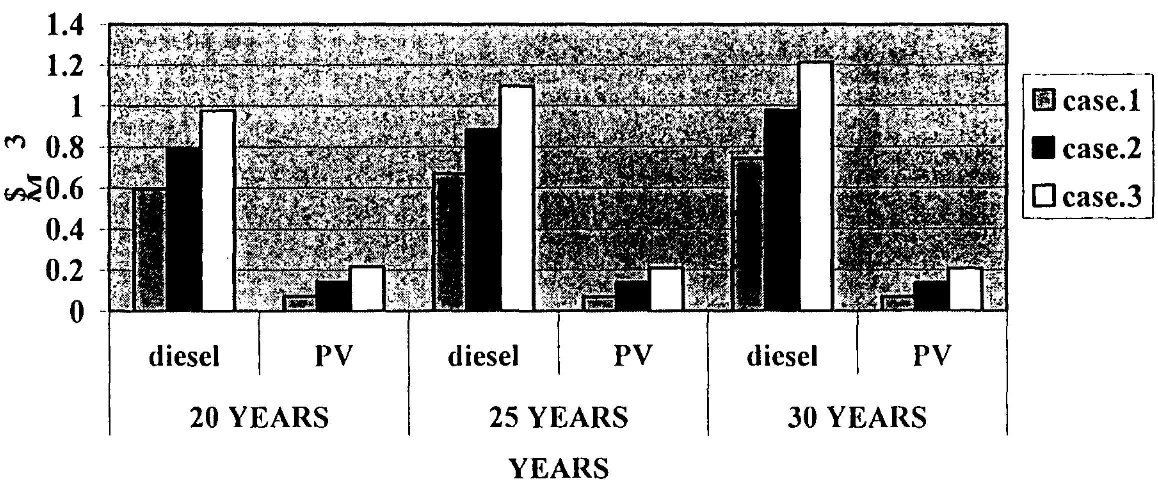
Diesel operation, repair and maintenance C_L cost

Cost comparison between PV and diesel

Worksheet illustrates the different values for the water cost in the three cases using PV and diesel system. It is clear and easy to compare between the costs of each systems as presented .

Diesel & PV water cost comparsion

		case.1 $	Case.2 $	case.3 $
20 YEARS	diesel	0.59713	0.78725	0.97734
	PV	0.07216	0.14309	0.21525
25 YEARS	diesel	0.66897	0.88166	1.09431
	PV	0.07018	0.1392	0.20938
30 YEARS	diesel	0.74077	0.97598	1.21115
	PV	0.06948	0.13783	0.20731



Cost comparison of PV versus diesel

Conclusion :

The field study of the East Owinat area, which is based on the following:

1- Area location, longitude, latitude, distance from the National Grid of Electric Power Supply, solar insolation, sunshine duration, ground water head and cultivated lands etc.

2- Disadvantages of diesel powered system in ground water pumping which were based on:

- The difficulties of repair, maintenance and operation costs
- Spare parts replacements; high-qualified technicians are very expensive.
- High costs of the petroleum materials like fuel, lubricants etc.
- The pollution of the environment caused by diesel engines and its bad effects on humanity.

3- Economic feasibility study of PV powered system over 20,25,30 years of life time, the prices in yeas 1990, 1995, 2000, and the suitable water head of 40, 80, 120 meters, the different price list of the components.

General conclusion of the study:

As a result of this study, it is found that; using PV powered systems in comparison with diesel-powered systems is more efficient and economic for ground water pumping especially at remote areas such as East Owinat area, under condition that the static water head is 120m maximum.

taking into consideration the life time of 20,25,30 years is assumed for the PV, Modern irrigation methods should be used, such as dripping, sprinkling irrigation, to decrease the waste of water. Certain crops and plants should be cultivated.

Taking into consideration the environmental impact cost of PV powered system and diesel powered system, it is found that the cost of impact on the environment of 1 kWh produced by traditional fuel is 20 times of that produced by PV powered system. The effect of lifetime of 20, 25, 30 years is limited in comparison with decreasing of the PV prices.

The distance of the area from the national grid, encourages us to use PV powered system.

As a result of this thesis, it is found that using PV powered system is more efficient and economic than using diesel powered system for ground water pumping, especially at remote areas such as East Owinat, taking into consideration the long life time (20,25,30 years) of the PV modules.

limitations, constrains of the results:

The study illustrates the following:

- PV powered system should be used more than 20 years of lifetime. It is very important to use the modern methods of irrigation like dripping, sprinkling irrigation to decrease the waste of water.
- Certain types of crops are suitable to be cultivated which need small quantity of water; the water head should not be more than 120 meters.

Suggested future works:

Integrated PV powered system is proposed to be used for different life sectors, as well as we think about modern society in the area, which is based on solar energy power supply.

We can use wind turbines beside PV system to make integrated hybrid system of power supply where the speed of the wind tends to 7 m/sec.

Recommendations:

It is recommended to promote the use of PV technologies and remove the barriers preventing its wide use and application. This can be achieved by awareness, researches, building capacity and governmental support.

The decreasing in PV prices from year (1990-2000) is very effective and strong, so we recommend that PV technology should be produced locally.

The water cost is strongly affected by the decrease of the PV systems prices, so it is recommended to start manufacturing PV cells and modules locally.

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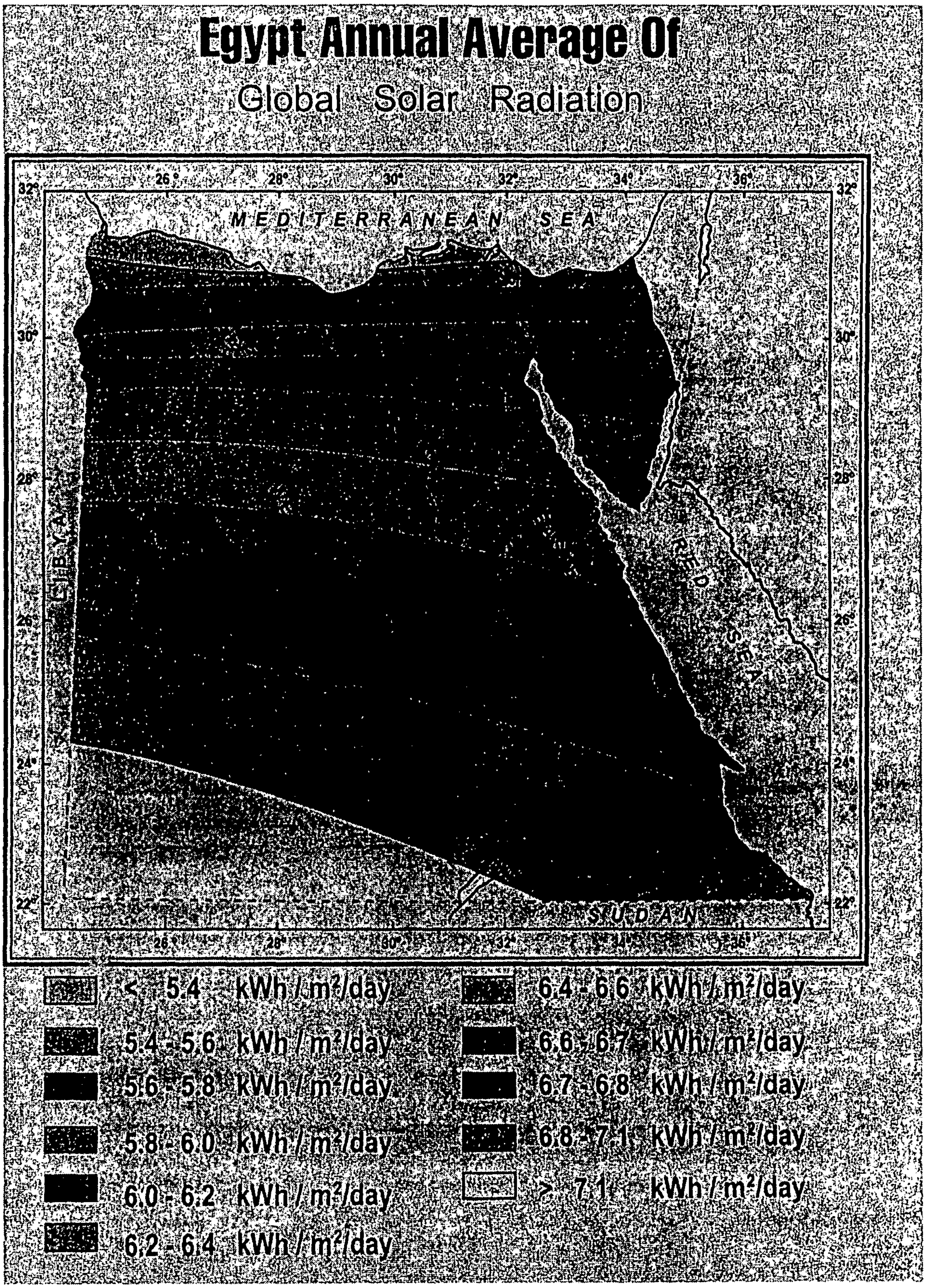
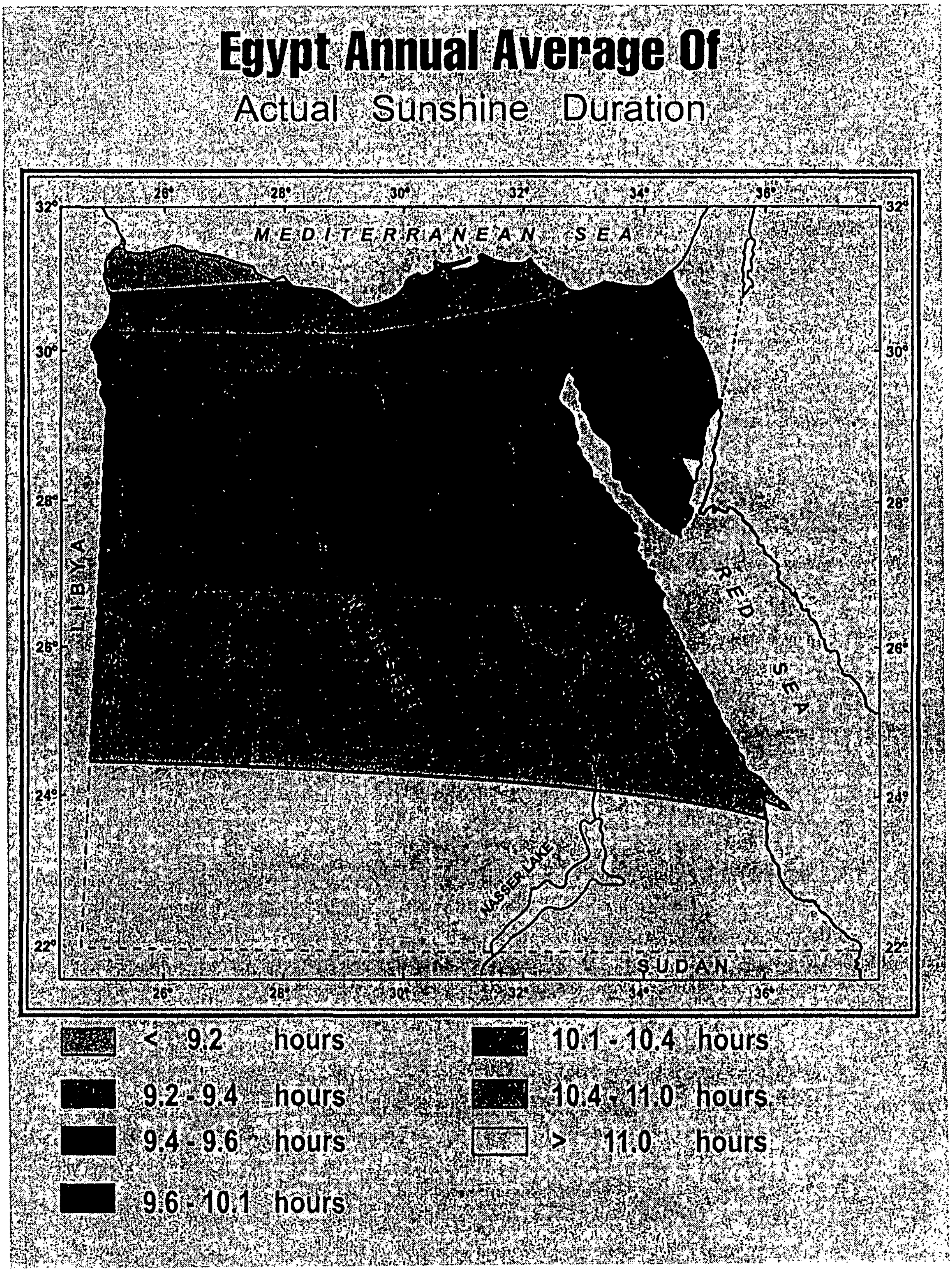


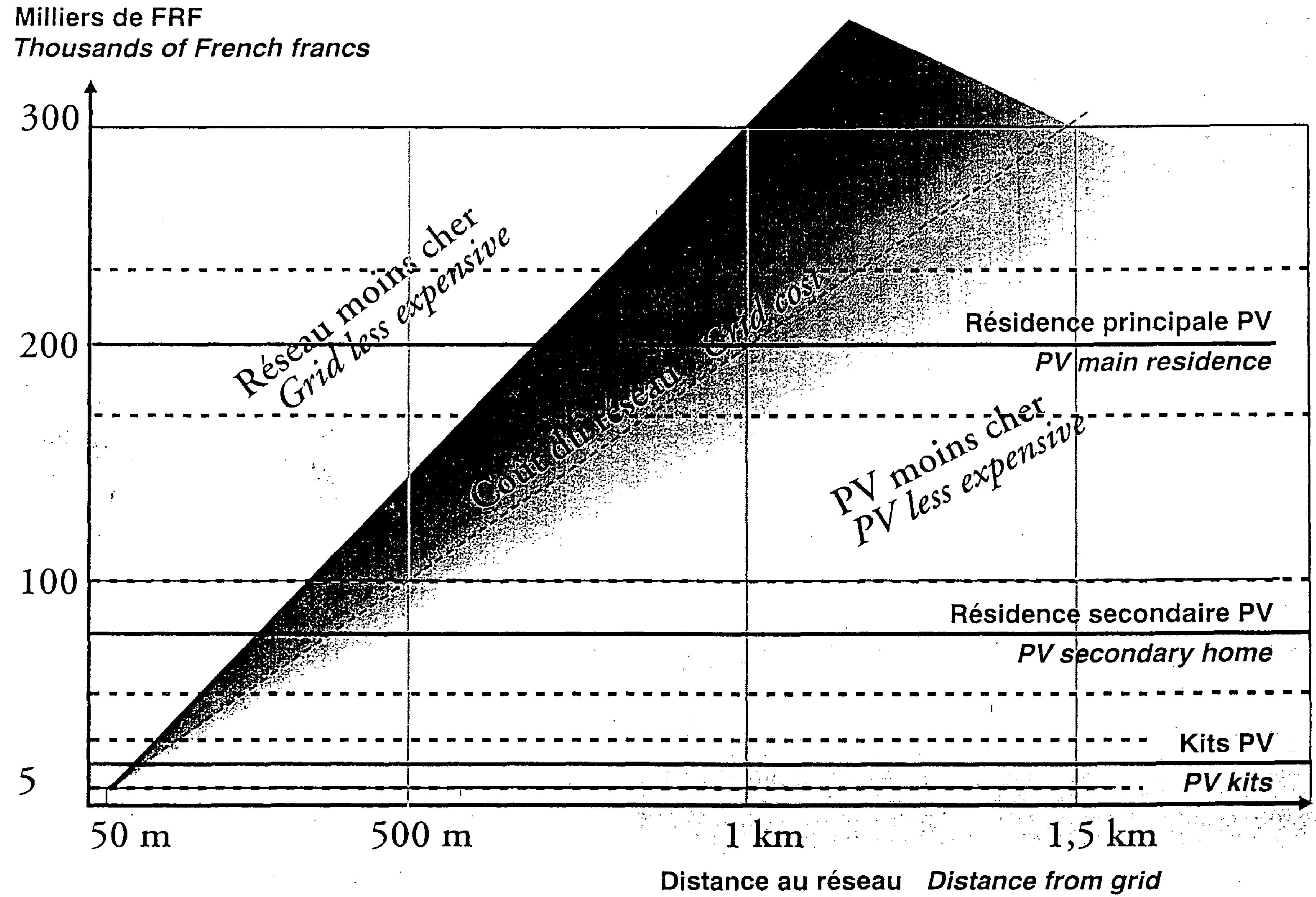
Annual average global solar radition over Egypt(kWh/m^3)

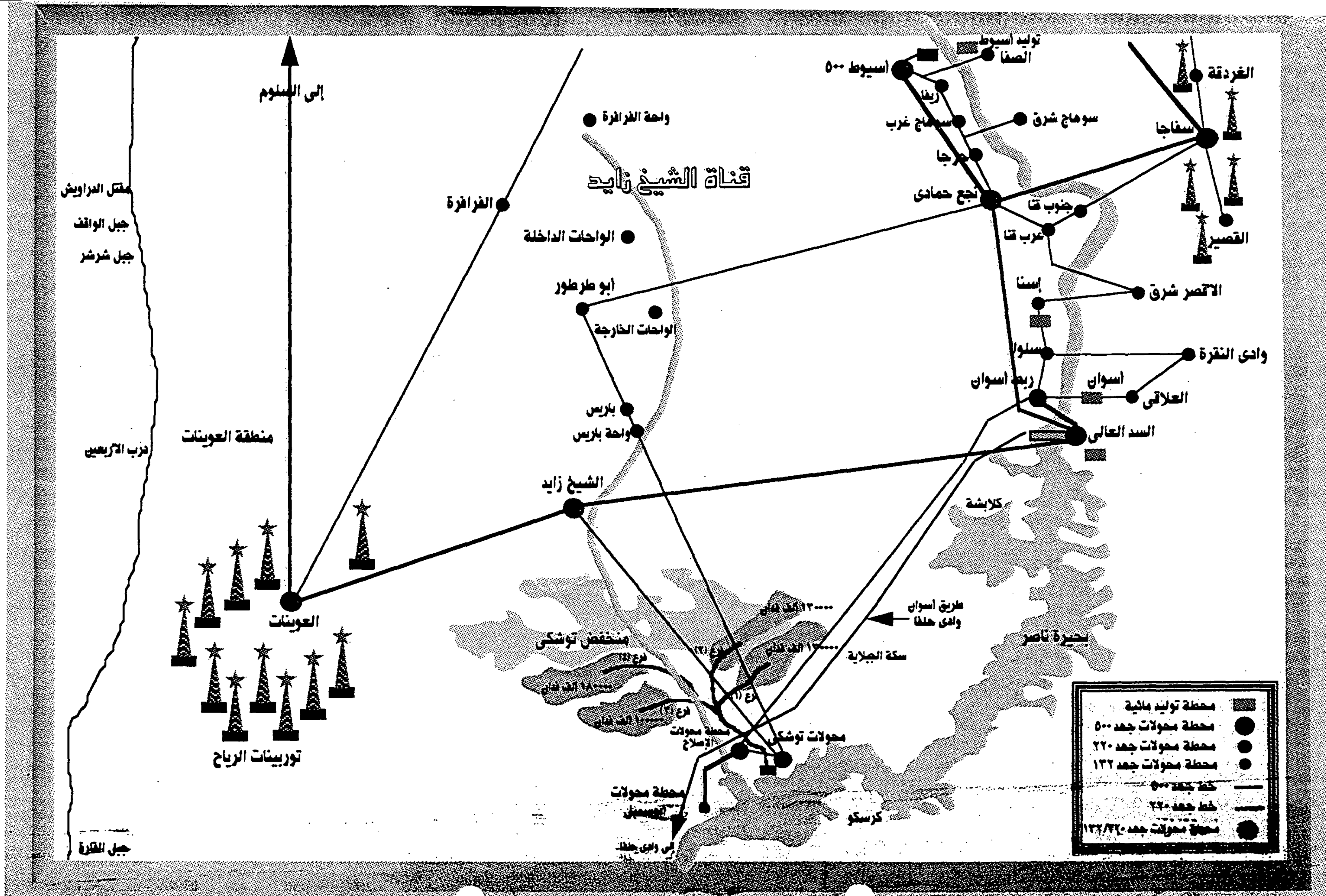


Annual average of actual sunshine duration over Egypt in hours

The average monthly solar insolation is presented in table 3.1. The main characteristics of the region are summerized in the follwing : -

الجيزة
السودان
°٢٨
°٣٠
°٣٢


Milliers de FRF
Thousands of French francs
300
200
100
5
Réseau moins cher
Grid less expensive
Coût du réseau
Grid cost
PV moins cher
PV less expensive
Résidence principale PV
PV main residence
Résidence secondaire PV
PV secondary home
Kits PV
PV kits
50 m
500 m
1 km
1,5 km
Distance au réseau
Distance from grid



قناة الشيخ زايد
إلى السلوم
منطقة العوينات
العوينات
توربينات الرياح
الشيخ زايد
الفرافرة
واحة الفرافرة
الواحات الداخلة
أبو طرطور
الواحات الخارجة
باريس
واحة باريس
مفتق الدراويش
جبل الواقف
جبل شرشر
درب الاربعين
جبل العقارة
أسيوط ٥٠٠
توليد أسيوط
الصفا
سوهاج شرق
سوهاج غرب
نجع حمادى
جنوب قنا
غرب قنا
الغردقة
سفاجا
القصير
الاقصر شرق
إسنا
وادى النقرة
ربط أسوان
أسوان
العلاقى
السد العالى
كلابشة
بحيرة ناصر
طريق أسوان وادى حلفا
سكة الجبلاية
منخفض توشكى
محولات توشكى
محطة محولات الإصلاح
محطة محولات
إلى وادى حلفا
كرسكو
محطة توليد مائية
محطة محولات جهد ٥٠٠
محطة محولات جهد ٢٢٠
محطة محولات جهد ١٣٢
خط جهد ٥٠٠
خط جهد ٢٢٠
محطة محولات جهد ١٣٢/٢٢٠

Worksheet 6.1

Sprinkling irrigation

Case one: - H=40 meters, N=50 faddans, $Q=20m^3$/faddan

Component	Nominal Rating	Unit Cost	Component Cost $	Maintenance And repair Cost $	Life time	Annual levelized cost C_L $ at Expected life time (years)		
						F_L=0.117 20 years	F_L=0.110 25 years	F_L=0.106 30 years
PV array size 1990 1995 2000	**KW_p** 48.657 ≈ 49	$ / W_p 4.5 3 2	$ 220500 147000 98000	**0.5%$/$w_p$** 250	**Years** 20 –25 - 30	25798.5 17199 11466	24255 16170 10780	23373 15582 10388
Power conditioning 1990 1995 2000	**KW_p** 48.657 ≈ 49	$ / W_p 1 0.75 0.50	$ 49000 36750 24500	0.6 % $ /w_p 300$	**Years** 20 –25 - 30	5733 4299.75 2866.50	5390 4042.5 26950.00	5194 3895.5 2597.00
Battery	Kw.h 103.697 ≈ 104	$/k.w.h 120	$12480	0.4%$/w.h $400	Years 5	4263.667	4543.968	4802.054
Pumping subsystem power	k.w 38.925 ≈ 39	$/kw 100	$ 3900	1%$/w $390	Years 5	1332.2	1419.99	1500.64
Installation	N/A (60: 200)	$/$w_p$ 0.3	$ 14700	1%$ comp. Cost 147	Years 20,25,30	1719.9	1617	1558.2

Motor/pump system

Worksheet 6.2

Sprinkling irrigation

Case two: - H=80 meters, N=50 faddans, Q=20m^3/faddan

Component	Nominal Rating	Unit Cost	Component Cost $	Maintenance And repair Cost $	Life time	Annual levelized cost C_L $ at Expected life time (years)		
						F_L=0.117 20 years	F_L=0.110 25 years	F_L=0.106 30 years
PV array size	**KW_p**	**$ / W_p**	**$**	**0.5%$/$w_p$**	**Years**			
1990	97.314	4.5	436500			51070.5	48015	46269
1995	≈ 97	3	291000	485	20,25,30	34047	32010	30846
2000		2	194000			22698	21340	20564
Power conditioning	**KW_p**	**$ / W_p**	**$**	0.6 % $ /w_p	**Years**	11349	10670	10282
1990	97.314	1	97000					
1995	≈ 97	0.75	72750	580$	20,25,30	8511.75	8002.5	7711.5
2000		0.50	48500			5674.5	5335	5141
Battery	Kw.h 207.395 ≈ 207	$/k.w.h 120	$24840	0.4%$/w.h $828	Years 5	8486.33	9044.24	9557.93
Pumping subsystem power	k.w 77.851 ≈ 78	$/kw 100	$ 7800	1%$/w $780	Years 5	2664.79	2839.98	3001.28
Installation	N/A (60: 200)	$/$w_p$ 0.3	$ 29100	1%$ comp. Cost 291	Years 20,25,30	4304.7	3201	3084.6

Worksheet 6.3

Sprinkling irrigation

Case three: - H=120 meters, N=50 faddans, $Q=20m^3$/faddan

Component	Nominal Rating	Unit Cost	Component Cost $	Maintenance And repair Cost $	Life time	Annual levelized cost C_L $ at Expected life time (years)		
						F_L=0.117 20 years	F_L=0.110 25 years	F_L=0.106 30 years
PV array size 1990 1995 2000	**KW_p** 145.971 ≈ 146	**$ / W_p** 4.5 3 2	**$** 65700 438000 292000	**0.5%$/$w_p$** 730	**Years** 20,25,30	76869 51246 34164	72270 48180 32120	69642 46428 30952
Power conditioning 1990 1995 2000	**KW_p** 145.971 ≈ 146	**$ / W_p** 1 0.75 0.50	**$** 146000 109500 73000	0.6 % $ /w_p 876$	**Years** 20,25,30	17082 12811.5 8541	16060 12045 8030	15476 11607 7738
Battery	Kw.h 311.093 ≈ 311	$/k.w.h 120	$37320	0.4%$/w.h $1244	Years 5	12750	13588.21	14359.99
Pumping subsystem power	k.w 116.776 ≈ 117	$/kw 100	$ 11700	1%$/w $1170	Years 5	3997.188	4259.97	4501.926
Installation	N/A (60: 200)	$/$w_p$ 0.3	$ 43800	1%$ comp. Cost 438	Years 20,25,30	5124.6	4818	4642.8

Worksheet 6.4

Drip irrigation

Case one: - H=40m, N=100 faddan, Q=15 m^3/faddan

Component	Nominal Rating	Unit Cost	Component Cost $	Maintenance And repair Cost $	Life time	Annual levelized cost C_L $ at Expected life time (years)		
						F_L=0.117 20 years	F_L=0.110 25 years	F_L=0.106 30 years
PV array size	KW_p	$ / W_p	$	0.5%$/$w_p$	Years			
1990	63.862	4.5	288000			33696	31680	30528
1995	≈ 64	3	192000	320	20,25,30	22464	21120	20352
2000		2	128000			14976	14080	13568
Power conditioning	KW_p	$ / W_p	$	0.6 % $ /w_p	Years			
1990	63.862	1	64000			7488	7040	6784
1995	≈ 64	0.75	48000	384$	20,25,30	5616	5280	5088
2000		0.50	32000			3744	3520	3392
Battery	Kw.h 136.103 ≈ 136	$/k.w.h 120	$16320	0.4%$/w.h $544	Years 5	5575.56	5942.11	6279.60
Pumping subsystem power	k.w 58.388 ≈ 58	$/kw 100	$ 5800	1%$/w $580	Years 5	1981.51	2111.78	2231.72
Installation	N/A (60: 200)	$/$w_p$ 0.3	$ 19200	1%$ comp. Cost 192	Years 20,25,30	2246.4	2112	2035.2

Worksheet 6.5

Drip irrigation

Case two:- H=80m, N=100 faddan, Q=15m³/faddan

Component	Nominal Rating	Unit Cost	Component Cost $	Maintenance And repair Cost $	Life time	Annual levelized cost C_L $ at Expected life time (years)		
						F_L=0.117 20 years	F_L=0.110 25 years	F_L=0.106 30 years
PV array size	**KW_p**	**$ / W_p**	**$**	**0.5%$/$w_p$**	**Years**			
1990	127.724	4.5	576000			67392	63360	61056
1995	≈ 128	3	384000	640	20,25,30	44928	42240	40704
2000		2	256000			29952	28160	27136
Power conditioning	**KW_p**	**$ / W_p**	**$**	0.6 % $ /w_p	**Years**			
1990	127.724	1	128000			14976	14080	13568
1995	≈ 128	0.75	96000	768$	20,25,30	11232	10560	10176
2000		0.50	64000			7488	7040	6784
Battery	Kw.h 272.205 ≈ 272	$/k.w.h 120	$32640	0.4%$/w.h $1088	Years 5	11151.12	11884.22	12559.21
Pumping subsystem power	k.w 116.776 ≈ 117	$/kw 100	$ 11700	1%$/w $1170	Years 5	3997.18	4259.97	4501.92
Installation	N/A (60: 200)	$/$w_p$ 0.3	$ 38400	1%$ comp. Cost 384	Years 20,25,30	4492.8	4224	4070.4

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Worksheet 6.6

Drip irrigation

Case three:- H=120m, N=100 faddan, Q=15m^3/faddan

Component	Nominal Rating	Unit Cost	Component Cost $	Maintenance And repair Cost $	Life time	Annual levelized cost C_L $ at Expected life time (years)		
						F_L=0.117 20 years	F_L=0.110 25 years	F_L=0.106 30 years
PV array size	**KW_p**	**$ / W_p**	$	**0.5%$/$w_p$**	**Years**			
1990	191.587	4.5	864000			101088	95040	91584
1995	≈ 192	3	576000	960	20,25,30	67392	63360	61056
2000		2	384000			44928	42240	40704
Power conditioning	**KW_p**	**$ / W_p**	$	0.6 % $ /w_p	**Years**			
1990	191.587	1	192000			22464	21120	20352
1995	≈ 192	0.75	144000	1152$	20,25,30	16848	15840	15264
2000		0.50	96000			11232	10560	10176
Battery	Kw.h 408.310 ≈ 408	$/k.w.h 120	$48960	0.4%$/w.h $1632	Years 5	16726.69	17826.33	18838.82
Pumping subsystem power	k.w 175.165 ≈ 175	$/kw 100	$ 17500	1%$/w $1750	Years 5	5978.70	6371.75	6733.65
Installation	N/A (60: 200)	$/$w_p$ 0.3	$ 57600	1%$ comp. Cost 576	Years 20,25,30	6739.2	6336	6105.6

Work sheet 6.7: Water cost calculations for sprinkling irrigation

(H=40,80,120m)

	Year	Array peak power			Power conditioning			Battery capcity			Pumping subsystem powe			Installation			Total		
		40	80	120	40	80	120	40	80	120	40	80	120	40	80	120			
Nominal Rating		49	97	146	49	97	146	104	207	311	39	78	117	60:200			40	80	120
	1990	220500	436500	657000	49000	97000	146000	12480	24840	37320	3900	7800	11700	14700	29100	43800			
	1995	147000	291000	438000	36750	72750	109500	12480	24840	37320	3900	7800	11700						
	2000	98000	194000	292000	24500	48500	73000	12480	24840	37320	3900	7800	11700						
Maint & Repair operation cost		250	485	730	300	580	876	400	828	1244	390	780	1170	147	291	438			
Present Worth PW								36442	72533	108974	11388	22776	34164						
Annual levelized Cost 20 years CL																			
	1990	25799	51071	76869	5733	11349	17082	4264	8486	12750	1332	2665	3997	1720	3405	5125	38847	76975	115823
	1995	17199	34047	51246	4300	8512	12812	4264	8486	12750	1332	2665	3997	1720	3405	5125	28815	57115	85929
	2000	11466	22698	34164	2867	5675	8541	4264	8486	12750	1332	2665	3997	1720	3405	5125	21648	42928	64577
Present Worth PW								41309	82220	123529	12909	25818	38727						
Annual levelized Cost 25 years CL																			
	1990	24255	48015	72270	5390	10670	16060	4544	9044	13588	1420	2840	4260	1617	3201	4818	37226	73770	110996
	1995	16170	32010	48180	4043	8003	12045	4544	9044	13588	1420	2840	4260	1617	3201	4818	27793	55098	82891
	2000	10780	21340	32120	2695	5335	8030	4544	9044	13588	1420	2840	4260	1617	3201	4818	21056	41760	62816
Present Worth PW								45302	90169	135472	14157	28314	42471						
Annual levelized Cost30 years CL																			
	1990	23373	46269	69642	5194	10282	15476	4802	9558	14360	1501	3001	4502	1558	3085	4643	36428	72195	108623
	1995	15582	30846	46428	3896	7712	11607	4802	9558	14360	1501	3001	4502	1558	3085	4643	27338	54201	81540
	2000	10388	20564	30952	2597	5141	7738	4802	9558	14360	1501	3001	4502	1558	3085	4643	20846	41349	62195
Water cost $/m3 (20 years)-Quantity																	300000		
	1990																0.12949	0.25658	0.38608
	1995																0.09605	0.19038	0.28643
	2000																0.07216	0.14309	0.21526
Water cost $/m3 (25 years)-Quantity																	300000		
	1990																0.12409	0.2459	0.36999
	1995																0.09264	0.18366	0.2763
	2000																0.07019	0.1392	0.20939
Water cost $/m3 (30 years)-Quantity																	300000		
	1990																0.12143	0.24065	0.36208
	1995																0.09113	0.18067	0.2718
	2000																0.06949	0.13783	0.20732

Work sheet 6.8 Water cost calculations for dripping irrigation (H=40,80,120m)

	Year	Array peak power			Power conditioning			Battery capcity			umping subsystem pow			Installation				Total	
		40	80	120	40	80	120	40	80	120	40	80	120	40	80	120			
Nominal Rating		64	128	192	64	128	192	136	272	408	58	117	175	60:200			H= 40	H = 80	H= 120
	1990	288000	576000	864000	64000	128000	192000	16320	32640	48960	5800	11700	17500	19200	38400	57600			
	1995	192000	384000	576000	48000	96000	144000	16320	32640	48960	5800	11700	17500						
	2000	128000	256000	384000	32000	64000	96000	16320	32640	48960	5800	11700	17500						
Maint & repair operation cost		320	640	690	384	768	1152	544	1088	1632	580	1170	1750	192	384	576			
Present Worth PW								47654	95309	142963	16936	34164	51100						
Annual levelized Cost 20 years CL																			
	1990	33696	67392	101088	7488	14976	22464	5576	11151	16727	1982	3997	5979	2246	4493	6739	50987	102009	152997
	1995	22464	44928	67392	5616	11232	16848	5576	11151	16727	1982	3997	5979	2246	4493	6739	37883	75801	113685
	2000	14976	29952	44928	3744	7488	11232	5576	11151	16727	1982	3997	5979	2246	4493	6739	28523	57081	85605
Present Worth PW								54019	108038	162058	19198	38727	57925						
Annual levelized Cost 25 years CL																			
	1990	31680	63360	95040	7040	14080	21120	5942	11884	17826	2112	4260	6372	2112	4224	6336	48886	97808	146694
	1995	21120	42240	63360	5280	10560	15840	5942	11884	17826	2112	4260	6372	2112	4224	6336	36566	73168	109734
	2000	14080	28160	42240	3520	7040	10560	5942	11884	17826	2112	4260	6372	2112	4224	6336	27766	55568	83334
Present Worth PW								59242	118483	177725	21054	42471	63525						
Annual levelized Cost30 years CL																			
	1990	30528	61056	91584	6784	13568	20352	6280	12559	18839	2232	4502	6734	2035	4070	6106	47859	95756	143614
	1995	20352	40704	61056	5088	10176	15264	6280	12559	18839	2232	4502	6734	2035	4070	6106	35987	72012	107998
	2000	13568	27136	40704	3392	6784	10176	6280	12559	18839	2232	4502	6734	2035	4070	6106	27507	55052	82558
Water cost $/m3 (20 years)-Quantity																	450000		
	1990																0.113306	0.226687	0.339992
	1995																0.084186	0.168447	0.252632
	2000																0.063386	0.126847	0.190232
Water cost $/m3 (25 years)-Quantity																	450000		
	1990																0.108635	0.217352	0.325987
	1995																0.081258	0.162596	0.243854
	2000																0.061702	0.123485	0.185187
Water cost $/m3 (30 years)-Quantity																	450000		
	1990																0.106352	0.21279	0.319142
	1995																0.07997	0.160026	0.239996
	2000																0.061126	0.122337	0.183462

Work sheet 6.9 Annual levelized cost calculation for diesel engine (sprinkling irrigation)

Sprinkling		N Faddans	Q M3/F/day	H Meters	Duty cycle hours	Hyd. Energy (KWh/day)	hyd. Power (KW/day)	dies. Eng. P. (KW)	dies. Eng. P. (HP)	Unit cost (300$/KW)
Case one		50.00	20.00	40.00	7.00	108.99	15.57	23.95	32.11	7186.22
PW $	7186.22									
PW (5 years)	5677.11									
PW (10 years)	4527.32									
PW (15 years)	3593.11									
PW (20 years)	2802.63									
PW (25 years)	2299.59									
PW Total (20 years)	20983.76									
CL Total (20 years)	2455.10									
PW Total (25 years)	23786.39									
CL Total (25 years)	2616.50									
PW Total (30 years)	26085.98									
CL Total (30 years)	2765.11									
Case two		50.00	20.00	80.00	7.00	217.98	31.14	47.91	64.23	14373.63
PW $	14373.63									
PW (5 years)	11355.16									
PW (10 years)	9055.38									
PW (15 years)	7186.81									
PW (20 years)	5605.71									
PW (25 years)	4599.56									
PW Total (20 years)	41970.99									
CL Total (20 years)	4910.61									
PW Total (25 years)	47576.70									
CL Total (25 years)	5233.44									
PW Total (30 years)	52176.26									
CL Total (30 years)	5530.68									
Case three		50.00	20.00	120.00	7.00	326.98	46.71	71.86	96.33	21558.79
PW $	21558.79									
PW (5 years)	17031.45									
PW (10 years)	13582.04									
PW (15 years)	10779.40									
PW (20 years)	8407.93									
PW (25 years)	6898.81									
PW Total (20 years)	62951.67									
CL Total (20 years)	7365.35									
PW Total (25 years)	71359.60									
CL Total (25 years)	7849.56									
PW Total (30 years)	78258.41									
CL Total (30 years)	8295.39									

Work sheet 6.11 Diesel running cost (sprinkling irrigation)

Case one Sprinkling	Sub. Total	Total	N Faddans	Q M3/F/day	H Meters	Duty cycle hours	life time years	daily op. hours/year	eng. Power KW	eng. Power HP	load fact.	litter pric. $
			50	20	40	7	5	300	23.95	32.10	0.7	0.1
Initial Cost $	7186.22											
Engine consumption cost $/year		1437.24										
Operation & Maint. & rep. Cost		2853.05										
fuel cost $/year	943.87											
oil & lubric. Cost/year	471.94											
rep. & Maint. Cost/year	1437.24											
labor cost $/year		9600.00										
		13890.30										
CL 20 years		176684.60										
CL 25 years		198075.66										
CL 30 years		219466.72										
total cost CL 20 years		179139.70										
total cost CL 25 years		200692.17										
total cost CL 30 years		222231.84										
water cost $/M3 20 year		0.597132344										
water cost $/M3 25 year		0.668973887										
water cost $/M3 30 year		0.740772792										

Case two Sprinkling	Sub. Total	Total	N Faddans	Q M3/F/day	H Meters	Duty cycle hours	life time years	daily op. hours/year	eng. Power KW	eng. Power HP	load fact.	litter pric. $
			50	20	80	7	5	300	47.91	64.22	0.7	0.1
Initial Cost $	14372.51											
Engine consumption cost $/year		2874.50										
Operation & Maint. & rep. Cost		5706.72										
fuel cost $/year	1888.14											
oil & lubric. Cost/year	944.07											
rep. & Maint. Cost/year	2874.50											
labor cost $/year		9600.00										
		18181.22										
CL 20 years *12.72		231265.08										
CL 25 years *14.26		259264.16										
CL 30 years *15.8		287263.23										
total cost CL 20 years		236175.69										
total cost CL 25 years		264497.59										
total cost CL 30 years		292793.91										
water cost $/M3 20 year		0.787252292										
water cost $/M3 25 year		0.881658646										
water cost $/M3 30 year		0.975979716										

Case three Sprinkling	Sub. Total	Total	N Faddans	Q M3/F/day	H Meters	Duty cycle hours	life time years	daily op. hours/year	eng. Power KW	eng. Power HP	load fact.	litter pric. $
			50	20	120	7	5	300	71.86	96.33	0.7	0.1
Initial Cost $	21558.79											
Engine consumption cost $/year		4311.76										
Operation & Maint. & rep. Cost		8559.78										
fuel cost $/year	2832.02											
oil & lubric. Cost/year	1416.01											
rep. & Maint. Cost/year	4311.76											
labor cost $/year		9600.00										
		22471.54										
CL 20 years *12.72		285837.99										
CL 25 years *14.26		320444.16										
CL 30 years *15.8		355050.33										
total cost CL 20 years		293203.34										
total cost CL 25 years		328293.72										
total cost CL 30 years		363345.73										
water cost $/M3 20 year		0.977344453										
water cost $/M3 25 year		1.094312394										
water cost $/M3 30 year		1.211152419										

Work sheet 6.10 Annual levelized cost calculations for diesel engine (dripping irrigation)

Dripling		N Faddans	Q M3/F/day	H Meters	Duty cycle hours	Hyd. Energy (KWh/day)	hyd. Power (KW/day)	dies. Eng. P. (KW)	dies. Eng. P. (HP)	Unit cost (300$/KW)
Case one		100.00	15.00	40.00	7.00	163.49	23.36	35.93	48.17	10779.36
PW $	10779.36									
PW (5 years)	8515.70									
PW (10 years)	6791.00									
PW (15 years)	5389.68									
PW (20 years)	4203.95									
PW (25 years)	3449.40									
PW Total (20 years)	31475.74									
CL Total (20 years)	3682.66									
PW Total (25 years)	35679.69									
CL Total (25 years)	3924.77									
PW Total (30 years)	39129.09									
CL Total (30 years)	4147.68									
Case two		100.00	15.00	80.00	7.00	326.97	46.71	71.86	96.33	21558.73
PW $	21558.73									
PW (5 years)	17031.39									
PW (10 years)	13582.00									
PW (15 years)	10779.36									
PW (20 years)	8407.90									
PW (25 years)	6898.79									
PW Total (20 years)	62951.48									
CL Total (20 years)	7365.32									
PW Total (25 years)	71359.38									
CL Total (25 years)	7849.53									
PW Total (30 years)	78258.17									
CL Total (30 years)	8295.37									
Case three		100.00	15.00	120.00	7.00	490.46	70.07	107.79	144.50	32338.22
PW $	32338.22									
PW (5 years)	25547.19									
PW (10 years)	20373.08									
PW (15 years)	16169.11									
PW (20 years)	12611.91									
PW (25 years)	10348.23									
PW Total (20 years)	94427.60									
CL Total (20 years)	11048.03									
PW Total (25 years)	107039.51									
CL Total (25 years)	11774.35									
PW Total (30 years)	117387.74									
CL Total (30 years)	12443.10									

Work sheet 6.12 Diesel running cost (dripping irrigation)

Case one Driping	Sub. Total	Total	N Faddans 100	Q M3/F/day 15	H Meters 40	Duty cycle hours 7	life time years 5	daily op. hours/year 300	eng. Power KW 35.93	eng. Power HP 48.16	load fact. 0.7	litter pric. $ 0.1
Initial Cost $	10779.36											
Engine consumption cost $/year		2155.87										
Operation & Maint. & rep. Cost		4279.88										
fuel cost $/year	1416.01											
oil & lubric. Cost/year	708.00											
rep. & Maint. Cost/year	2155.87											
labor cost $/year		9600.00										
		16035.76										
CL 20 years		203974.83										
CL 25 years		228669.90										
CL 30 years		253364.96										
total cost CL 20 years		207657.49										
total cost CL 25 years		232594.66										
total cost CL 30 years		257512.65										
water cost $/M3 20 year		0.4614611										
water cost $/M3 25 year		0.516877										
water cost $/M3 30 year		0.5722503										
Case two Driping	**Sub. Total**	**Total**	**N Faddans 100**	**Q M3/F/day 15**	**H Meters 80**	**Duty cycle hours 7**	**life time years 5**	**daily op. hours/year 300**	**eng. Power KW 71.86**	**eng. Power HP 96.33**	**load fact. 0.7**	**litter pric. $ 0.1**
Initial Cost $	21558.73											
Engine consumption cost $/year		4311.75										
Operation & Maint. & rep. Cost		8559.77										
fuel cost $/year	2832.02											
oil & lubric. Cost/year	1416.01											
rep. & Maint. Cost/year	4311.75											
labor cost $/year		9600.00										
		22471.51										
CL 20 years *12.72		285837.66										
CL 25 years *14.26		320443.79										
CL 30 years *15.8		355049.92										
total cost CL 20 years		293202.98										
total cost CL 25 years		328293.32										
total cost CL 30 years		363345.29										
water cost $/M3 20 year		0.6515622										
water cost $/M3 25 year		0.7295407										
water cost $/M3 30 year		0.807434										
Case three Driping	**Sub. Total**	**Total**	**N Faddans 100**	**Q M3/F/day 15**	**H Meters 120**	**Duty cycle hours 7**	**life time years 5**	**daily op. hours/year 300**	**eng. Power KW 107.79**	**eng. Power HP 144.49**	**load fact. 0.7**	**litter pric. $ 0.1**
Initial Cost $	32338.22											
Engine consumption cost $/year		6467.64										
Operation & Maint. & rep. Cost		12839.68										
fuel cost $/year	4248.02											
oil & lubric. Cost/year	2124.01											
rep. & Maint. Cost/year	6467.64											
labor cost $/year		9600.00										
		28907.32										
CL 20 years *12.72		367701.16										
CL 25 years *14.26		412218.44										
CL 30 years *15.8		456735.72										
total cost CL 20 years		378749.19										
total cost CL 25 years		423992.79										
total cost CL 30 years		469178.82										
water cost $/M3 20 year		0.8416649										
water cost $/M3 25 year		0.9422062										
water cost $/M3 30 year		1.0426196										

حساب القيمة الايجارية للمعدات / الساعة

طريقة تكاليف الملكية والتشغيل

أولاً : تكاليف الملكيـة : -

الإهلاك :-

قيمة الإهـــلاك / ســاعة = قيمة شــراء المعــدة (سـعر الشــراء الأساســي) ÷ [(عدد سنوات الإهــلاك) × (عــدد ســاعات التشــغيل اليومــي × ســنة)]

....

ثانياً : تكـاليف التشغيل :-

١) تكلفة الوقود / الساعة = ٠,٢ × أقصى قدرة للمحــرك H.P × معــامل التحميــل × ســعر لــتر الوقــود

حيث أن معامل التحميل = ٠,٧

٢) تكلفة الزيوت والتشحيم / الساعة = ٠,٥ تكلفـــة الوقــود / الســاعة

٣) *تكلفة الصيانة والإصلاحات/ الساعة* = قيمة الإهلاك / ساعة

إجمالى تكلفة التشغيل / الساعة = (١) + (٢) + (٣)

....

ثالثاً : تكلفة عمالـة التشغيل :-

تكلفة عمالة التشــغيل / الســاعة = [٤ × المرتــب الأساســي × الســــنة] ÷ [عــدد ســاعات التشــغيل / ســنة]

إجمالى تكلفة الاهلاك والتشغيل والصيانة الفعلية / الساعة = أولاً + ثانياً + ثالثاً
الإهلاك + التشغيل + العمالة

بسم الله الرحمن الرحيم

جمهورية مصر العربية
محافظة أسوان
القطاع الزراعى

بيان الاحتياجات المائية لبعض المحاصيل الحقليه

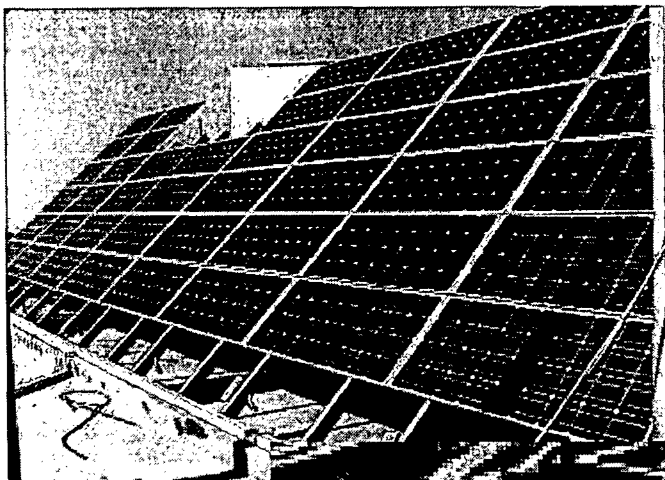
أسم المحصول	الاحتياجات المائية للفدان بالمتر المكعب			ملاحظات
	رى بالراحه	رى بالتنقيط	رى بالرش	
القمح	٢١٠٠	١٢٦٠	١٥٧٥	
الفول	١٦٠٠	٩٦٠	١٢٠٠	
الشعير	١٧٠٠	١٠٢٠	١٢٧٥	
الحلبة	١٢٩٠	٧٧٤	٩٦٧ر٥٠	
الترمس	١٤٠٠	٨٤٠	١٠٥٠	
الحمص	١٤٠٠	٨٤٠	١٠٥٠	
العدس	١٢١٧	٧٢٠ر٢٠	٩١٢ر٧٥	
البرسيم البلدى	٤٠٠٠	٢٤٠٠	٣٠٠٠	
البصل	٢٧٠٠	١٦٢٠	٢٠٢٥	
الثوم	١٩٠٦	١١٤٣ر٦٠	١٤٢٩ر٥٠	
الذره الشامى	٢٢٠٠	١٣٢٠	١٦٥٠	الاحتياجات الصيفيه
" الرفيعه	٢١٠٠	١٢٦٠	١٥٧٥	هى ذاتها النيليه
السمسم	٢٤٤٠	١٤٦٤	١٨٣٠	
الفول السودانى	٢٨٦٠	١٧١٦	٢١٤٥	
القصب	١٢٠٠٠	٧٢٠٠	٩٠٠٠	

فى ٢١/٣/٩٩

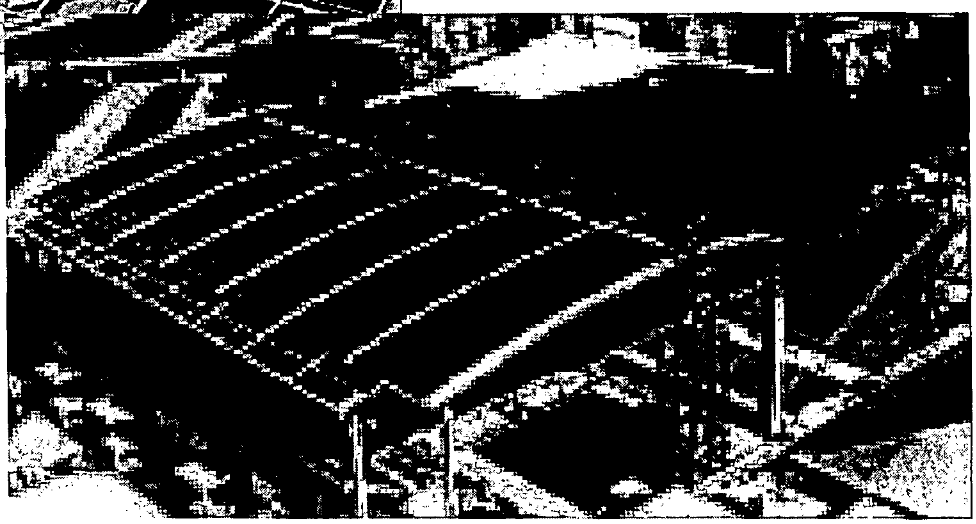
مدير عام الزراعه باسوان
١٩٩٩ ٢١
مهندس/ " سمير مرغنى بيومى "

THE GREEN POWER FROM BIC

For Electronics, Environment & Energy



PV Industry In Egypt



Presented By:

Eng. Sherif Bahnas

THE GREEN POWER FROM BIC
For Electronics, Environment & Energy

Presentation Outline

1- **Source of Energy:** Explaining the various factors affecting the solar radiation on PV modules.

2- **The Photovoltaic Principle:** Explaining the principle of cell and module production.

3- **Photovoltaic Systems:** Describing the different types of Photovoltaic systems.

4- **System Components:** Describing the main components that are integrated to form Photovoltaic systems.

5- **General Applications:** Examples of different types of applications.

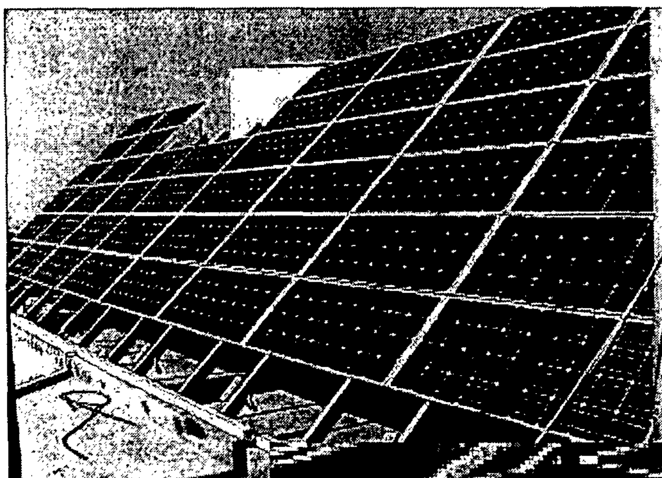
6- **BIPV:** Briefly discussing the main differences between Building Integrated PhotoVoltaics, and other systems.

7- **Case Studies:**

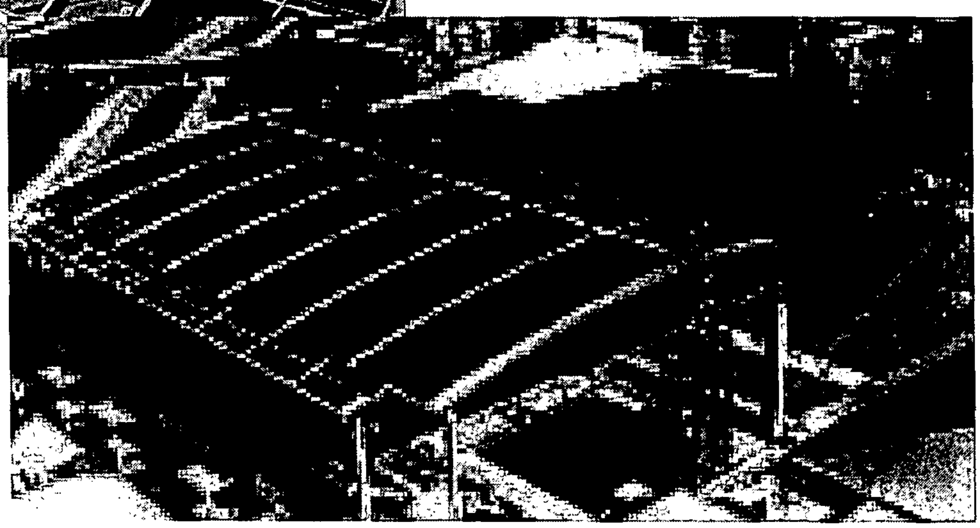
- Diesel Generator Vs. Solar Energy application
- BIPV application

THE GREEN POWER FROM BIC

For Electronics, Environment & Energy



PV Industry In Egypt



Presented By:

Eng. Sherif Bahnas

Questions

1- Cell or Module Manufacturing?

2- Why PV Booming in World Market?

3- How to Encourage PV Industry in Egypt?

4- Why Oil Companies?

Module Manufacturing line

- This line depends on availability of cells.

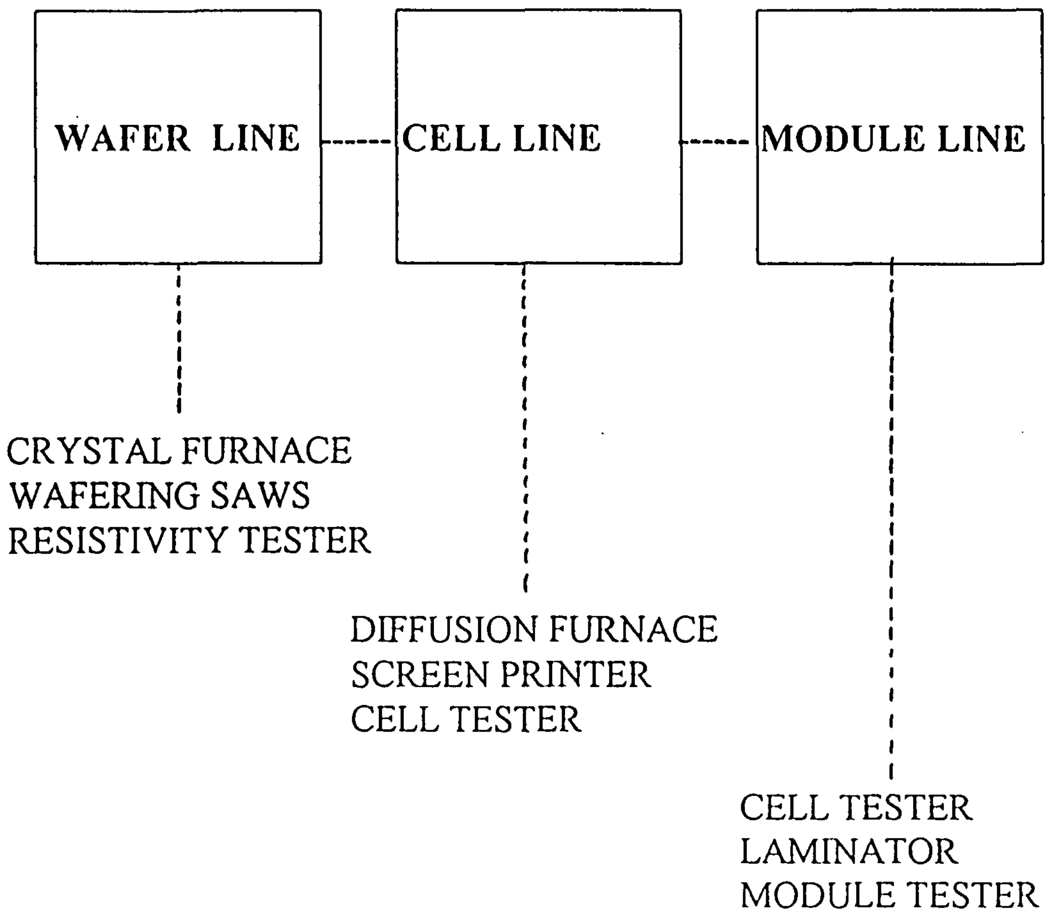
- The difference between the price of Module and the price of the Module kit is 0.45$/w.

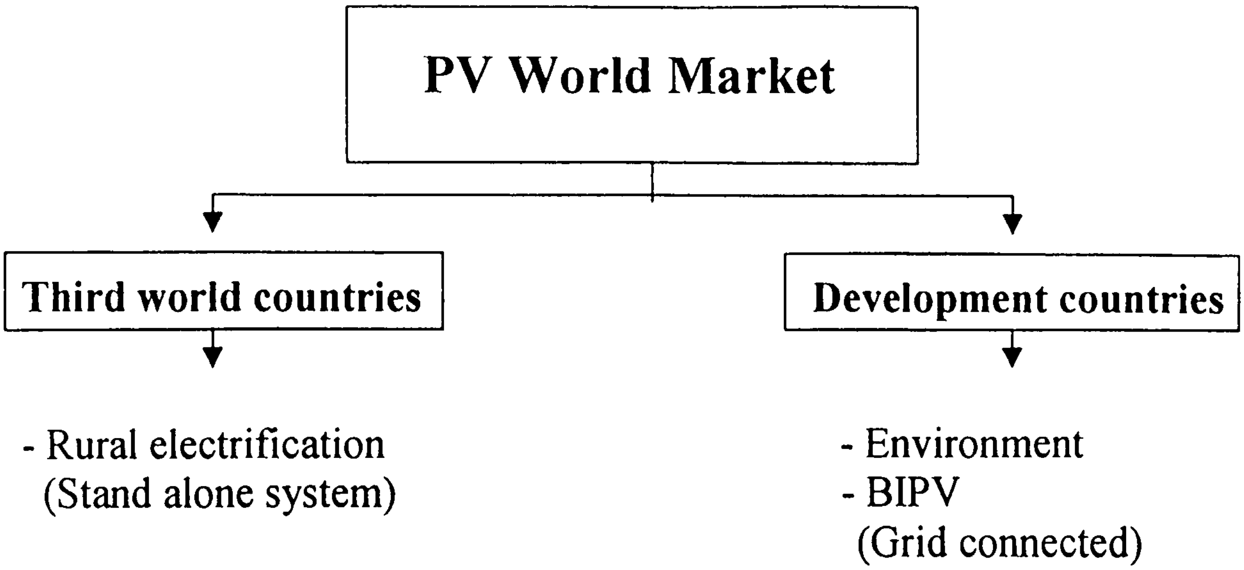
Cell Manufacturing line

- This line depends on availability of wafers .

- The difference between cell prices and wafers is 0.8$/w.

PV MANUFACTURING





Suggestions to encourage PV industry in Egypt

1- Education

2- Import Duty

3- Sales Tax

4- Soft loan

5- 100% Depreciation over 2 years

SIMPLE ECONOMIC ANALYSIS OF GRID-CONNECTED PV SYSTEMS IN JAPAN

Option	No subsidy 1999 8% capital recovery	35% subsidy 1999 5% capital recovery
Installed cost ($/Wp AC)	$8.00	$8.00
Annual sun peak hours/year	1200	1200
Capital recovery factor	0.08	0.05 (20-year simple payback)
Subsidy	00	2.80/w
Electricity price	$0.27/kWh	$0.27/kWh
Electricity cost (PV)	$0.53/kWh	$0.217/kWh

Development Bank of Philippine

100 SHS 25% Equity
9% subsidy from the government
66% loan (5 years)

Problems → Used equipment in excess of installed power.
Maintenance .
Trained technician looking for other opportunities.

After 5 years 10 SHS are only working.

Why Oil Companies ??

BP acquired ⟶ Solarex

Shell acquired ⟶ Siemens Solar

Providing PV Solutions in Egypt

General Mohamed Abdel-Hai
ASET (Arabian Solar Energy & Technology Co.), Sinai Branch

The presentation discusses the following main points:

1- Introduction; What about "ASET"?

2- Solar Systems

3- Major Projects; Billboards, Street Lighting, Home; Telecom, Railroad Signaling, Grid Connected, Toll Stations, etc.

4- Obstacles facing the expansion of using PV in Egypt.

5- Cost comparison between (prime Diesel – PV Diesel Hybrid, Stand Alone PV and Utility)

6- Suggested Solutions (Government and Bank support and encouragement).

Arabian Solar
Energy and
Technology co

ASET

الشركة العربية
للطاقة الشمسية
والتكنولوجيا

Providing PV Solutions in Egypt

ASET Profile

- Established in 1992
- Specialized in PV, and Industrial Batteries
- Promoting PV in Egypt & Middle East
- 60 Employee (Full Time)

- **ISO 9001**
  - **By DNV**
  - ***In Design, Sales, Installation, and Servicing of Solar Systems, Solar Components, and Industrial Batteries.***

DET NORSKE VERITAS

QUALITY SYSTEM CERTIFICATE

Certificate No. QSC - 4658

This is to certify that the Quality System of

Arabian Solar Energy and Technology (ASET)

at

11, Sherif St., Cairo, Egypt

has been found to conform to the Quality System Standard:

ISO 9001:1994

This Certificate is valid for the following product or service ranges:

Design, Sales, Installation and Servicing of Complete Solar Systems, Solar Components and Industrial Batteries.

Place and date:
Rotterdam, September 16th, 1999

This Certificate is valid until:
September 16th, 2002

Original Certification date:
September 16th, 1999

for the Accredited Unit:
DNV CERTIFICATION B.V., THE NETHERLANDS

Accredited by the RvA

Ron J. Meijer
Management Representative

Elhab El Sherif
Lead Auditor

Lack of fulfilment of conditions as set out in the Appendix may render this Certificate invalid.

DOCNO. CERTIS_9710

DNV CERTIFICATION B.V., Haastrechtstraat 7, 5079 DC Rotterdam, The Netherlands; TEL.INT.:+31 10 2922 688, FAX:+31 10 4706 768

ASET Profile

- Agents of :
  - Siemens Solar. Germany & USA
  - Siemens Showa. Australia
  - GNB Technologies. USA
  - Rosendahl GmbH. Germany
  - PECO II. USA
  - Egycel. EGYPT

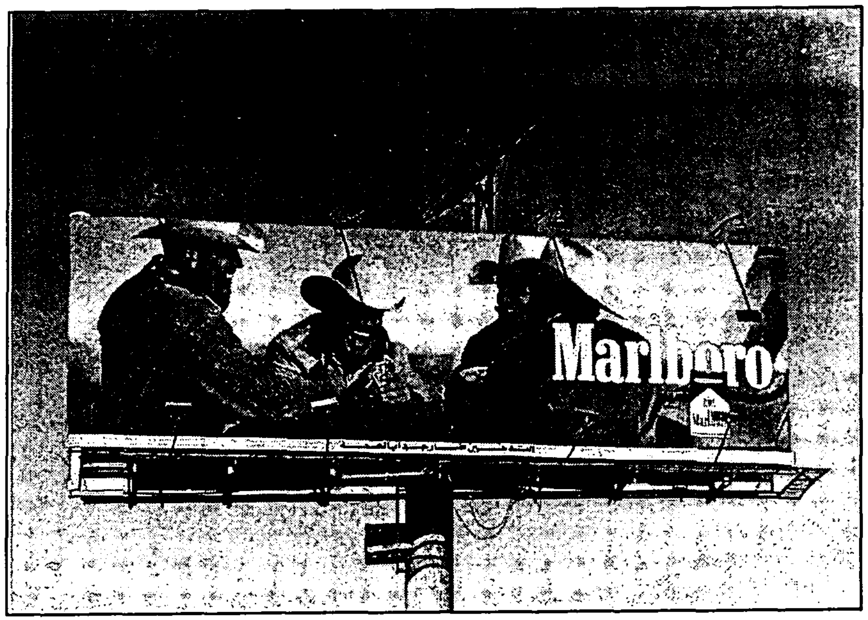
ASET Profile

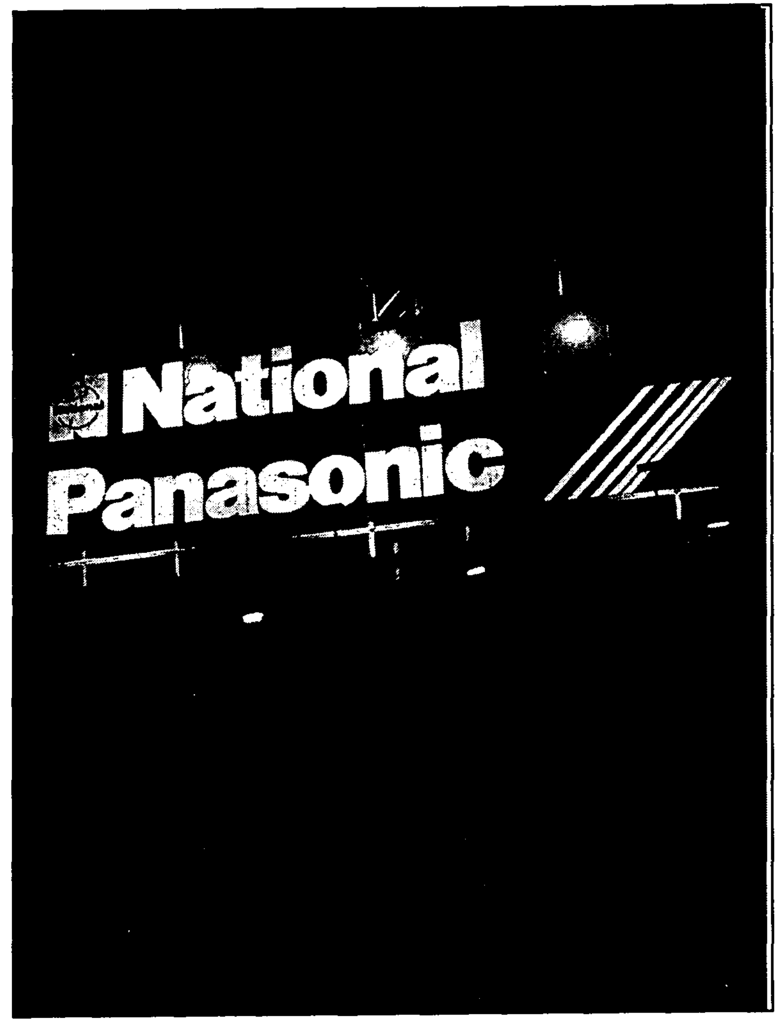
- Head Quarter (Down Town, Cairo)
- Installation (Embaba, Giza)
- Maintenance (Warak, Giza)
- Workshop 1 (AL-Haram, Giza)
- Workshop 2 (Bassous, Dakahlia)
- Sinai Branch (Sharm EL-Shekh)

Major Projects

Billboards

- More thank 160 Billboards in Egypt
- Major Advertising Companies
  - AL-Ahram Advertising Agency
  - American Advertising Agency
  - AL-Masria Advertising Agency
  - Link Company
  - Shine Advertising

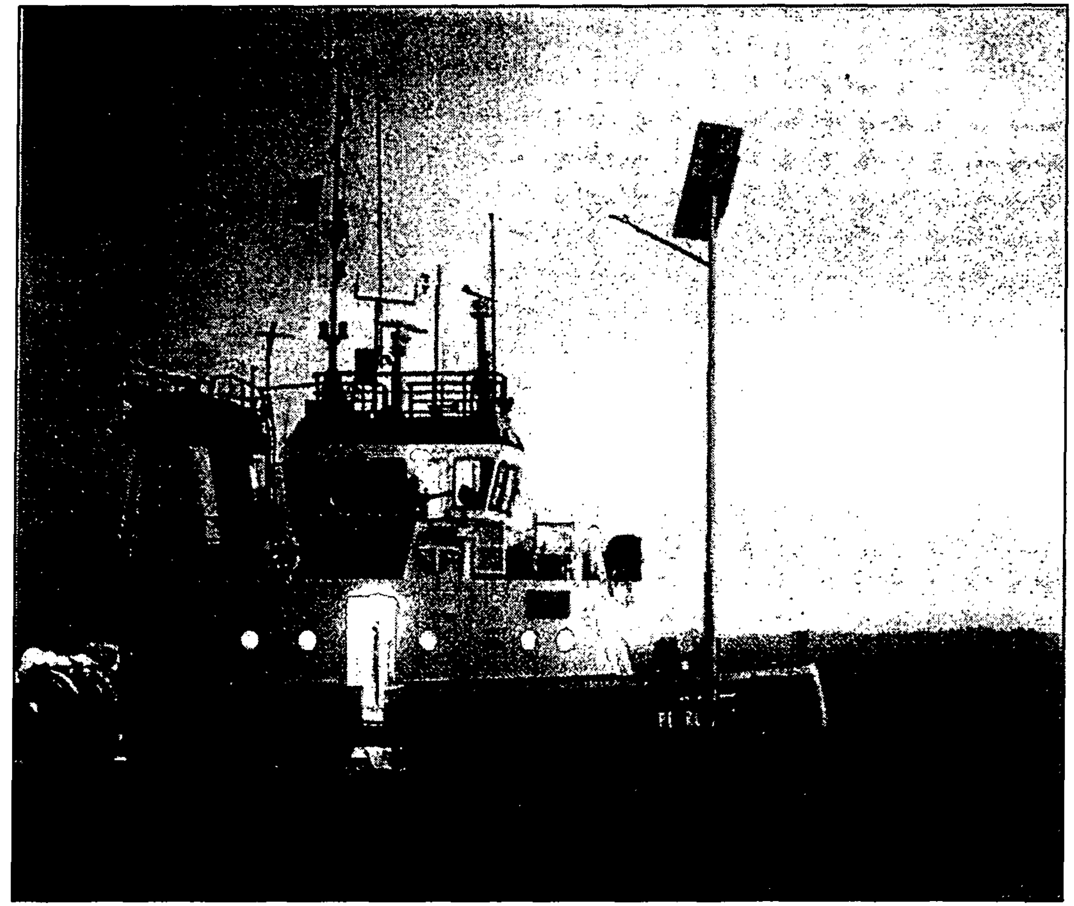




Major Previous Projects

Street Lighting

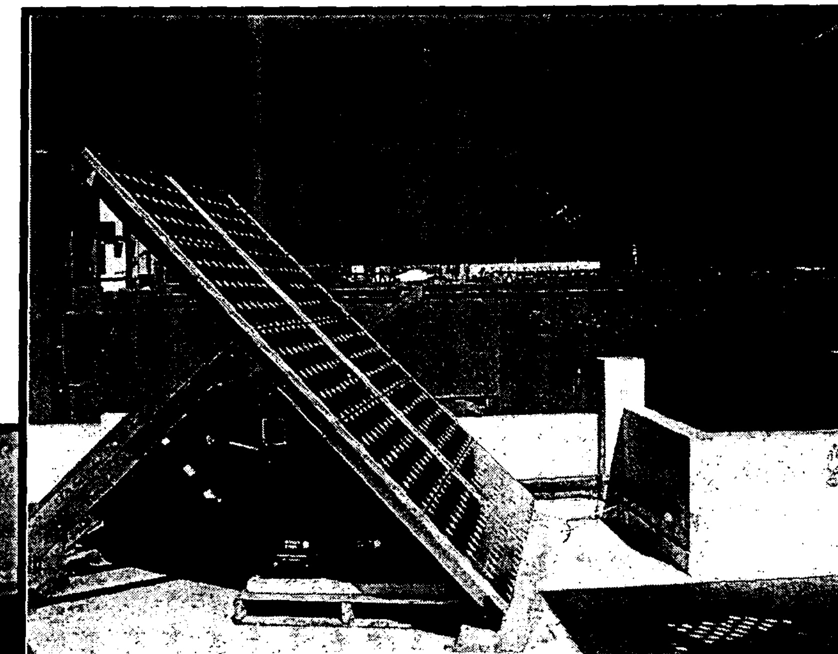
- Marine Port
- Petroject Oil Services
  - •16 Street Lighting System
  - •36 Watt Florescent Lamps
  - •36 Watt LPS Lamps



Major Previous Projects

Home & Camping

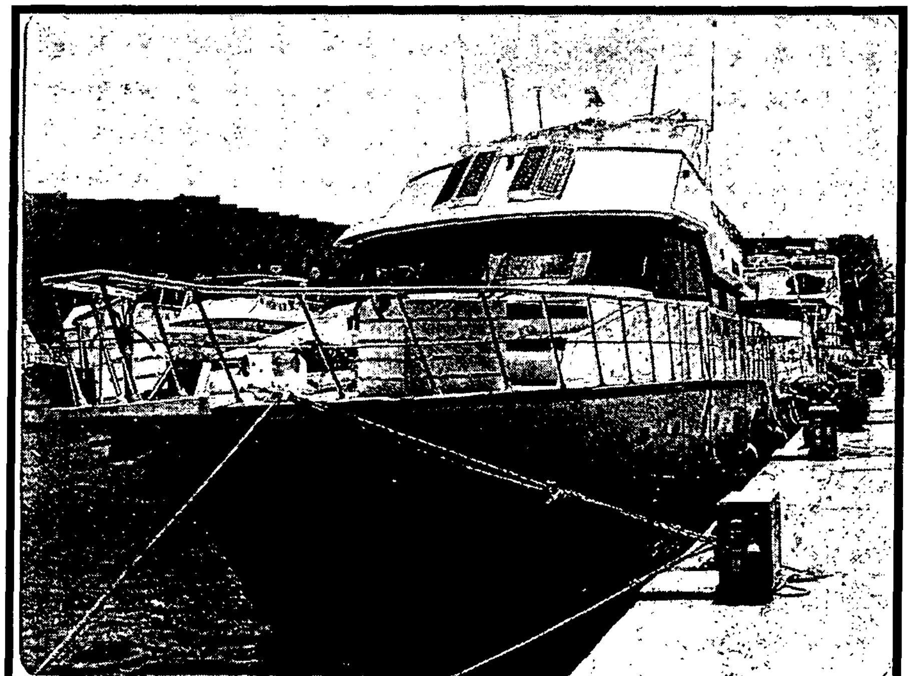
- More than 550 Sites around Egypt
  - Egyptian Ministry of Defense
  - U.S. AID
  - South Sinai Protectorate
  - New Bassaysa Community

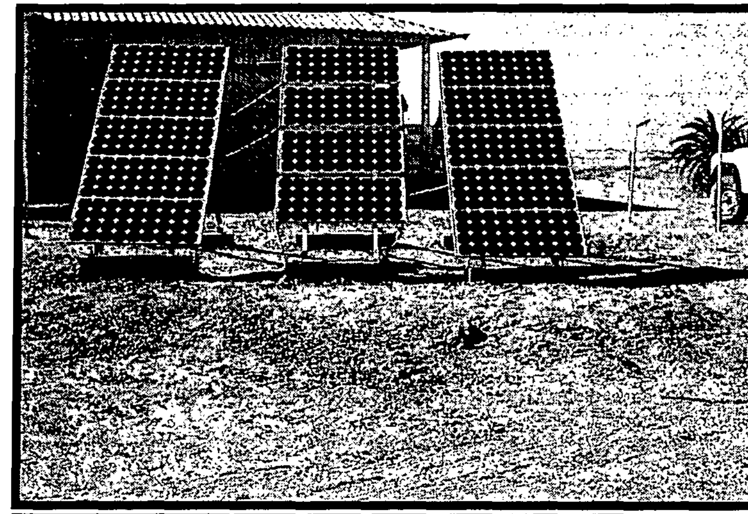


Major Previous Projects

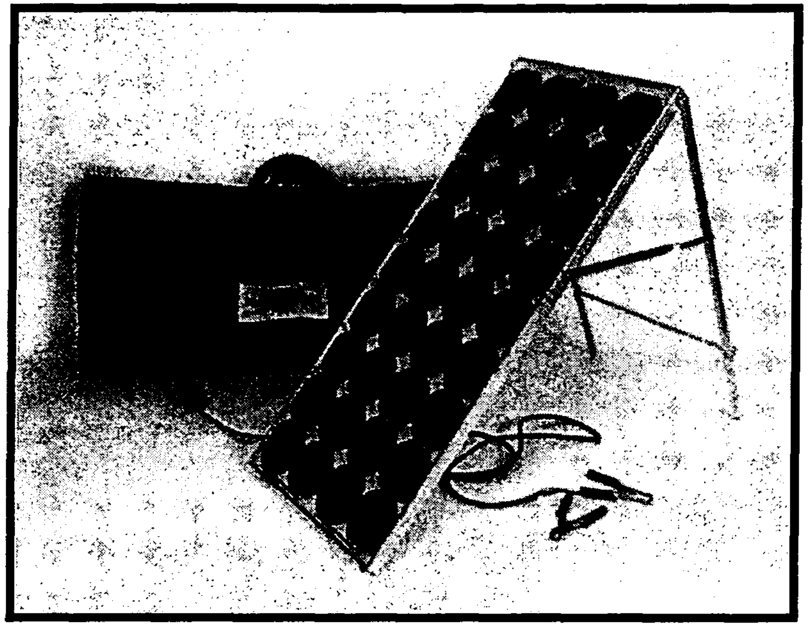
Home & Camping

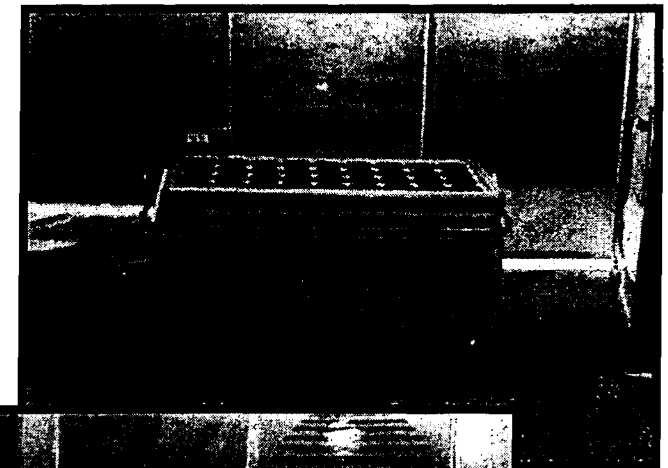
- More than 550 Sites around Egypt
  - Boats in Hurghada, and Sharm EL-Shekh
  - Remote houses in Reclamation Lands

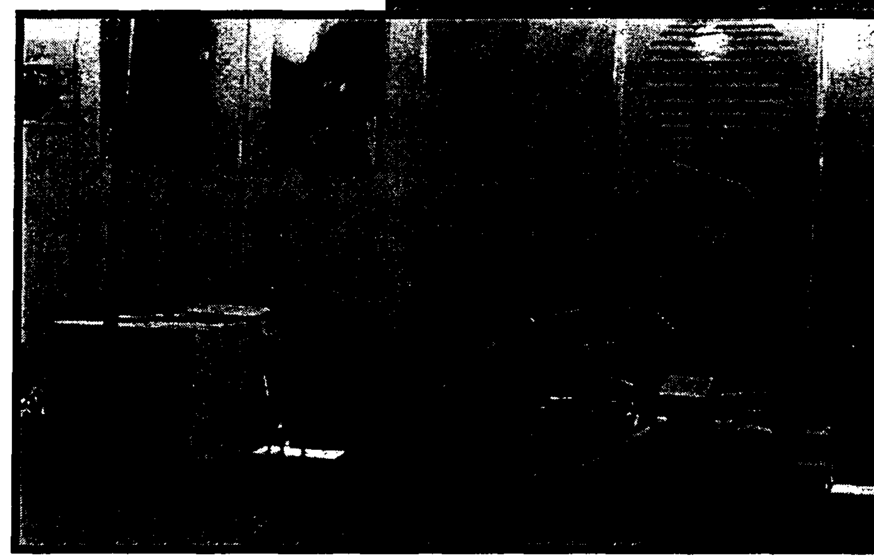




Home & Camping







SAFARI Systems

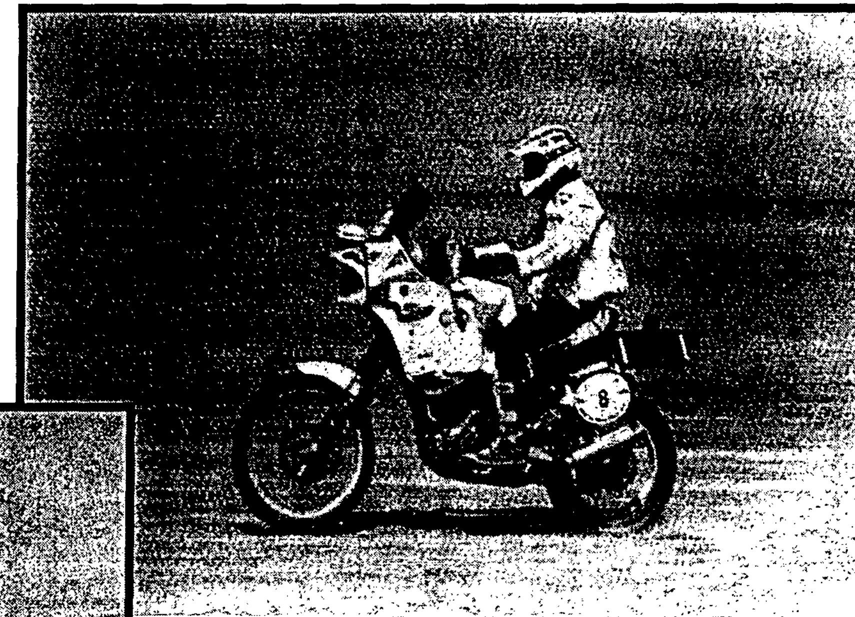
Systems : 1, 2, and 3 Solar Modules
Module : SP75 Solar Modules
Battery : GNB 12-5000X (1, 2, and 3)
Voltage : 12, 24 VDC, and 220 VAC
Purpose : Mobile Systems for Camping and Safari Trips

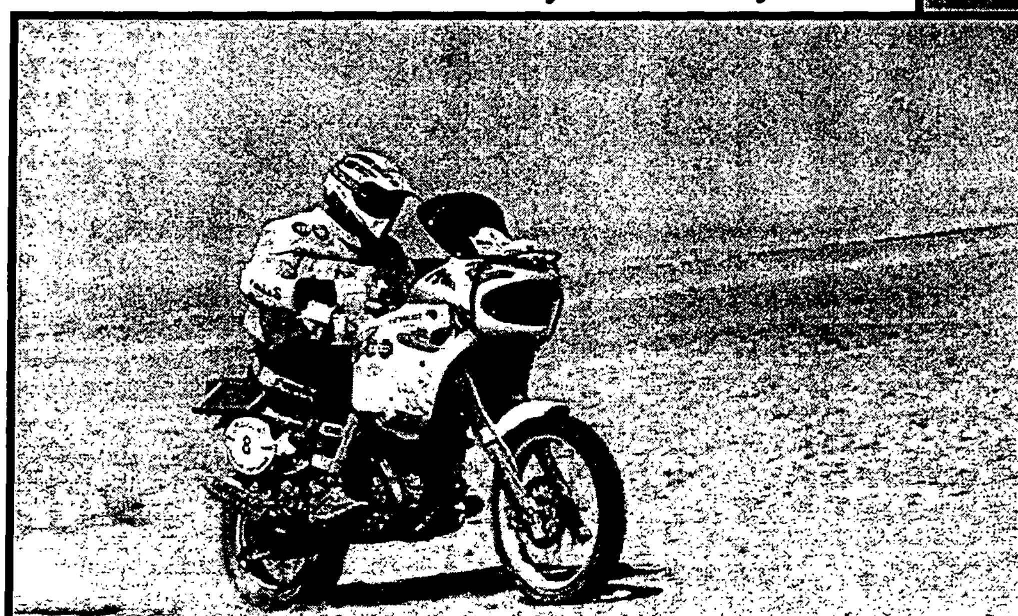
Major Previous Projects

Home & Camping

GPS

Owner : Raed Badar "Pharos Rally"
Power : (2) SM5 Solar Modules
Battery : 12 AH
Voltage : 12 VDC
Purpose : GPS operation independently from the Motorcycle Battery

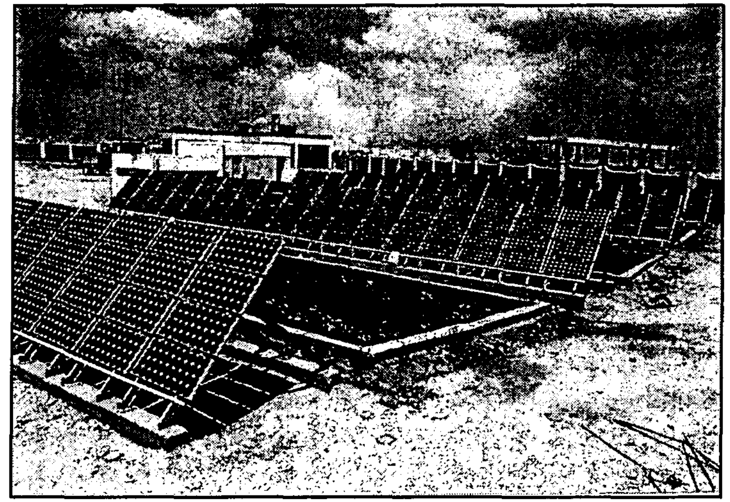


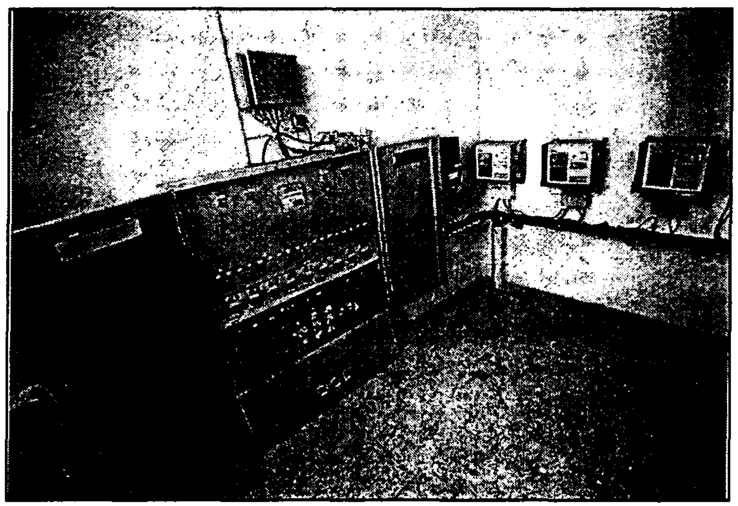


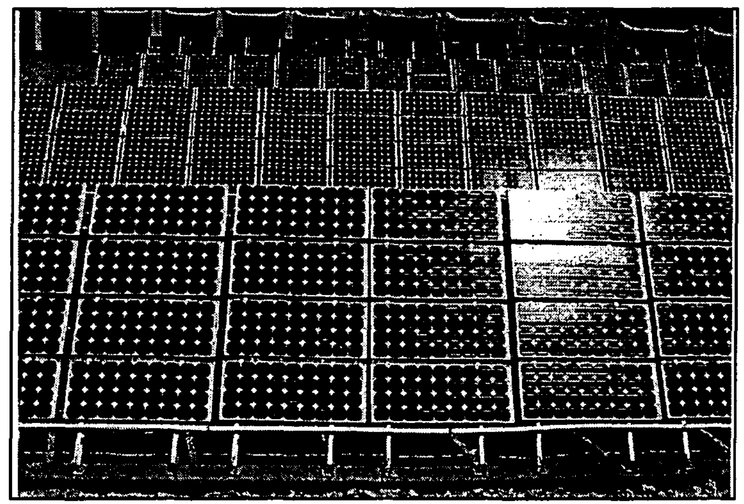
Major Previous Projects

Central Stations

- Center Stations
  - Roads & Bridges Authorities
  - 2 Sites in EL-Suze & EL-Een EL-Sokna
  - EL-Sokna 23,700 Watt p
  - EL-Suez 9,900 Watt p
  - Fully Automated
  - Remote Controlled



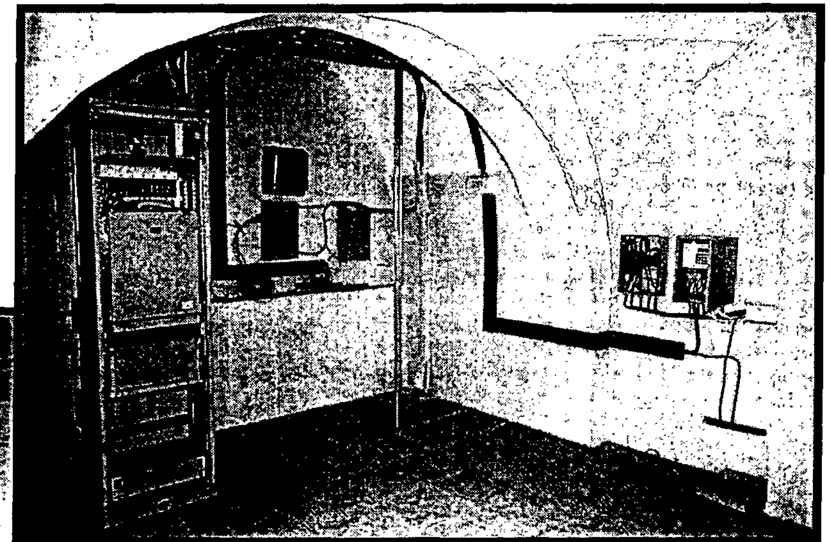


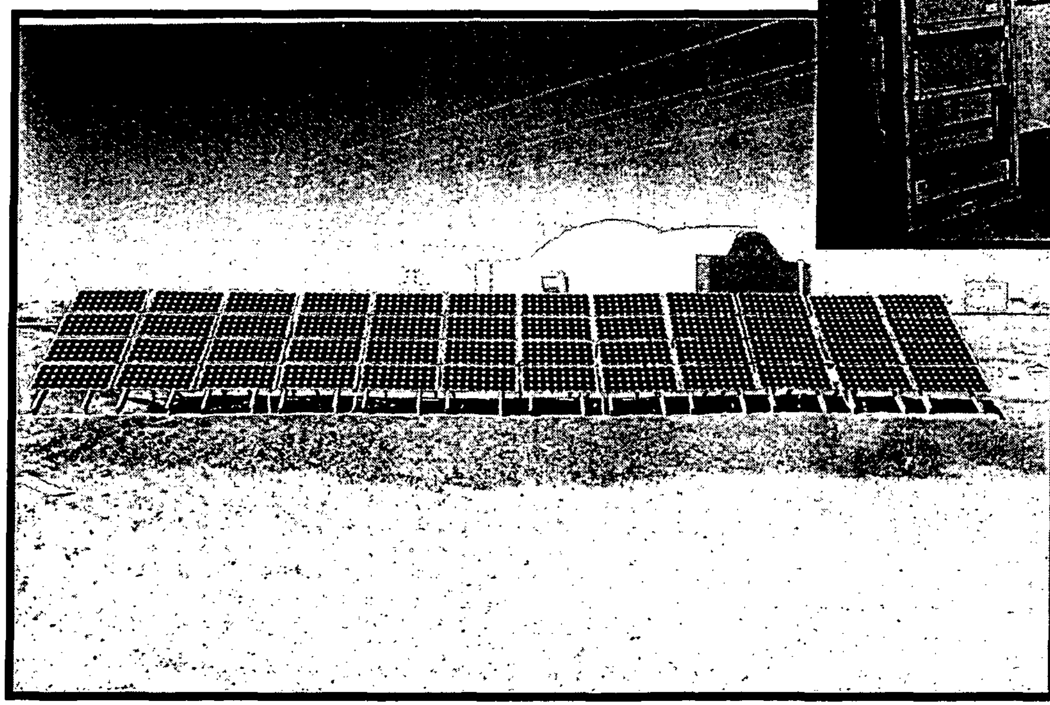


Major Previous Projects

Telecom Sites

- More than 50 Sites for Telecom Egypt
  - Toushki
  - Owinat
  - Darb EL-Arbeen
  - EL-Farafra



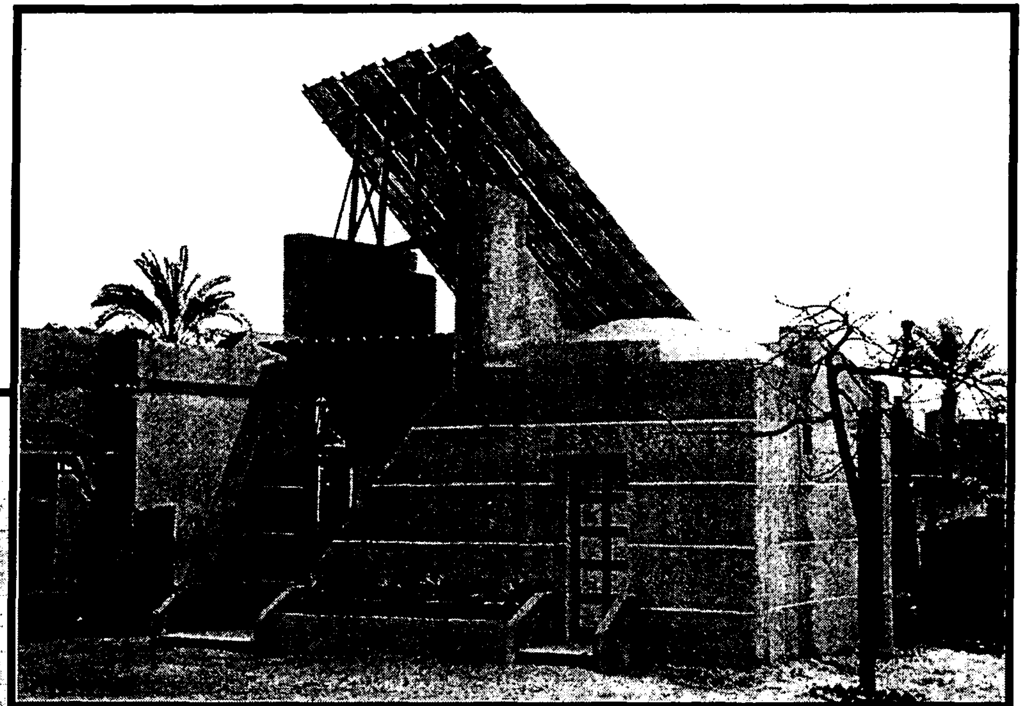


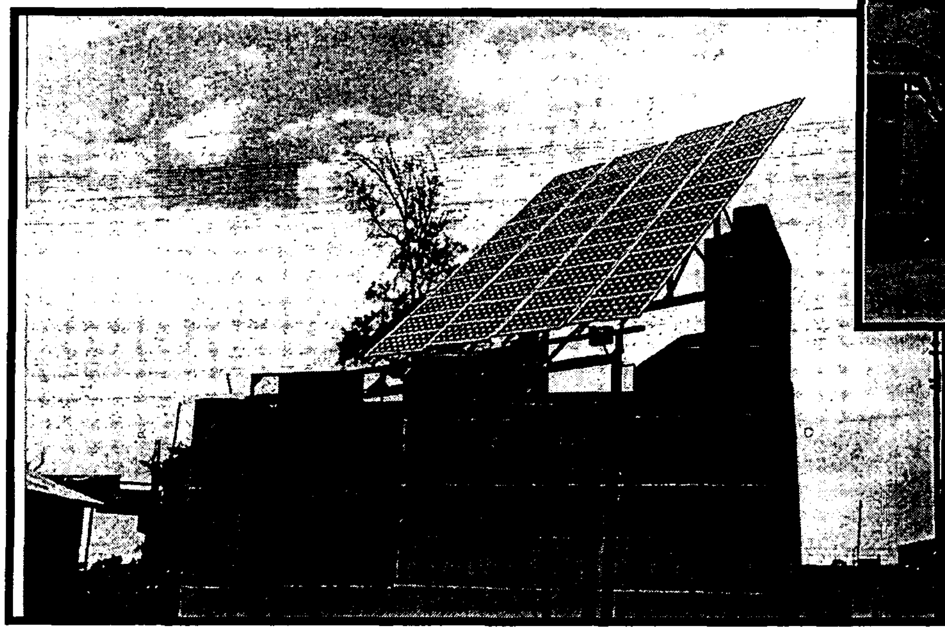
Major Previous Projects

Rail Road Signaling

Rail Way Signaling

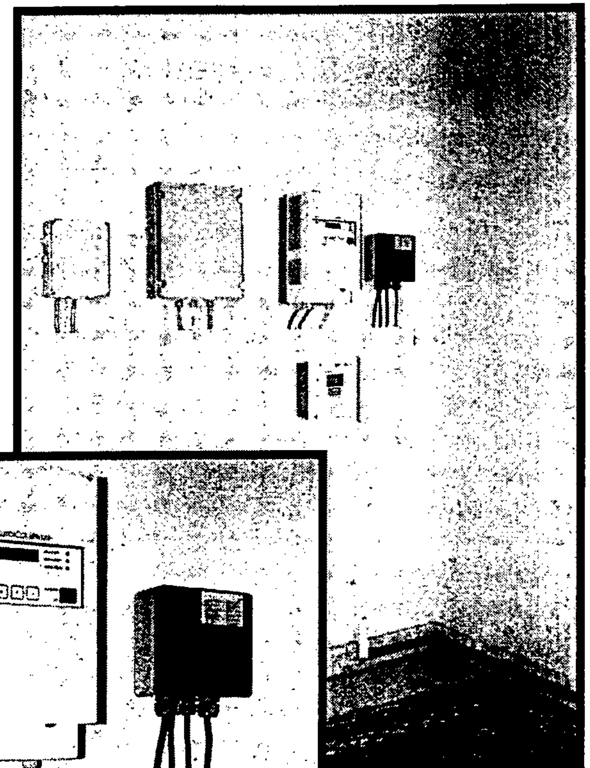
Owner : Rail Way Authority
Power : (40) SP75 Solar Modules
Battery : 1200 AH, GNB ABSOLYTE IIP
Voltage : 24 VDC, and 220 VAC
Purpose : Control Traffic Signaling on Cairo Alexandria Line

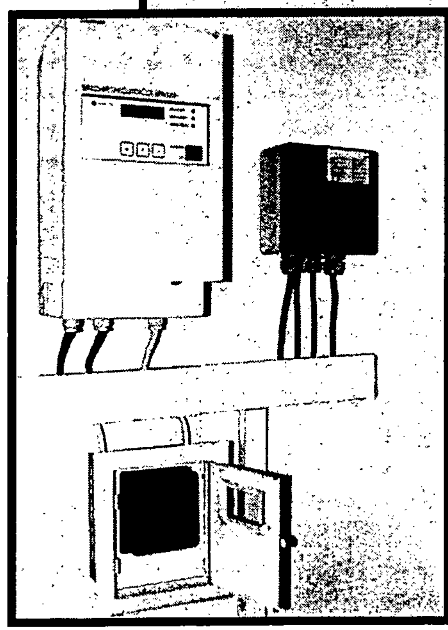


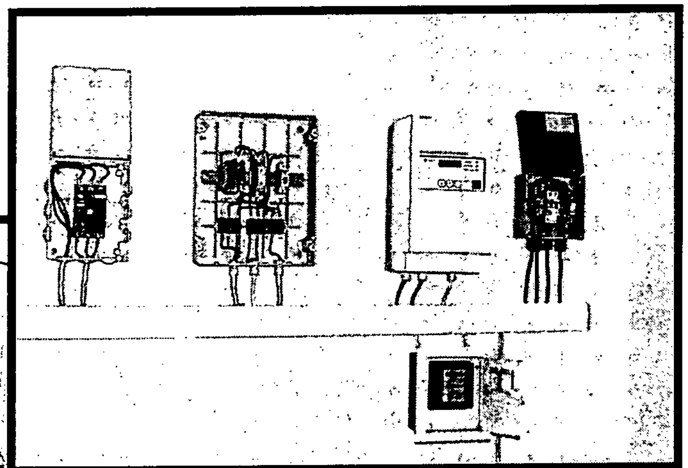


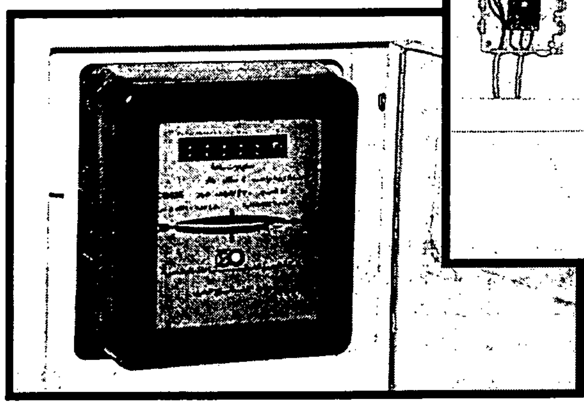
Grid Connected

- First Grid Connected System in Egypt
  - City Council of Sharm EL-Shekh
  - 12 SP75 Solar Modules directly connected to the Grid through Siemens Grid Inverter
  - Generating Around 5.5 KWH/Day





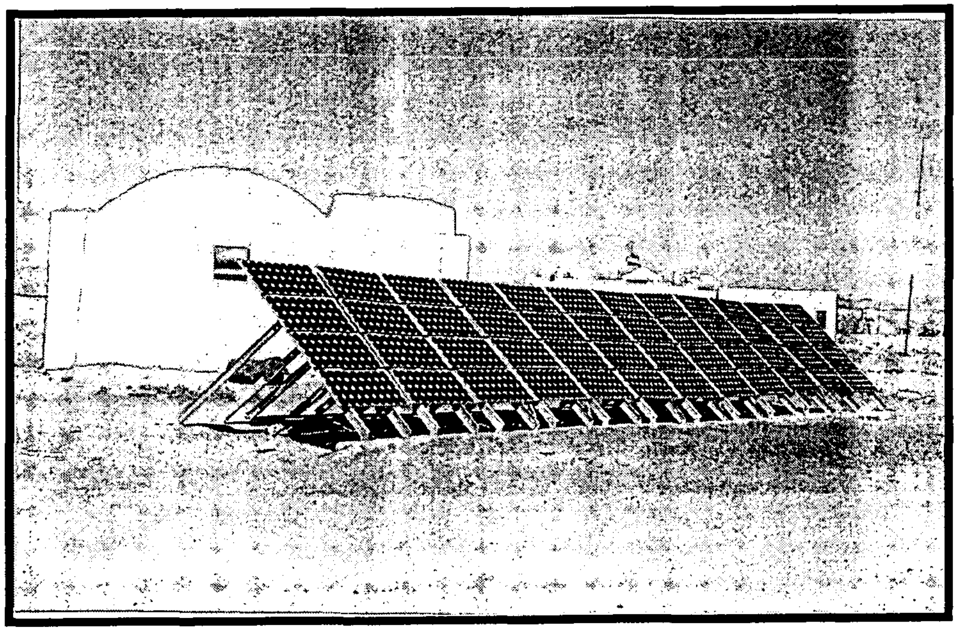


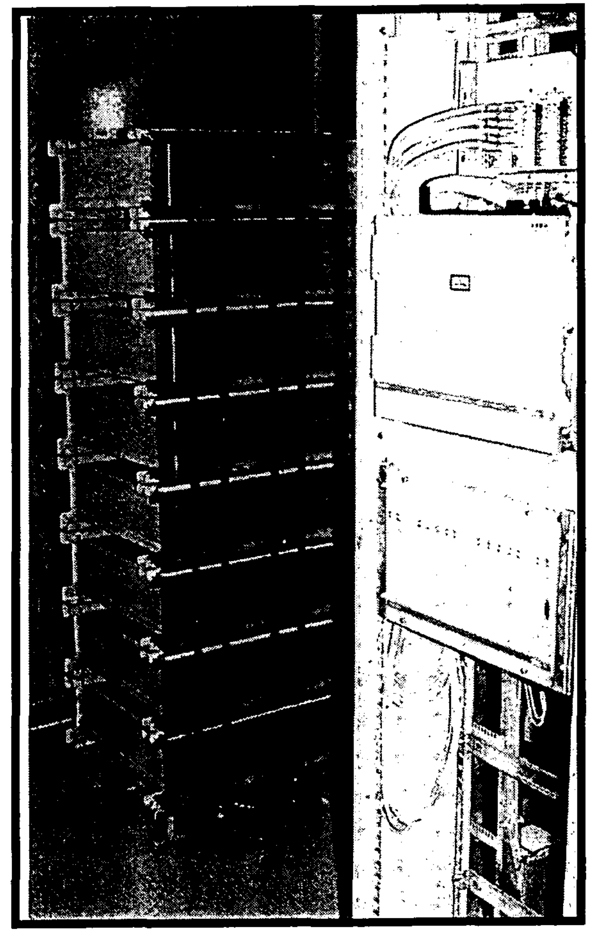


Details of Some Projects

Telecom Egypt

- The Biggest Telecom Solar System in Egypt is under construction now:
  - 240 SP75 Siemens Solar Modules - 18000 Watt p
  - GNB ABSOLYTE IIP Batteries 10370 AH, C_{100}
  - (-) 48 VDC
  - Operating Base Station
  - Remote Control Using Siemens Controller

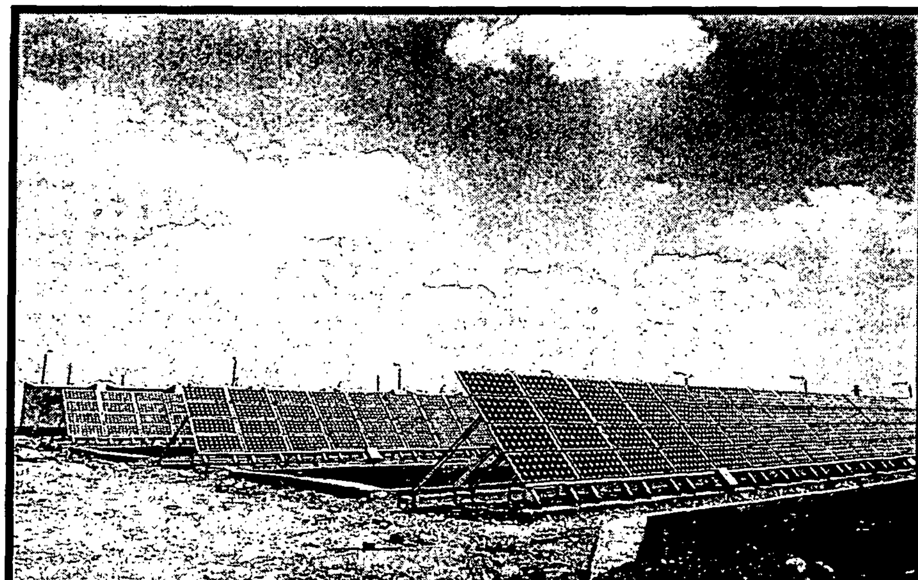


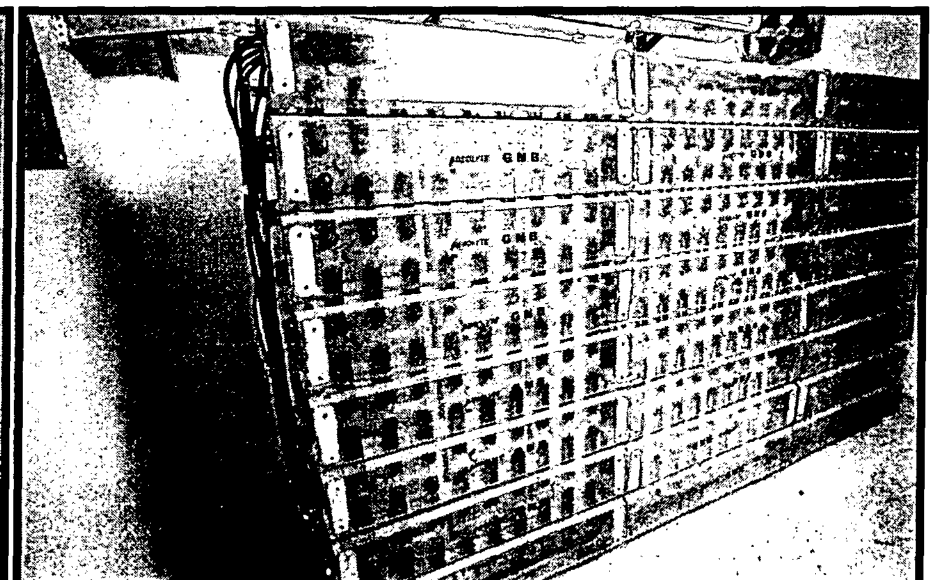


Details of some Project

Toll Station (Sokna)

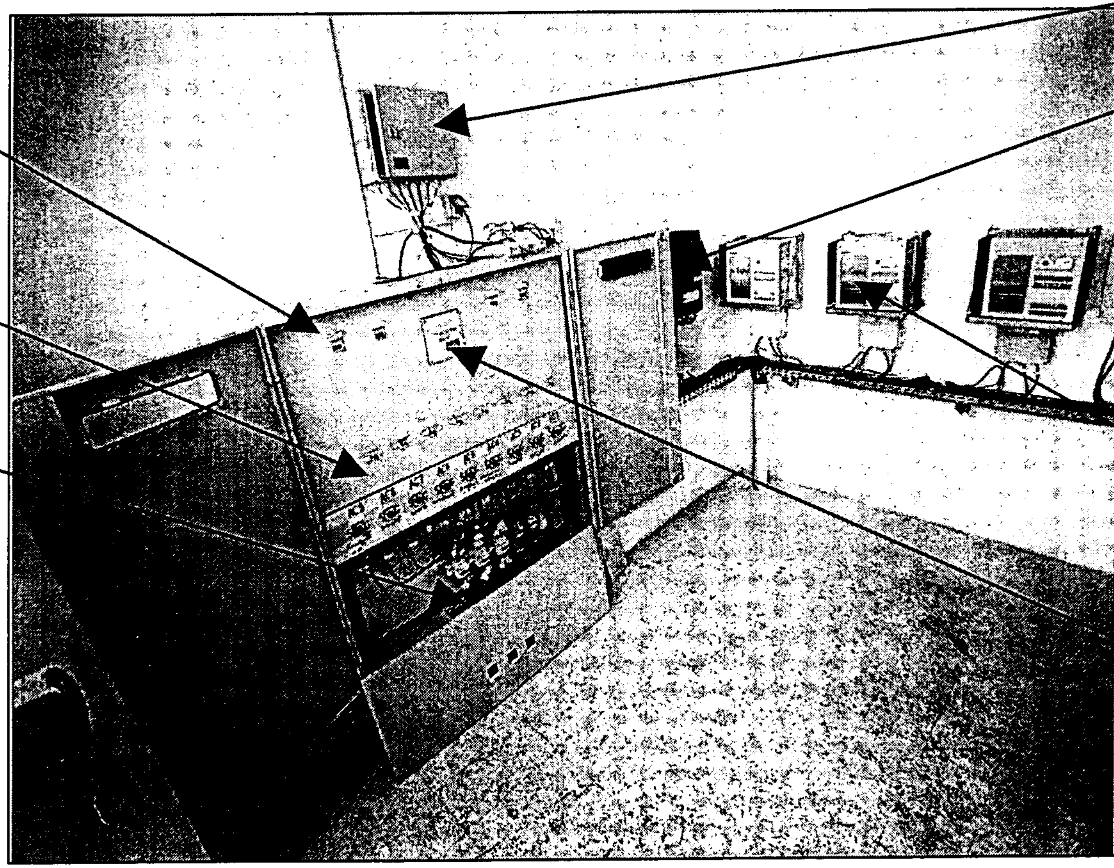
- **General Specifications**
  - Roads & Bridges Authorities
  - (316) SP75 Siemens Modules
  - 23,700 Watt p
  - GNB Technologies Batteries ABSOLYTE IIP 5585 AH, C_{100}
  - Solar System 48 VDC
  - Final System Voltage 220 VAC
  - Fully Automated, and Controlled by MODAS 1632 (NES)
  - Remote Controlled via Telephone Modem



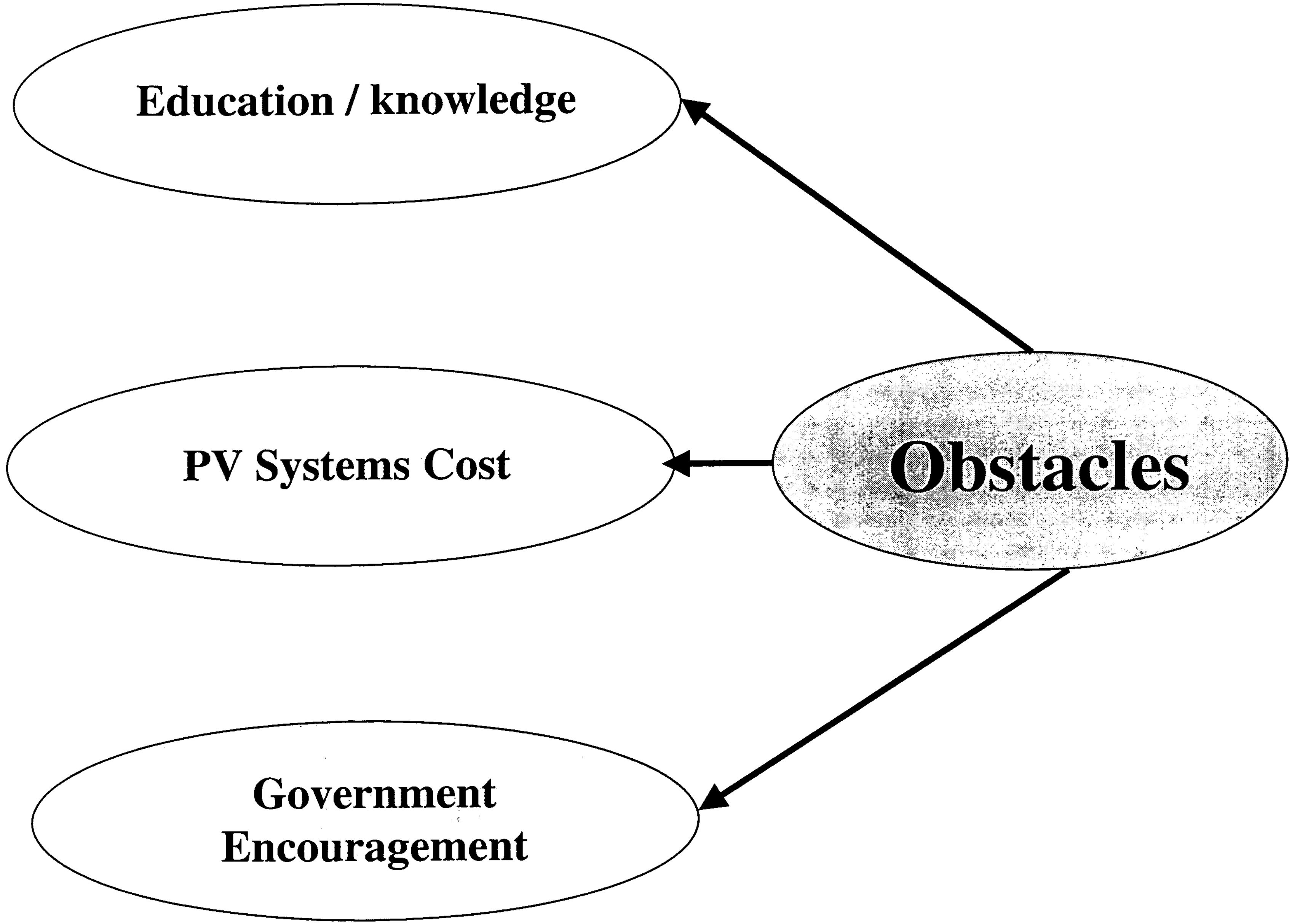


Toll Station (Sokna)

Components



Obstacles that prevent the expansion in using Photovoltaic in Egypt


Education / knowledge
PV Systems Cost
Government
Encouragement
Obstacles

Education / knowledge

Many People do not know that electricity can be produced through solar energy

Furthermore, some people confuse in the use of photovoltaic and thermal heat

[redacted]

Prices are already high from original manufacturers Sources

Customs & Taxes				
Total	Government Tax	Sales Tax	Customs	Type
26.50%	5%	10%	10%	Solar Modules
26.50%	5%	10%	10%	Controllers
37.50%	5%	10%	20%	Inverter
59.50%	5%	10%	40%	Batteries

Government Encouragement

↓

Government dos not give special facilities for photovoltaic users

Cost Comparison between (prime Diesel – PV Diesel Hybrid – Stand alone PV – Utility)

TECH CORNER

Life Cycle Cost Analysis

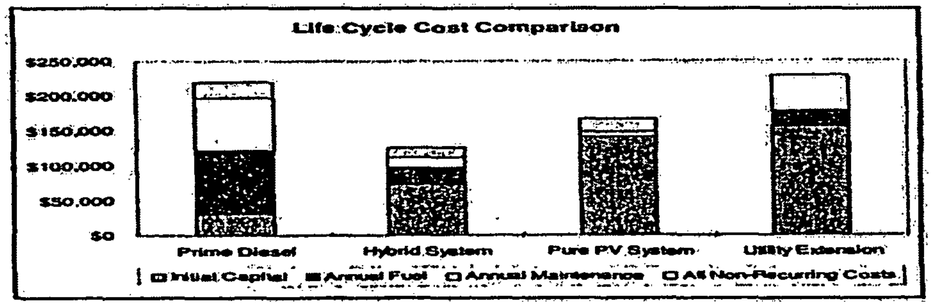
Costs are incurred at different times throughout the life of different power generation systems. It is not fair to compare only the initial costs. The total costs over time must be assessed and added to the initial costs to arrive at a true "life cycle cost" for different approaches. A technique called Life Cycle Cost Analysis (LCC) looks at the total costs of different energy solutions over their operational lifetime, and the results can be quite surprising.

Three different types of costs should be analyzed:

- ***Initial capital costs*** of equipment and installation, including modules, batteries, controls and wiring, civil work, generators and fuel systems and storage, or utility line extension costs.
- ***Recurring costs*** that occur on schedule during every year of operation, such as fuel and regular maintenance.
- ***Nonrecurring costs*** that may occur on an irregular basis, such as repairs, or battery or generator replacement.

An expense in the future will probably cost more than the same expense today, due to general "price escalation." However money invested today to pay for that future cost will also increase in value. The "net present value" of an expense occurring in the future is in a sense the equivalent amount of money you would need to invest today to be equal to the cost of the expense at that future date, taking into account the price escalation and the increase in value of money that could be invested today to pay for that future cost. Net present value discounting is used in LCC, and results in comparisons in "constant dollars", where future costs are made equivalent to investing money today.

	Prime Diesel	PV Diesel Hybrid	Stand-alone PV	Utility
Cash Flow	$120,312	$184,800	$186,241	$197,868
LCC Total	$218,445	$127,699	$161,525	$175,200
LCC Ratio $ / kWh	1.25	0.73	0.92	1.00



Dividing the total energy produced by a power system over its operational life by the total LCC discounted to today's "constant dollars" gives a cost per kWh factor that can easily compare the true cost of electricity from different approaches.

We have performed a 20-year LCC analysis for a power system for a rural village in Hyderabad, India, to illustrate how LCC can help compare solutions. The daily load is 24 kWh AC per day, or an average of 1 kW continuous. The total energy required for a period of 20 years is therefore 175,200 kWh.

Our analysis will compare four typical energy solutions:

- **Pure Standalone PV System**
- **Prime Diesel System**
- **PV Diesel Hybrid System**
- **Utility Grid Extension**

The results of each system design are summarized:

Pure Standalone PV System: 12.3 kW array, 7 days of battery autonomy, with the battery needing full replacement during year 11;

Prime Diesel System: two 8 kW generators sharing the load continuously, operating 8760 hours/year and needing replacement after 30,000 hours of operation, during year 8 and 15. Diesel fuel is priced at $0.50/liter, and maintenance is required every 250 hours for oil and filter changes, every 1500 hours for a minor tune up, and every 6000 hours for a full overhaul;

PV Diesel Hybrid System: a 50/50 load sharing between the solar array and the generator is used, resulting in a 4.2 kW array and 2 days of battery autonomy, and requiring only a single 8 kW generator operating for only 927 hours/year. Battery replacement is assumed during year 8 and again in year 15;

Utility Grid Extension: a 15 km extension is assumed, at a cost of $10,000/km, with minimal energy and maintenance costs over the 20 years.

The total accumulated costs over 20 years is presented, as is the discounted LCC cost (in constant dollars), and the cost per kWh factor, often used as the crucial comparison of value. The breakdown of the total LCC into components such as initial capitol and operating costs is also shown in the graph.

The total life cycle cost of the hybrid system is the lowest at $127,699 over 20 years, or $0.73 /kWh, and the pure standalone photovoltaic solution is next at $161,525 or $0.92 /kWh. The utility line extension costs out at an even $1/kWh, and the prime diesel solution is the most costly at $1.25 /kWh or $218,445 over 20 years. But the prime diesel had the lowest initial cost of all!

Cont. on Page 3

Suggested Solutions
Education / Knowledge

More education knowledge should be given throughout mass media (TV, newspapers, Magazines, etc...)

Seminars about environment in Universities

Suggested Solutions

Governmental Engorgement

Government should instruct banks to give special facilities for solar companies, and users

Government through the environmental affairs Authority and NREA should put rules and regulations, which engorge users to use Photovoltaic especially in areas away from the grid, and in tourism areas.

PHOTOVOLTAICS TECHNOLOGY ADVANCES, MARKET DEVELOPMENT, LOCAL MANUFACTURING

Prof. Dr. FUAD ABULFOTUH
DIRECTOR
Middle East Center For Energy and Environment Technologies (MCEET)
Arab Academy for Science and Technology and Maritime Transport

INTRODUCTION

The purpose of this report is to discuss and update status of, directions, and expectations for the photovoltaic (PV) technologies. It also discusses various elements of the feasibility study, which is required to support efforts to establish regional or local manufacturing of photovoltaic wafers, cells, and modules in the middle-east. It is true that the technology has passed the state of evolution, during which it went through a rapid transformations from the demonstration and pilot projects to real, cost-effective deployment into the user marketplace. Accordingly, the challenges for those working in this energy-producing technology have also changed. Among those new challenges are, Making the right decisions, identifying and making ready viable markets, ensuring adequate funding, enhancing the production and manufacturing capabilities of the industry, and most important, building consumer, government and user confidence in photovoltaic to penetrate various energy end-use sectors. Moreover, efforts should be devoted to form partnerships among manufacturers, utilities and other users, universities, and government and state agencies.

A strategic plan for sustainable development, depends basically on the available surface, and available energy and water resources, and the environmental impact and require increasing supply of energy services. The structural changes inherent in the process of improving national security and development, especially urbanization, and the building of the commercial, industrial and transportation infrastructure augment this demand.

PV technology, in most cases, can be used effectively to resolve this issue. To support such a statement a study of all the issues that relates the availability (PV production and price and solar resources), economy (energy cost), reliability and durability, and environmental advantages should be carried out.

The following are the elements to be considered in such a study:

1. Why Should We Consider Photovoltaics?

2. Aspects of the Economics of Photovoltaic Power Generation

This part of the study reflects on the following two tasks:

Task I. Investigation of the current technologies

Task II. Identification of equipment and supplies.

The best possible approaches to establish a working facility should be identified. This will include:

- Equipment required, to process the Si wafers from raw material, converting the wafers into cells, and encapsulation of the cells into modules.
- Costs of equipment, including accurate estimates of deliveries.
- Operational/maintenance costs.

- Estimates of equipment lifetimes, typical downtimes (from industry experience), and past experience and input from users.

Task III. Identification of expertise for facility.

The staffing and management of the facility will require some expertise with specific experience in these technologies. This is very important since the economic viability of such an operation is critically linked with a proper start-up and abilities of the technical leadership. This task will include:

- Initial identification of the key technical positions required for the PV cells and modules production facility.
- Identification of potential technical and scientific experts (from worldwide sources) to fill these needs.
- Establishment of recommended practices for training for the facility staff operations.

Task IV. Resource analysis

The purpose of this task is to provide a complete analysis of the financial, physical, energy, facilities, materials, and other requirements for the establishment of the facility. This includes:

- An accurate estimate of the plant energy requirements, including a detailed evaluation of the electrical utility needs and costs.
- An estimate of the other utilities (water, heating/cooling, materials handling) needed for the plant.
- A total statement of capital investment.
- Raw materials and other consumable needs.
- Special handling and safety requirements.
- An analysis of financial viability based upon production levels.
- An overall estimate of staffing based upon level of expertise, automation, and operations.

3. Market analysis

The current market and resources of PV cells and modules should be reported, including current and projected costs for the product. Information on industry projections for expansion is required. The markets for PV products produced from the new facility should be provided, including an exact identification of international markets for photovoltaics. This market analysis will provide the basis for projecting and plant sizing based upon its own needs, as well as other available markets to enhance its economic position.

4. Study of future technology developments, trends, and applications.

This study will encompass the identification of technology developments that can affect the economic feasibility and future directions of the emerging operation. This will include anticipated demands, and projected production based on industry trends and projections. Other application projects anticipated from this operation should be evaluated, especially relating to large scale development projects in the region.

PHOTOVOLTAICS TECHNOLOGY ADVANCES, MARKET DEVELOPMENT and LOCAL MANUFACTURING

Prof. Dr. FUAD ABULFOTUH

DIRECTOR

Middle East Center For Energy and Environmental Technologies(MCEET)

Arab Academy for Science and Technology and Maritime Transport

1. INTRODUCTION

The purpose of this report is to discuss and update the status of current directions and expectations for photovoltaic (PV) technologies. It also discusses various elements of the feasibility study, which is required to support efforts to establish regional or local manufacturing of photovoltaic wafers, cells, and modules in the Middle East. It is true that the technology has passed the state of evolution, during which it went through a rapid transformation from demonstration and pilot projects to real, cost-effective deployment into the user marketplace. Accordingly, the challenges for those working with this energy-producing technology have also changed. Among those new challenges are; making the right decisions, identifying and making use of ready viable markets, ensuring adequate funding for large scale application projects, enhancing the production and the existing manufacturing capabilities of the industry, and most importantly, building consumer, government and user confidence in photovoltaics to penetrate various energy end-use sectors. Moreover, efforts should be devoted to forming partnerships among manufacturers, utilities and other users, universities, as well as government and state agencies.

PV: The Egyptian Opportunity

The area of Egyptian land used in investment and urbanization does not exceed at the present time 10 million acres from a total of 238 million acres, which is less than 5% of the total surface area. Therefore, efforts have to be directed toward geographic growth to change the situation of the populated area from being "a delineated oasis within a desert framework" to a vast stretch of land with multiple integrated resources.

Such an effort demands a rapid and increasing supply of energy services. The structural changes inherent in the process of improving national security and development, especially urbanization, and the building of the commercial, industrial and transportation infrastructure augment this demand. Moreover, the continuous increase in energy demand resulting from the 1.6 percent increase in population has to be also accommodated. A strategic development plan that depends on the available surface, energy, and water resources, as well as the environmental impact becomes a necessity to maintain economic growth at a reasonable rate. Therefore, it was decided that 1,200,000 acres of land should be reclaimed in Upper Egypt (including Toshka, Owainat, and Al-Kargah). The emerging question is then; **where is the Energy?**

PV technology, in most cases, can be used effectively to resolve this issue. To support such a statement an independent study of all the issues that relate to the availability (PV production, price, and solar resources), economy (energy cost), reliability and durability, and environmental advantages should be carried out.

2. OVERVIEW OF THE STUDY

The aim of the study is to provide a set of recommendations for the establishment of a PV solar cell and module production facility. The study should include a detailed and complete review of the current processes used worldwide in the production and processing of this important product; an identification of the required equipment, sources, and accurate costs; an identification of expertise to implement the facility for a specific owner; a determination of the financial resources, facilities, staff, materials, and energy requirements to realize a cost-effective facility and operation; an analysis of current markets and sources of Silicon feedstock; and an identification of anticipated future technical and financial developments that would affect the establishment and economic viability of this facility. It should be emphasized that contacts in both the semiconductor and photovoltaic industries are necessary and should be utilized to carry out a risk analysis for establishment of individual processes.

The issues to be considered and tasks to be carried out in such a study are summarized below.

1. Why Should We Consider Photovoltaics?

Many opportunities have been identified for applying cost-effective Photovoltaic (PV) systems to loads usually served by utilities. The common features of these loads are their relatively small power requirements, scattered locations, distance from power transmission lines and high cost of service if conventional technologies are used. In many circumstances, PV can provide a less expensive solution for this particular load requirement when compared to the cost of extending the utility line to the site or the cost of operating an on-site diesel generator. Stand-alone PV systems installed on site also allow fast and easy expansion without affecting any existing networks. In fact, today there are many examples showing that PV is selected because its installed cost is less than the cost of connection to the local utility. PV can compete well in urban situations. However, planners or engineers should weigh all cost factors when considering the use of either PV or utility power for remote urban or rural applications.

2. Aspects of the Economics of Photovoltaic Power Generation

In order to understand the fundamental issues in least-cost PV power generation planning, it is important to understand the nature of the PV solar cell and how it works. A solar cell is a very simple device, made of a thin silicon wafer that can convert light energy directly into electricity. Figure 1 shows the cell structure and demonstrates how the conversion of light rays into electricity takes place. The major advantage this device has over other energy converting devices is the fact that it has no moving parts, which means it is a maintenance-free source of electricity. Figure 2 demonstrates the two main system configurations used for electric power supply by PV arrays. These are described as stand alone PV systems (fig.2.a) and the grid connected systems of fig. 2b.

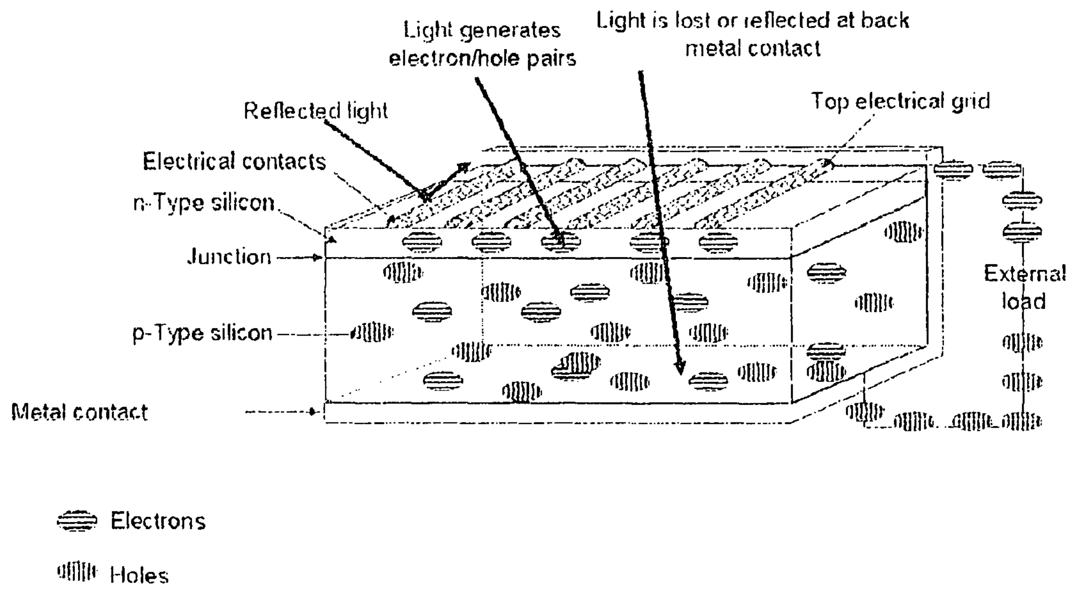


Figure 1: Solar Cell structure and operation

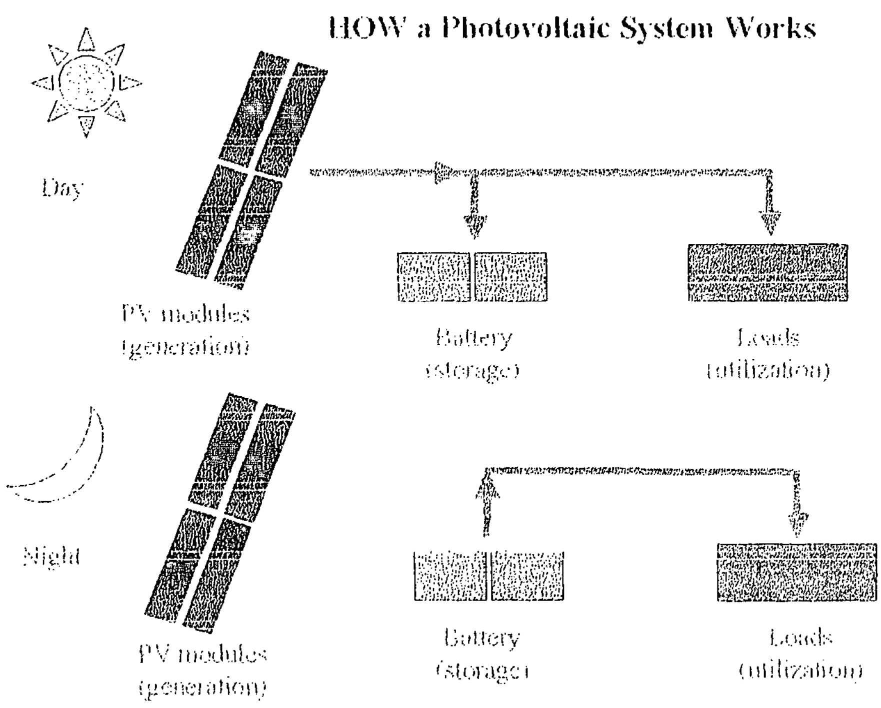


Figure 2a: Stand-alone PV system

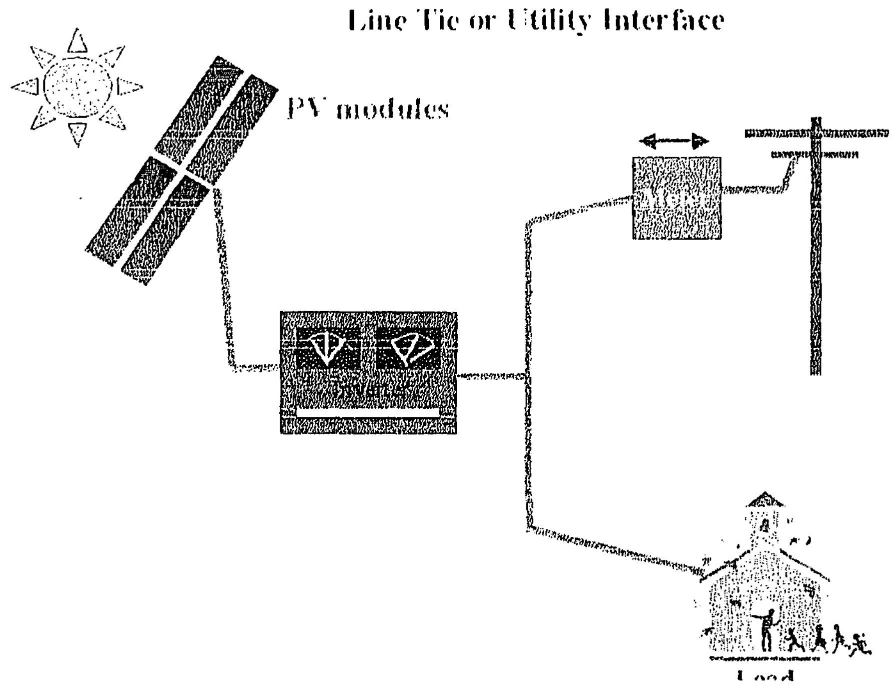


Figure 2b: Grid connected PV system

The following are additional issues related to PV applications:

2.1. PV is a modular and reliable energy source that has the potential for providing a wide range of applications and fulfilling a variety of requirements (whether several watts of stand-alone systems or hundreds of megawatts of grid connected power).

2.2. It can complement other available energy sources and offer excellent solutions to load management problems.

2.3. PV requires a relatively short period from the design phase to electric energy production. This reduces the construction finance needed (as compared to conventional fossil or nuclear energy) and allows a closer match of utility production capacity.

2.4. The impact of PV on the environment is minimal, making PV a very attractive energy option.

3. MARKET ANALYSIS

PV technology is growing and developing rapidly and will continue to do so steadily as long as there is confidence in the technology along with a high level of commitment to its use. Moreover, it is expected that PV technology will be one of the major electric power generating industries within three years or less. This statement is supported not only by the varied and extremely large markets already available, but also by the recent advances made in cell and module efficiency, reliability and manufacturing power. This market expansion will definitely result in a decline in the price of implementation of the technology in the market place. The three centers of photovoltaic production that currently dominate the market are Europe, Japan, and the United States. The world PV module shipments are depicted graphically in Figure 3, covering the time period 1988-2002. It is clear that the world production has multiplied more than fifteen times over this time frame, where more than 600 MW are expected to be shipped in 2002. Dominating these shipments are the single-crystal and polycrystalline Si technologies, accounting for more than 75% of the total in 2001, as summarized in Figure 4. Amorphous Si has contributed about 20% of the total shipment.

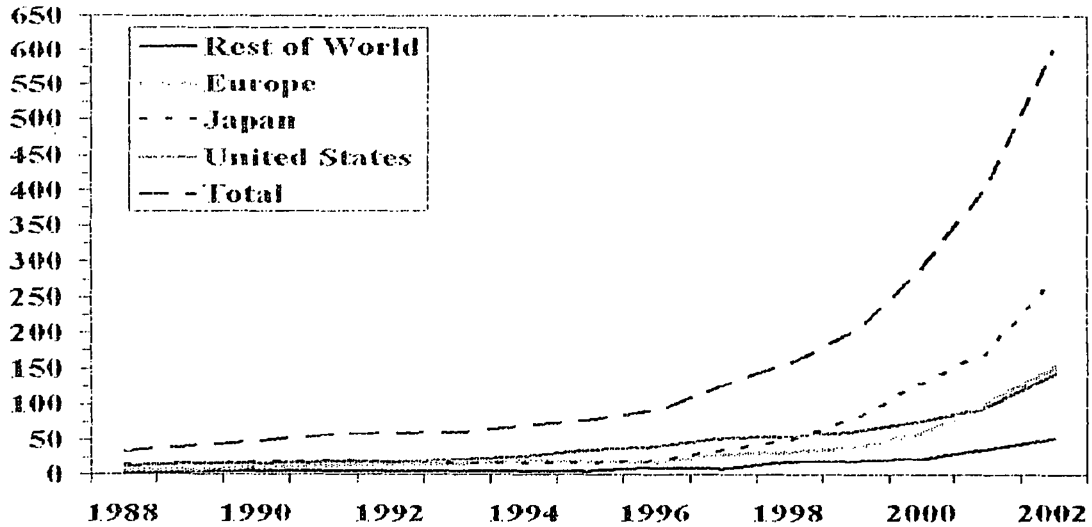


Figure 3: World shipment of PV modules

Technology	U.S.	Japan	Europe	Rest	Total	Percent
Silicon						
Single-crystal	32.00	25.00	18.00	18.00	110.00	27.00
Multicrystalline	33.00	121.00	50.00	6.00	210.70	52.00
Thin Si (on low-cost substrate)	2.00				2.00	0.05
Ribbon/Sheet	12.00		6.00		18.00	4.50
Total	79.00	146.00	91.00	24.00	330.00	84.00
Thin films						
Amorphous	10.00	423.00	9.00	12.00	54.00	13.70
CdTe	3.00	3.00			6.00	1.50
Total	13.00	26.00	10.00	12.00	60.00	15.20
Concentrator						
Crystalline Si	3.00				3.0 ~~0.60~~	0.81
Total	3.00				3.0 ~~0.60~~	0.81
Grand Total	95.00	171.00	100.00	36.00	403.00	100.00

Figure 4: World shipment by technology

4. PHOTOVOLTAIC TECHNOLOGIES OPTIONS

The aim of this portion of the study is to establish the direction for the proposed PV manufacturing facility. The recommendations should include alternative paths, with risk analysis for each. It should also include:

- An accurate and detailed description and evaluation of the technologies, input and output products.
- A comparison of the performance of various types of cells and modules suitable for application in order to form a technology basis for establishment of a facility and process.
- A recommendation for the most appropriate process/technology based upon economy, plant size and capacity, material source, and product diversity.

It should be noted that the choice of production also is mandated by the quality of Si available in the market. Figure 5 demonstrates all PV technologies considered for electric power generation together with state of the art efficiencies and beginning of the R&D work lead to the evolution of each technology.

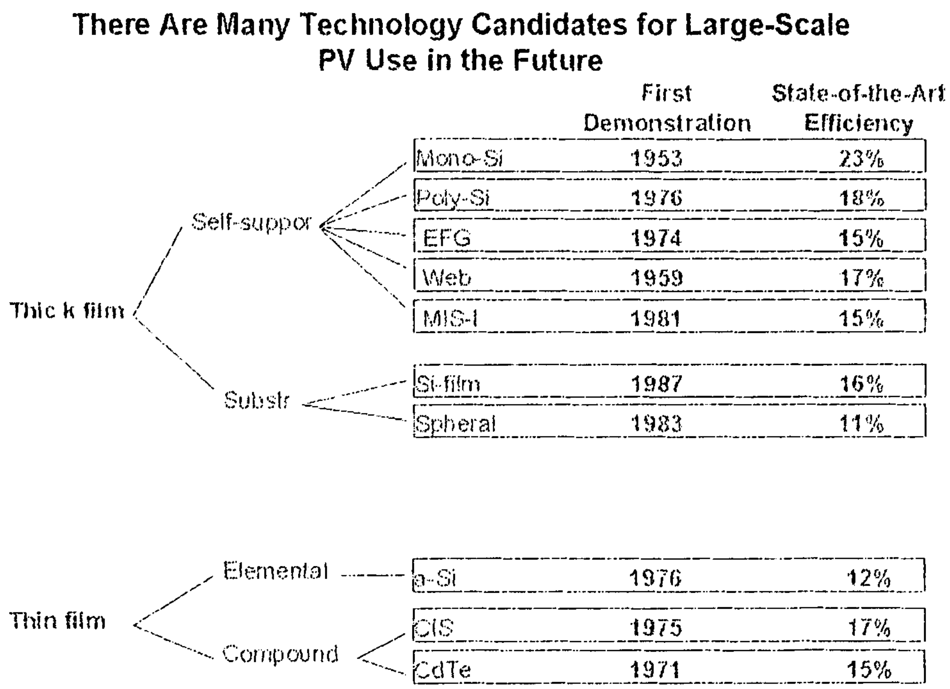


Figure 5: Various PV technologies considered for electric power generation

5. IDENTIFICATION OF EQUIPMENT AND SUPPLIES

This task provides essential details that should be emphasized in the feasibility study. If the task is done carefully, which means that the best possible approaches to establishing an efficient working facility are identified, successful operation will be assured. This task includes the following:

- Equipment required to process the Si wafers from raw material, converting the wafers into cells, and encapsulation of the cells into modules.
- Costs of equipment, including accurate estimates of deliveries.
- Shipping costs and operational/maintenance costs.

- Alternative suppliers and manufactures of critical equipment to ensure the best choices.
- Estimates of equipment lifetimes, typical downtimes (from industry experience), and past experience, as well as input from users.

6. IDENTIFICATION OF EXPERTISE FOR FACILITY

Another crucial issue of the study is staffing. The staffing and management of the facility will require some expertise with specific experience in these technologies. This is very important since the economic viability of such an operation is critically linked with a proper start-up and the abilities of the technical leadership. Gaining experienced staff from the existing industry will give the new facility an edge in ensuring success. A list of potential and available technical staff should be made available by the developer of the study to the facility owner to help him in the start-up and operations. This task will also include:

- Initial identification of the key technical positions required for the PV cells and modules production facility.
- Identification of potential technical and scientific experts (from worldwide sources) to fill these needs.
- Initial contacts with potential key staff to help fill key positions.
- Based upon current market and potential staff requirements, suggestions on salaries and benefits for key staff will be provided.
- Establishment of recommended practices for training for the facility staff operations.

7. RESOURCE ANALYSIS

This task will provide a complete analysis of the financial, physical, energy, facilities, materials, and other requirements for the establishment of the facility. This includes:

- An accurate estimate of the plant energy requirements, including a detailed evaluation of the electrical utility needs and costs.
- An estimate of the other facilities (water, heating/cooling, materials handling) needed for the plant.
- A total statement of capital investment.
- Raw materials and other consumable needs.
- Special handling and safety requirements.
- An analysis of financial viability based upon production levels.
- An overall estimate of staff based upon level of expertise, automation, and operations.

8. PHOTOVOLTAIC TECHNOLOGY PERFORMANCE AND PRODUCTION COST

This section will address photovoltaic technology, performance, and cost in detail. All technical cell options will be summarized with emphasis on cell efficiency in volume production; module efficiency and stability; and module manufacturing costs.

8.1. Silicon: The Backbone of the PV Industry

The most commonly used sunlight-to-electricity conversion material is silicon. The projections in this study are primarily confined to silicon-based options. The projected decline in cost and increase in performance of silicon-based modules makes it difficult for any other conversion material to be competitive for general terrestrial use. However, the new materials can indeed play a role in the market, provided costs, performance, and stability are competitive with the options described herein. The sunlight conversion efficiencies of modules made by each of the five commercial processes using silicon and related marketable price levels for years 1997 and 2002 are compared in Figure 6. Projected values for year 2010 are also given.

Cell Technology	1997	2002	2010
Single Crystal	15/13	18/16	22/20
Polycrystalline Ingot	14/13	16/15	20/18
Ribbon (Sheet)	14/13	17/15	21/20
Concentrators (Silicon Cell)	22/18	25/22-25	30/25-28
Amorphous Si (Includes stacked cell)	6-8/-6	7-9/8	14/12
Copper Indium di-Selenide	7-9	15 /12	17/14
Cadmium Telluride	7-9	15/12	17/14
Si Film	8-10	15/13	17/15

2010 Forecast is the Practical Limit of Technology.

Figure 6: Efficiency Forecast for Production Modules

8.2. Single Crystal Silicon: Cylindrical ingots of single crystal silicon are sliced into 5- or 6-inch wafers, which are made into circular or square solar cells and mounted and wired together in a weather resistant package to create a module. Figure 7 demonstrates the structure and various components of the module.

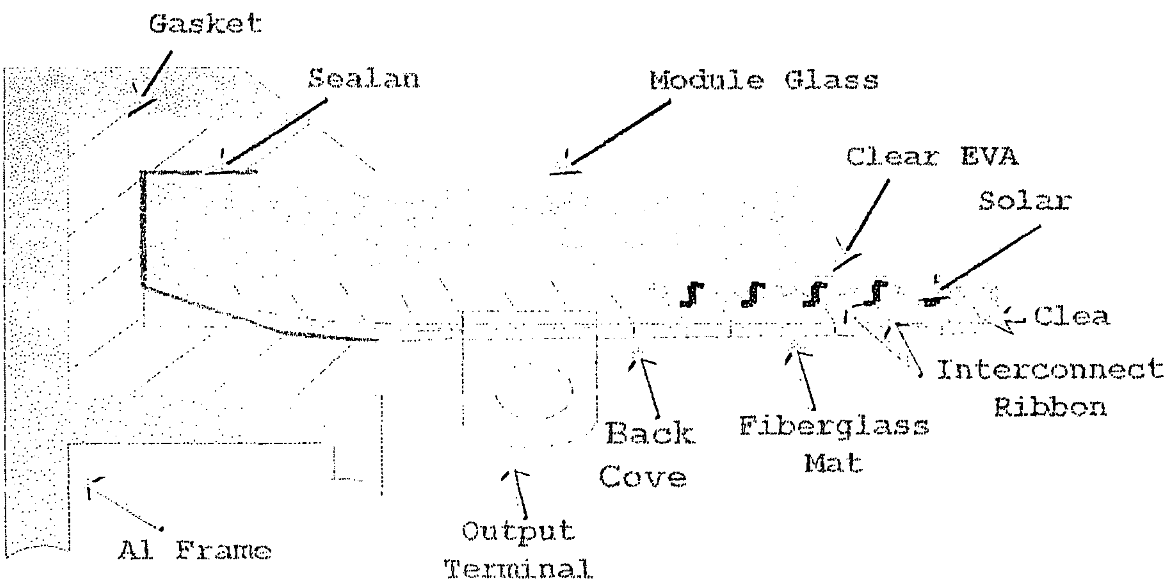


Figure 7: Cross-section of a module.

8.3. Polycrystal-Cast or Semicrystal Silicon:

Castings of polycrystalline silicon ingots as large one-half m^2 are sliced into 4- to 5-in^2 wafers, which are made into cells. The cells are mounted and wired together in a weather resistant package to form modules as shown in figure 7.

8.3.1 Technology Forecast for Cast Polycrystalline Silicon

The following table (fig.8) summarizes the players, processes, and cost reduction opportunities for cast silicon technology. The manufacturing costs forecast of $2.50/watt in 2002, is based on poly-silicon cost of $8-10 per kilogram to produce 16% six-in^2 cells. Several companies achieve the objectives mentioned above.

Figure 8. Technology Forecast for Cast Poly-silicon (Semi-crystal)
(Includes Solarex, Kyocera, Crystal Systems, Crystallox, Eurosolare [Italsolar], Photowatt, and ASE GmbH, and ASE America)

Factor	1997	2002*	2010+
Cell Efficiency (%)	15	18	24
Module Efficiency (%)	14	17	22
Polysilicon Cost ($/kg)	10	10	10
Warranty (Years)	12	20-25	25
Manufactured Cost ($/W)	3.5	2.5	1.50
Price ($/W)	4.5	3.5	2.20

*Nearly identical to the costs of product in the 20 MW plants that exist in 2002.
+ Based on the production in 80-100 MW plants

Figure 8: Performance and cost of production of poly-crystalline Si modules.

8.4. Ribbon or Sheet:

A ribbon or sheet of silicon is pulled directly from a bath of molten silicon in a continuous operation and cut into 2- or 4-inch rectangles, which are made into cells. The cells are mounted and wired together to make modules. A thick film sheet (50-150 microns) is grown on a low cost substrate to make 100 cm^2 cells, which are also made into modules.

8.4.1. Technology and Price Forecast for Silicon Ribbon/Sheet

It is estimated that Mobil Solar has invested more than $150 million since 1972 on the edge-defined film process to grow EFG ribbons of silicon directly from the melt. Recent successes include conversion of all pullers to 8-sided cylinders with .015" thickness and 4" strips; use of lasers to cut slices from a octagon; obtaining 12% efficient modules from 14-15% efficient cells; use of passivation to increase efficiency and reduce stress-related breakage; design construction of a module packaging line capable of 1 MW per year production. ASE Americas has completed the commercialization of EFG ribbon, expanded the plant production to more than 3 MW per year and shipped 3 MW in 1996. Since then, the company has continuously expanded until it reached 28 MW and an additional 60 MW plant is now under construction. Schematics of the process are depicted in Fig10.

FIG. 9 Silicon Ribbon/Sheet Manufacturing Cost/Technology Forecast

	1997	2002	2010
Ribbon Thickness	0.010"	0.008"	0.008"
Material Yield	80	90	95
Cell Efficiency (%)	14	17	22
Module Efficiency (%)	13	15	19
Warranty (Years)	10	20	25
Manufactured Cost ($/Wp)	4.00	3.20	1.50
Profitable Price	5.00	4.00	2.50

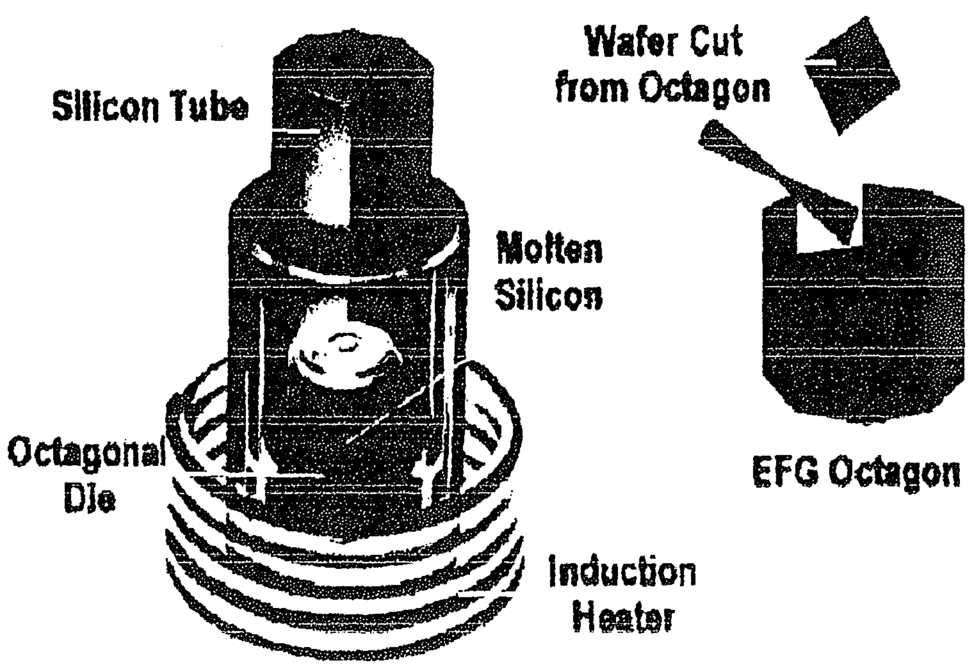


Figure 10: EFG Si Ribbon processing

8.5. Amorphous Silicon (A-Si) Films:

Very thin layers, less than a micron thick, of nano-crystalline silicon (amorphous) are deposited on a glass, metal or plastic substrate in a process that provides "cells" with areas ranging from 1 cm^2 to 10,000 cm^2

8.5.1. Summary of A-Si

.A-Si competition is very intense, with $80 to $100 million (U.S.$) being spent annually to develop increased efficiency and stability. The intense R&D on a-Si can result in a stable, moderately efficient product (8%) at very low cost. The 80% probability forecast for a-Si is shown in the following chart. (Note: The forecast for stable efficiency has been reduced since 1987.) Many of the entrepreneurs in A-Si forecast profitable prices below $1/watt and module efficiencies in the 12% level. It is believed that stable 11% modules with profitable prices of $1.50/watt can occur by 2005. The a-Si technology status and projection is presented in figure 11.

FIG. 11 A-Si Technology Forecast

Factor	1993	1997*	2002	2010
Cell Efficiency (%)	5-7	8-10	12	14
Module Efficiency (%)	5	6-7	9	11
Area Yield (%)	80	90	95	98
Warranty (Years)	10	10	20	20
Manufactured Cost ($/Wp)	4.50	4.00	3.00	1.3
Price	5.00	4.50	4.00	2.0

8.6. Concentrators:

An optical system focuses sunlight onto small single crystal solar cells as shown in figure 12. The cells are mounted in modules on two-axis tracking pedestals. Either point focus or linear focus optics are used. Figure 13 shows a history of cell efficiency. Concentrator cells (gallium arsenide and gallium aluminum arsenide) have reached efficiencies approaching 40%. One-sun silicon cells in the laboratory have exceeded 25%. Concentrator cells with 20-24% cell efficiency can be purchased from several sources.

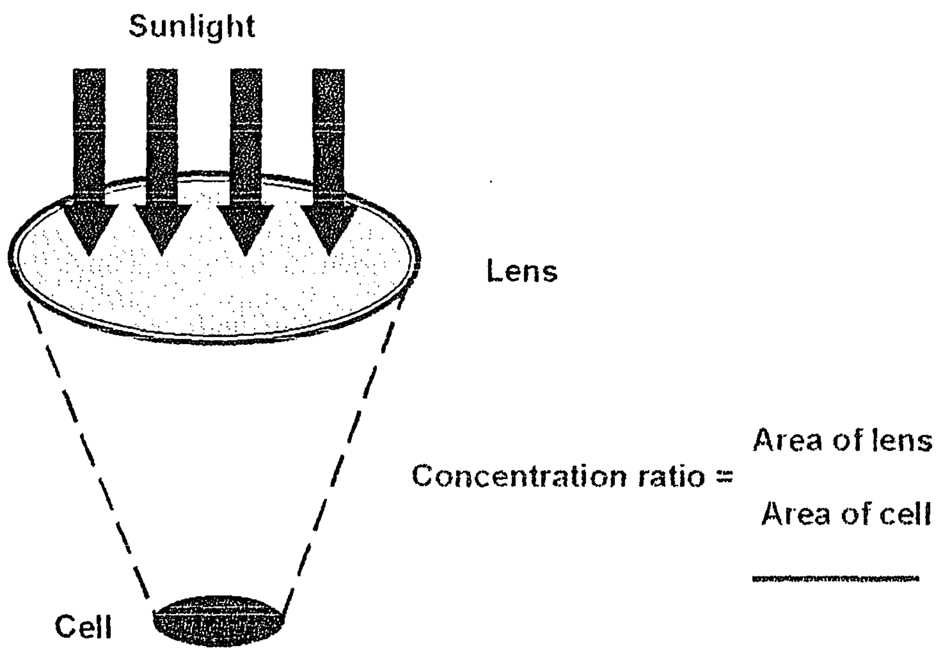


FIG. 12 Sunlight focused on a small solar cell.

8.6.1. Forecast for Concentrators:

Performance—Concentrator modules are now 18 to 22% efficient and require 20 to 50% more land per kilowatt than flat plate collectors. By 2005, it is forecast that silicon-based concentrators with efficiencies of 25% will be reached. The practical limit appears to be in the 30% range.

FIG.13. Concentrator Module Outlook

	1997	2002	2010
Cell Efficiency (%)	24	27	35
Module Efficiency (%)	20	25	30
Warranty (Years)	10	15	15
Manufacturing Cost* ($/Wp)	3.50	2.50	1.00
Price	5.00	3.50	1.67

*Includes Pedestal/Tracker

Cost—Current prices are $8 per watt installed. In perfect climates, the concentrator generates 20 to 30% more energy per year than fixed flat plate collectors. Profitable concentrator module prices at $2.00/W are forecasted by 2010. Concentrators could become the preferred option for large (100 kW) ground-mounted systems by 2005, and will become the most popular option for large power stations because of very high efficiency and very low cost.

Reliability—Third generation concentrators have increased reliability and require less maintenance and less down time than 1982-83 concentrator systems. Per watt, they also have about 1/50th the part count. Systems will be built larger to minimize maintenance, and the reliability issue has largely disappeared. Second, U.S. companies including Alpha Solarco, Amonix, Entech, SunPower, Midway, and SEA are developing and marketing PV concentrators. In 1996 BP Solar announced production plans for a concentrator based on its high-efficiency single-crystal silicon solar cells.

9. SUMMARY AND CONCLUSIONS

9.1 PV Technology/Cost Summary

Single crystal silicon will continue to serve the high reliability, unattended, remote power commercial markets. If the promise of the new ten MW thin film plants now under construction becomes reality, single crystal market share will stabilize at 20-30%. Module efficiency will increase to 20% and profitable module prices can drop to $2.5 per watt by 2010.

Polycrystalline silicon will continue to serve the high reliability, unattended, remote power commercial markets. Market share will stabilize at 25% to more than 30% unless unexpected progress is made in the new thin film areas. Some remote power attended systems will choose polycrystalline because of its proven reliability and lower cost than single crystal. Module efficiencies will increase from 12 to 18% and profitable prices will be $2.20 per watt by 2010.

Ribbon/Sheet silicon technology progress and capacity installation lagged all other options until ASE purchased the Mobil Solar operation and started full production. The Westinghouse dendritic web technology was purchased by Ebara of Japan and the MIT ribbon technology was purchased by Evergreen Solar. These new startups will accelerate the promise of ribbon/sheet PV technology. Astro Power entered the market in 2002 with their thick film sheet silicon on low cost substrate, boasting a multi-megawatt capacity and costs less than $3.00 per watt.

Concentrators using single crystal cells have the potential for the highest efficiency and lowest cost of any PV module option. The concentrator will serve the large (100 kW plus) system markets in the areas of the sun belt with high direct radiation. The EPRI point contact-cell development and concentrator engineering effort coupled with potential multi-megawatt purchases, are likely to make the concentrator the leading candidate for central power by 2005.

Amorphous silicon thin films can gain more than 40% of the world market by 2005 (including consumer products), with Japan and the U.S. in direct competition. Module efficiencies increased to 8% in 2002. Profitable module prices near $2 per watt are likely by 2005. Stacked cells of a-Si and copper indium diselenide or a-Si, amorphous silicon (C), amorphous silicon (Ge) could be the principal product by 2005 with prices less than $2 per watt and module efficiencies of 12%. The key to a-Si cost reduction is to get the capital cost per watt produced per year to $2 or less and to have 95% yields of 8% efficient, very large cells. The following table summarizes the current and projected efficiencies and production cost of the most common technologies in use today for the period from 1990 until 201

Technology/Cost for Key Silicon-Based Options Summary of All Technology/ Cost Status and Forecast ($1995)

Option	1990	2000	2005	2010
Single Crystal Silicon				
- Module Efficiency (%)	10-12	15	18	22
- Profitable Price ($/Wp)	5.40	4.70	3.00	2.50
Cast Ingot (Polycrystalline)				
- Module Efficiency (%)	9-11	14	16	20
- Profitable Price ($/Wp)	5.00	4.7	2.50	2.20
Ribbon/Sheet				
- Module Efficiency (%)	10-12	14	17	21
- Profitable Price ($/Wp)	6.00	4.50	3.50	2.50
Concentrators				
- Module Efficiency (%)	15-17	22	25	30
- Profitable Price ($/Wp)	6.00	5.00	3.00	2.00
Amorphous Silicon				
- Module Efficiency (%)	4-6	7-9	10	14
- Profitable Price ($/Wp)	5.00	4.50	3.00	1.50

9.2 Local Manufacturing

PV technologies have gone through substantial advancement in all aspects. In other words, performance (cell and module), manufacturing (volume and process), economics (price and system reliability and durability) and availability (expansion in production facilities) have all shown significant progress. The result is confidence in the technology and fast presentation in the market place. The vast solar resources available in the region when combined with the future promise of PV provide a strong case in support of local or regional manufacturing of PV cells and modules. It is definitely needed to supply electric power to various crucial development projects (e.g. land reclamation of desert areas in Upper Egypt). It is definitely environmentally friendly; and it is definitely less expensive when compared to diesel generators used for water pumping on a large scale. Therefore, it is definitely feasible and profitable to pursue the establishment of such a facility.

9.3 Applications

PV technology has passed the state of demonstrations and pilot projects and should now be fully utilized in real large-scale economic applications. In order to arrive at the most convincing feasibility study of PV manufacturing, the data used should be based on the proven economic viability of large-scale projects like PV water pumping in Upper Egypt or electrification of villages far from transmission grids. Therefore, developing an action plan to establish at least one viable project followed by accurate evaluation of the local needs for PV (market volume) should be enough to stimulate the interest of various investors in manufacturing PV cells and modules. Furthermore, the study should be based on the specific objectives of the investor or interested party requesting it. In other words, the feasibility study must be tailored to meet specific objectives, rather than simply provide "generic" results.

SOLAR CAR

Demonstrated by:

Samah Mohammed El- Bashir
Assistant Lecturer (Physics)
Faculty of Science
Zagazig University   Benha Branch
e-mail: elbashireg@yahoo.com
samah@mail.solgel.com

Specifications :

Light weight and durable designed encapsulated solar panel is weather resistant for outdoor use provides 12 V /100 mA to power the approperiate car motor of velocity (101.6 cm/sec).

SOLAR FAN

Demonstrated by:

Samah Mohammed El- Bashir
Assistant Lecturer (Physics)
Faculty of Science
Zagazig University Benha Branch
e-mail: elbashireg@yahoo.com
samah@mail.solgel.com

Specifications :

Amorphous sillicon Solar cell panel provides 3V /30 mA full sun output to power the approperiate 3V fan motor.

SOLAR RADIO

Demonstrated by:

Samah Mohammed El- Bashir
Assistant Lecturer (Physics)
Faculty of Science
Zagazig University Benha Branch
e-mail: elbashireg@yahoo.com
samah@mail.solgel.com

Specifications :

Amorphous sillicon Solar cell panel provides 3V /30 mA full sun output to power the approperiate 3V radio.

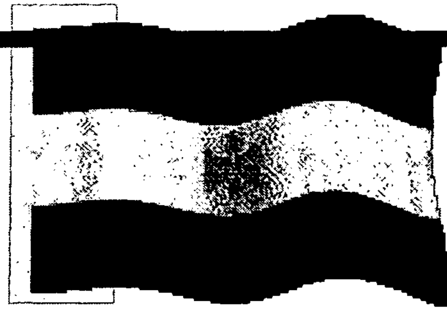
SOLAR CHARGER

Demonstrated by:

Samah Mohammed El- Bashir
Assistant Lecturer (Physics)
Faculty of Science
Zagazig University Benha Branch
e-mail: elbashireg@yahoo.com
samah@mail.solgel.com

Specifications :

Amorphous sillicon Solar cell panel provides 3V /30 mA full sun output to charge capacitors of (5.5 V / 0.47 F).



PHOTOENERGY CENTER

FOR TRAINING, RESEARCH & DEVELOPMENT

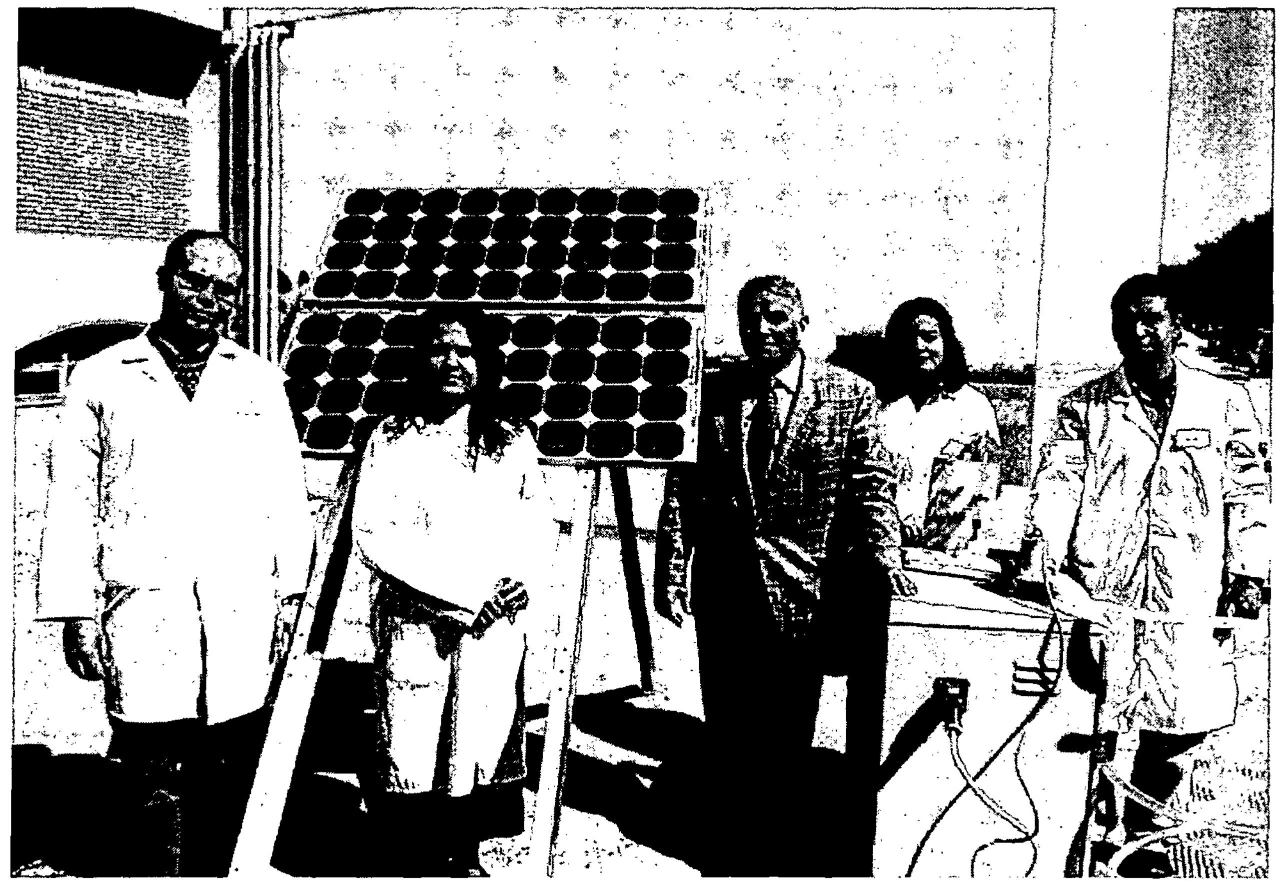
Faculty of Science, Ain Shams University,
Cairo, Egypt
Director M. S. A. Abdel-Mottaleb

PV Systems for Training

PVP System for irrigation

PV Systems for Training

PVP System for irrigation/Hydrogen Production

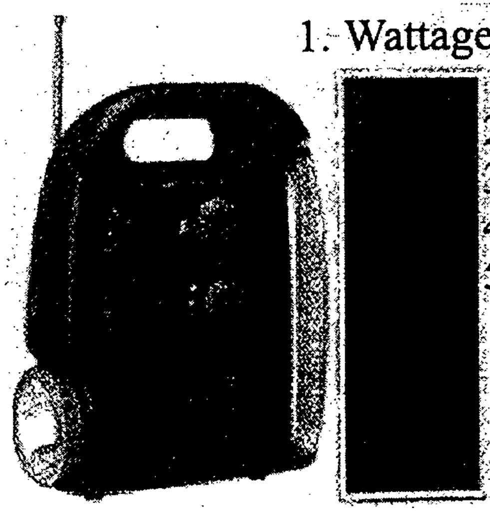


PV Systems for Training

1. Wattage of the bulbs: 6w/each
2. Voltage of the battery: 6v 4Ah
3. Power of the module: 3W 7.5V
4. Working temperature range:
   -20 to +50
5. Moisture protection:
   panel is water
   proof while lantern is not

PV Systems for Training

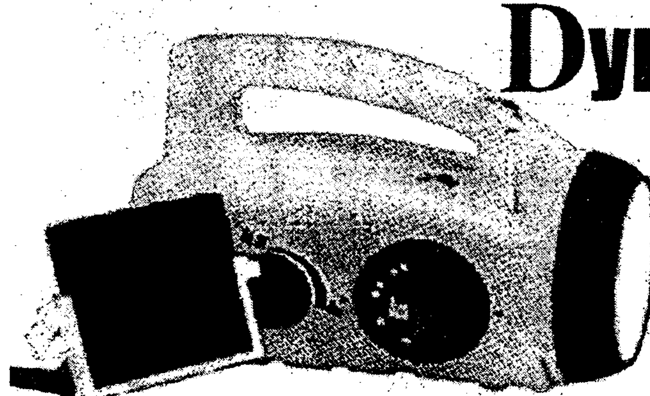
Solar Lantern with AM/FM Radio



1. Wattage of the bulbs: Two pcs of 6W/each and
   One pc of 6v 4.5w bulb
2. Voltage of the battery: 6V 4AH
3. Power of the module: 3W 7.5V; or 6W 7.5V
4. Working temperature range: -20 to +50
5. Moisture protection: panelis water proof while lantern is not.

PV Systems for Training

Dynamo Radio



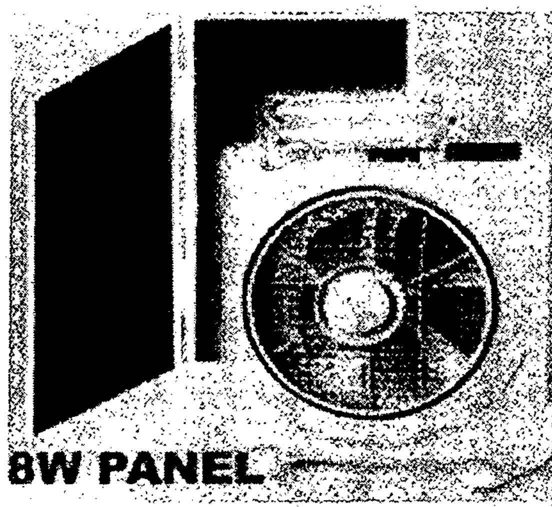
1. Power Supply: DC 3V
2. Adaptor: 100mv AC/110V/60Hz or 220V/50Hz
   DC 3V Output jack 3.5mm
3. Output: 150mw
4. Radio Frequency: AM: 530-1600KHz
   FM: 88-108MHz

5. S/N Ratio: Better then 40db   6. Loudspeaker Impedance: 8
7. Power Consumption: 1Watt APP   8. Dimension: 182x80x125mm
9. Internal Rechargabel Battery: AA Size NI-MH 1000mah x 2(Nickel Metal Hydride)

CHARGING INFORMATION:
Charge with Adaptor: 8hours charge will operate the radio for 12 hours & 4hours light
Charge with Dynamo(Crank): Turning for 3 minutes will give a charge for 3 hours for radion and 1 hour for light.

PV Systems for Training

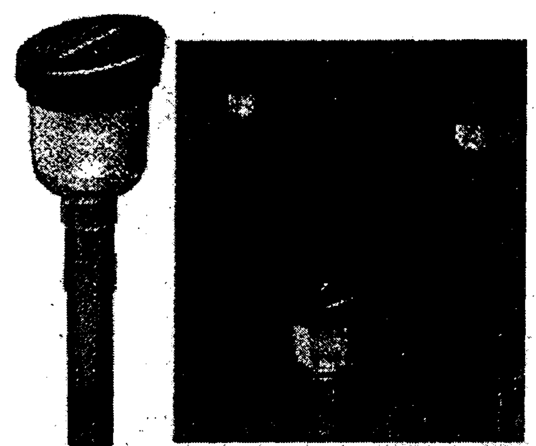
Solar Fan with Light



1. 10 inches fan with emergency light
2. having 2pcs built-in 6v 5Ah long-life and free-maintenance lead acid batteries.
3. Adopting advanced UPS circuit design with over-heat auto-protection and fall-down safety switch.
4. If use the fan and the light at the same time, it can work for over 2 hours; if use its lights only, it can last for over 8 hours.
5. Charged by 8W amorphose solar panel or 6W mono solar panel according to our customer's particular requirement.
6. With three different charging methods: by solar panel, 110V AC or 220V AC

PV Systems for Training

Solar GcardenLight



1.Solar powered by mono panel
2. Power of solar panel: 0.45w at full sun
3. Type of battery: two Ni-Cd 500 mAh
4. Light source: Super bright LED
5. Up to 8 hours of light at night
6. Three ways of being mounted:ground,wall & portico
7. Automatically switch on at night
8. White LED & Amber colored LED available.
9. Packing: 4sets/colored box; 8 boxes/carton.

PV Systems for Training

Solar Cooling Caps

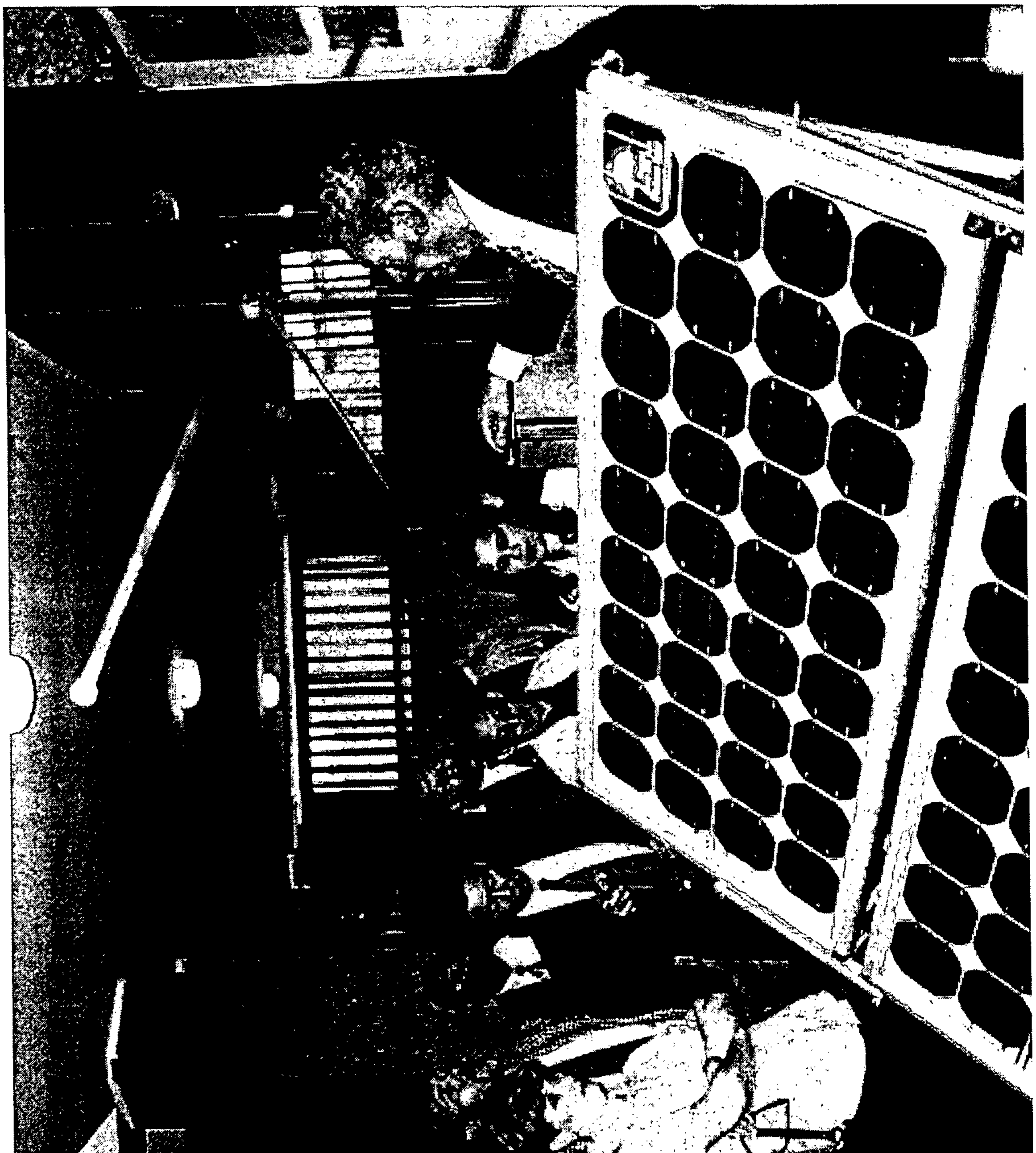
It's the best promotional gift for big companies such as airline companies, travel agencies or for baseball, football fans.

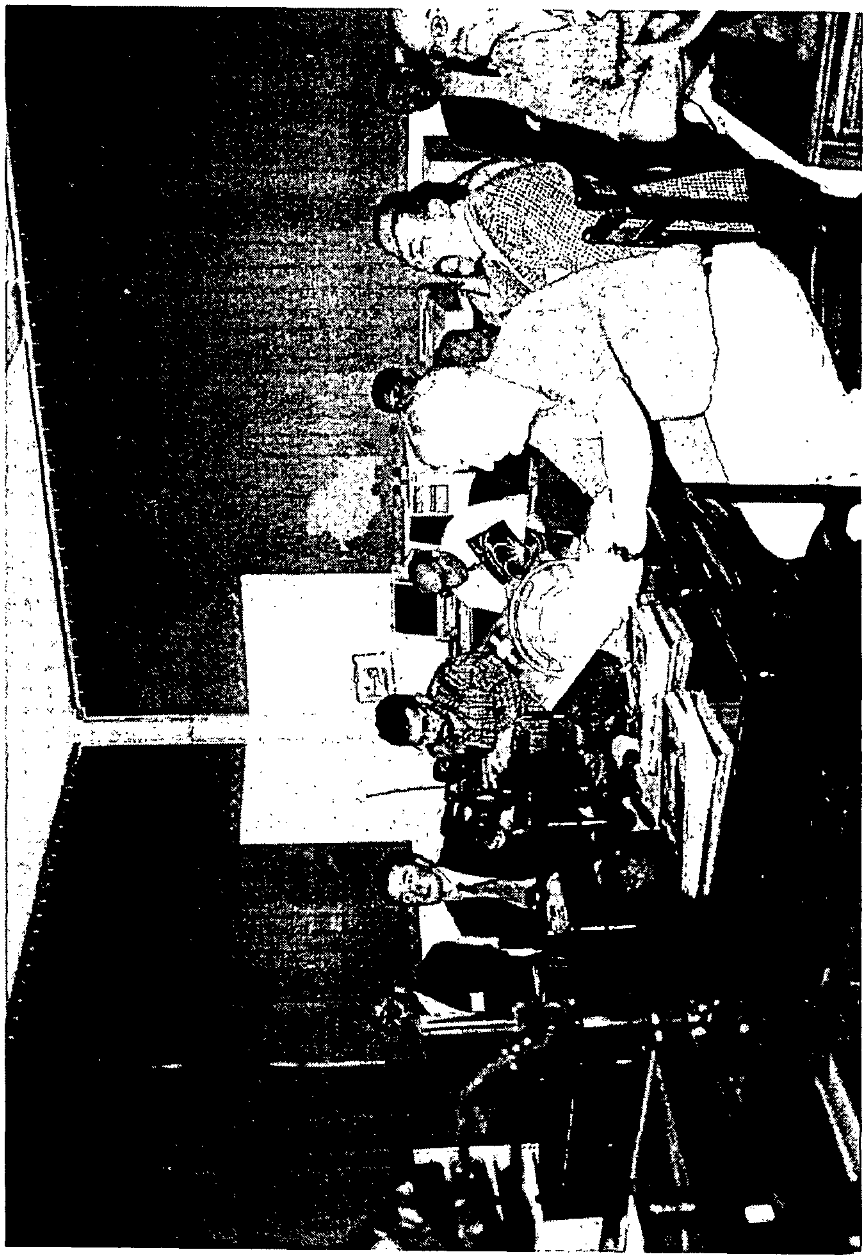
Customers' logo can be printed in the front of the caps.

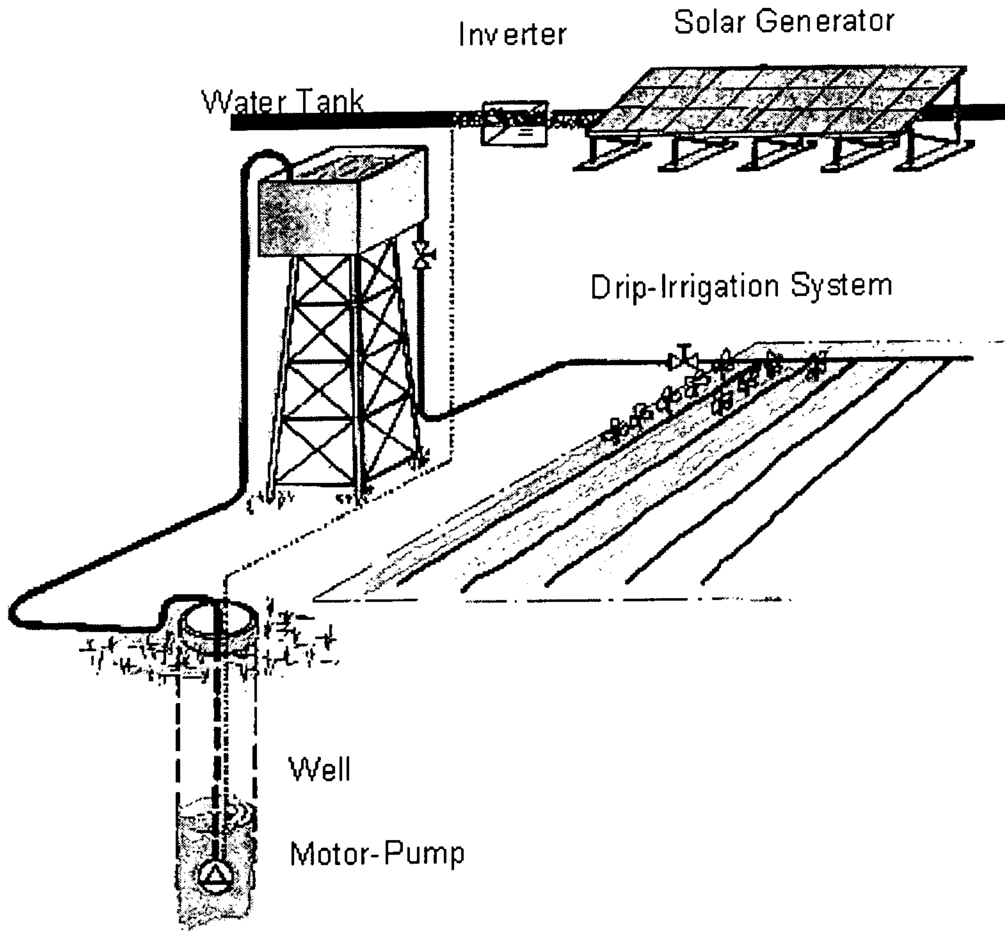
Solar cell can be monocrystalline silicom cells (round) or amorphose silicon cells (angular)

Minimum order: 3,000pcs/order

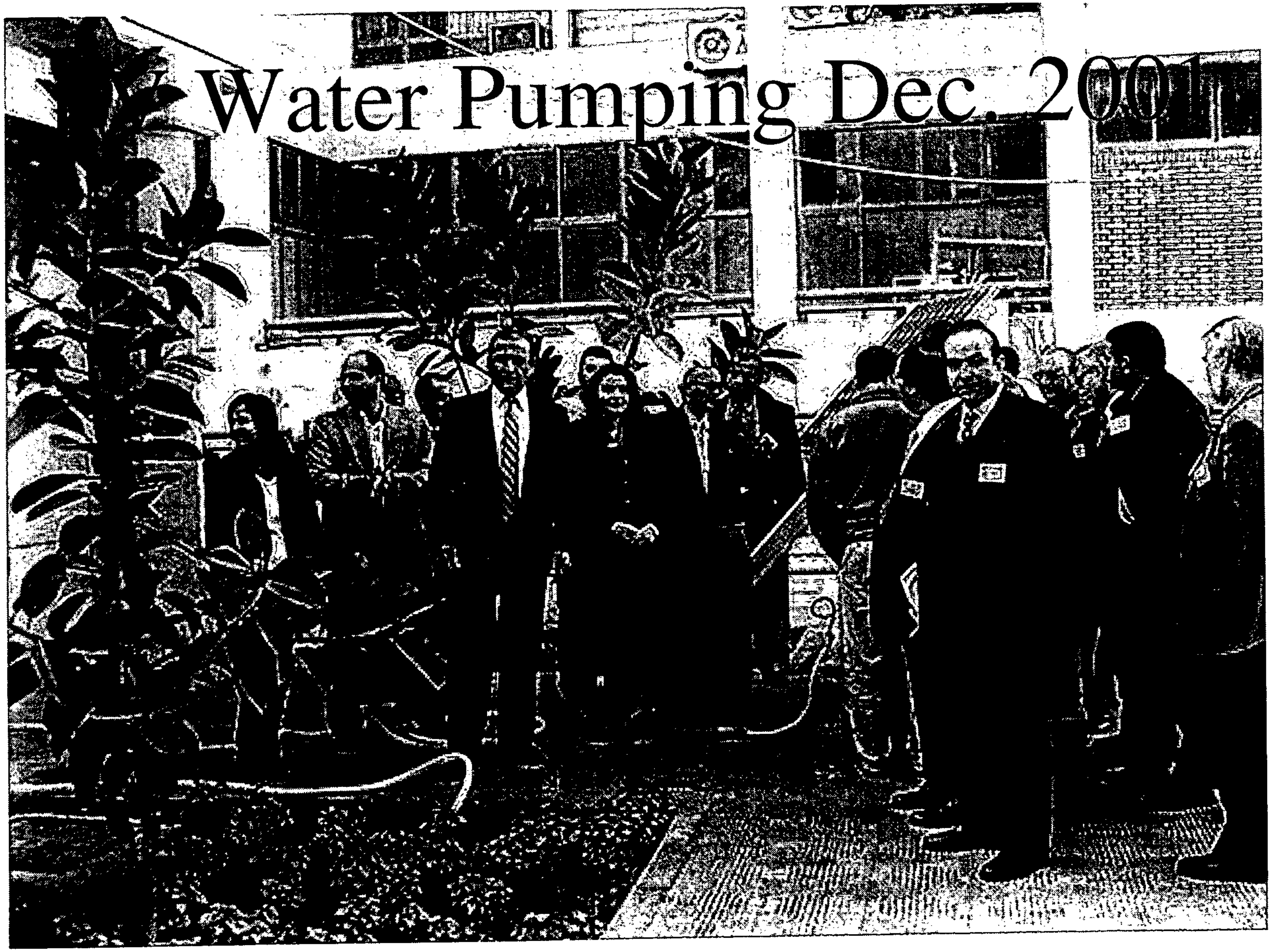
Expert Group Meeting on Networking PV Systems and Applications, April 2000






Solar Generator
Inverter
Water Tank
Drip-Irrigation System
Well
Motor-Pump

a


Water Pumping Dec. 2001

Progress of PV Applications in the Kingdom of Saudi Arabia

Ahmed O. Al-Amoudi,
Assistance Professor, Director of Solar Village and Head of PV Group
KACST, Saudi Arabia, E-mail alamoudi@kacst.eud.sa

Abstract:

The applications of photovoltaic (PV) energy in the Kingdom of Saudi Arabia has started in early 1960, where the first PV beacon installed by French company at Madinah airport. Since then, no specific applications appear till 1980 when Saudi Arabia has entered into an international agreement with USA for joint economical and Technical Corporation in the field of solar energy. The program named SOLERAS. The outcome of this agreement was the solar village, a big research site which was built for demonstrating PV applications in remote areas. Later on, Research and Development (R&D) have commenced by the establishment of Energy Research Institute (ERI) a department of King Abdul Aziz City for Science and Technology (KACST) in 1988. KACST then entered into several corporation agreements with USA and Germany as a means of transferring technology to the Kingdom and utilising it in promoting development.

The experience has shown that thought the Kingdom of Saudi Arabia has stated utilizing PV energy earlier than other countries in the region, the progress of utilizing PV is too slow. This may be due to economical or technical problems. In addition, lack of customers awareness of utilizing this type of energy is one of the essential problems.

This report summarizes some of PV applications in the Kingdom of Saudi Arabia and the reasons of their slow progress. It also discusses the technical and economical problems and end up with some conclusions and suggestions for overcoming the problems and speeding up the progress of PV applications.

Progress of PV Applications in the Kingdom of Saudi Arabia

Ahmed O. Al-Amoudi,
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The experience has shown that thought the Saudi Arabia has started utilizing PV energy earlier than other countries in the region, the progress of PV utilization is quit slow. This may be due to economical or technical problems. In addition, lack of customer's awareness of utilizing this type of energy is one of the essential problems.

This report summarizes some of PV applications in the Kingdom and the reasons of their slow progress. It also discusses the technical and economical problems and end up with some conclusions and suggestions for overcoming the problems and speeding up the progress of PV applications.

PV Applications in Saudi Arabia:

1-Research Development and Demonstration (RD&D) PV Applications:

Most of the RD&D applications in the Kingdom has performed by Energy Research Institute (ERI) in King Abdul Aziz City for Science and Technology (KSCST). The following are the major research PV project:

♦ Solar village:

A research project resulted from a technical co-operation with the United States in the field of solar energy utilization in remote regions. The site was built in 1980 with a capacity of 350kW. Originally, the project supplied the electricity for three remote villages, namely Al-Oyaynah, Al-Jubaileh, and

Al-Hijrah. The system uses a concentrating photovoltaic cells and tracking system. In few year of operation the project has the following achievements:

- Utilizing PV energy in different applications
- Increase public awareness and training of Saudi technicians and engineers in the field of solar energy technology.
- Establishment of scientific research and test labs.
- Technology transfer through the cooperation programs.

♦ HYSOLAR:

This plant was built at the Solar Village in 1986. It contains equipment, large installations such as the electrolyser, temperature, pressure and humidity sensors, and various gas storage tanks. The 350 kW plant was considered to be the largest solar hydrogen production plant in the world. The project aimed to the following:

- Design and installation of a safe hydrogen production plant and gaining the basic scientific and technical knowledge of this topic.
- Feasibility study of solar hydrogen utilization technologies.

♦ PV water pumping and desalination

A research plant was installed at Sadous village north-west of Riyadh in 1994. It was aimed to find the feasibility of a typical phtovoltaic system for water pumping and desalination in remote areas. The installed system includes a submersible pump, reverse osmosis unit, photovoltaic panels and battery storage. The system is continually updated in order to improve the operating conditions, and thus to find the optimum designs of such new systems for villages and rural areas in Saudi Arabia. An 11.3 kW PV system was used to produce 600 L/h of drinking water. The objects of the research project were:

- Calculating the mathematical relation between the amount of pure water and incident solar radiation.
- Study of the performance of PV cells in Saudi Climates.
- Feasibility Study of PV water pumping and desalination.

♦ PV Greenhouse Project:

A greenhouse research project of (92 PV modules) powered by 14.72 kW PV system was made in operation in 2000. The main aim of the project was to optimize the use of PV power system for desert climate. The location was selected to be at the research station of KACST at al-Muzahmyah village. site refinery. The project aims to achieve the following objectives:

- Continue the operation of a stand-alone PV power system to supply electricity to a commercial available greenhouse.
- Quantify the operating efficiency of the new SANYO PV module designed to sustain harsh desert climate.
- Quantify the potential harmony between the solar radiation availability and the demand for electricity
- Quantify the economics of implanting heating elements to the PV-Greenhouse system.

- Analyze system measurements and alter the existing system to propose an optimum system.

♦ Solar Camp:

In 1997, a solar camp was designed and built at the solar village. The project demonstrates a typical stand-alone PV energy system used for lighting and cooling purposes. It also consists of several solar energy systems, such as solar water heating system (thermal collectors) and solar still for water desalination.

♦ Grid-Connected System (6 kW):

The project deals with technical and economical studies of integration between PV system and utility grid. It highlighted the contribution of the system in energy management and conservation. Furthermore, the project studies the peak shaving during summer seasons where the electricity demand is increasing.

♦ Mountain Tunnels Lighting:

In collaboration with ministry of communication a research project has established in 1985 by KACST for illuminating two tunnels in the south west region of Saudi Arabia (nearby Abha City). The tunnels lengths were 240 and 646 meters, while the system sizes were 48.72 and 57.6 kW respectively. The system has demonstrated to public the utilization PV energy in a rude mountain area far away from the grid. However, system in such areas needs to be at least 30 % more in size to compensate for the short daytime, due to the surrounding obstacles. A continuous maintenance was also one of the main problems which need to be considered in the system cost.

2- Industrial PV Applications:

♦ PV applications in Saudi Arabian Oil Company (ARMCO):

Since 1993, Saudi Arabian oil company (ARAMCO) has utilized the PV energy in many folds. More than 170 PV power systems have build for offshore telemetry and instrumentations. Cathodic protection is also one of the main PV applications. In addition, ARAMCO also use some PV systems for wireless communications.

♦ Saudi Telecom (STC) utilizing PV power for:

Saudi Telecom (STC) can be considered as the second PV power user in Saudi Arabia. From 1998 to 2001 more than 30 PV powered systems for microwave repeaters have been installed. Recently, most of rural communication utilise PV energy. STC is also uses PV modules for all coin phones distributed along the motorways.

♦ Saudi Consolidated Electricity Company (SCECO):

From 1992 to 2001, more than 202 low intensity PV powered aircraft warning light systems has been built by Saudi Consolidated Electricity

Company (SCECO) in different regions of the Kingdom. SCECO also uses around 110 PV powered warning light for navigational aid.

♦ **Miscellaneous PV Applications:**

PV energy applications have also proven some potential in some governmental agencies for telecommunications applications. Since 1995, the ministry of defence and aviation (MODA) has built three systems with total power of 54 kW for communication and navigational aid. Lately, the ministry of interior has built a 20 kW PV powered system in Rbuah Alkali for communication repeaters. The ministry of agriculture also has 22 PV systems for telemetry purposes. Finally, the ministry of post telegraph and telegram has more than 140 PV powered systems for telecommunication repeaters

PV Manufacturing in Saudi Arabia:

Most of the PV systems in Saudi Arabia are supplied by local PV manufacturers. Two main factories have established in Riyadh industrial area, namely Al-Jazeerah and BP solar Arabia factories. Both are only assembling the PV modules. Siemens is also planning to utilize its world-wide experiences in the dissemination of PV technology and interested to establish a PV factory in Saudi Arabia in order to enhance the commercialization process in the field of PV technology. Al-Afandi Establishment, Jeddah, has started work in the field of solar thermal technologies, as well as the manufacturing of PV modules, but their products need some time for development before commercialization. In general, solar cells manufacturing are not yet started in spite of, the availability of raw materials for silicon manufacturing in some regions of the Kingdom. The lower man power and land cost, may also introduce some good potential for solar cells manufacturing.

Obstacles of PV Widespread

The last experiences have proven that there are multitudes potential of PV utilization in rural telecommunications, cathodic protection and offshore telemetry and instrumentations. Saudi Arabia has started PV application earlier then other countries in the regions, however, the progress of PV applications in the country and ccommercialization process of PV energy technology are quit slow. The major obstacles are the higher cost of such systems as compared to subsidized utility power. Lack of awareness of the potential of solar energy amongst the general public is another obstacle for widespread of PV systems in the Kingdom. Furthermore, some promising applications, such as water pumping, rural electrification and lighting using PV energy are still need to be explored. Governmental support and legalization are also essential to push up PV applications. Finally, some technical problems such as the degradation of silicon PV cells under Saudi hot-arid weather and maintenance of PV systems need to be discussed. These two factors need to be considered in the system design. A research is currently undergo for PV cells degradation in Energy Research Institutes in King Abdulaziz City for Science and Technology, Riyadh to come up with a good view of economical feasibility of PV systems..

Summary:

Long term research of solar energy in Saudi Arabia is currently underway of improvement by ERI and other universities research centres. RD&D and industrial PV activities have confirmed that solar energy has a multitude of practical uses in the Kingdom. Unfortunately, the commercialisation process of solar energy technology is very slow for the various reasons. The major obstacles are the higher cost of the PV systems as compared to subsidised utility power, where the electricity tariff is cheaper than other countries in the regions. The dissemination and commercialization of solar energy can be achieved by some steps, like interaction between research centres such as, ERI and the local industry for mass production of experimentally and seasonally tested PV energy technologies. In addition, the country is in need for PV energy education and training programmes and creation of local credit and other facilities, which may enable the general public to get access to owning and operating PV energy technologies. Finally, some government support and legalization are needed to be stated for large electricity users in using PV energy, especially for peak load shaving during summer seasons.

Progress of Photovoltaic (PV) Applications in Saudi Arabia

- Dr. Ahmed O. Al-Amoudi
  - *King Abdul Aziz City for Science and Technology (KACST)*
  - *Energy Research Institute (ERI)*

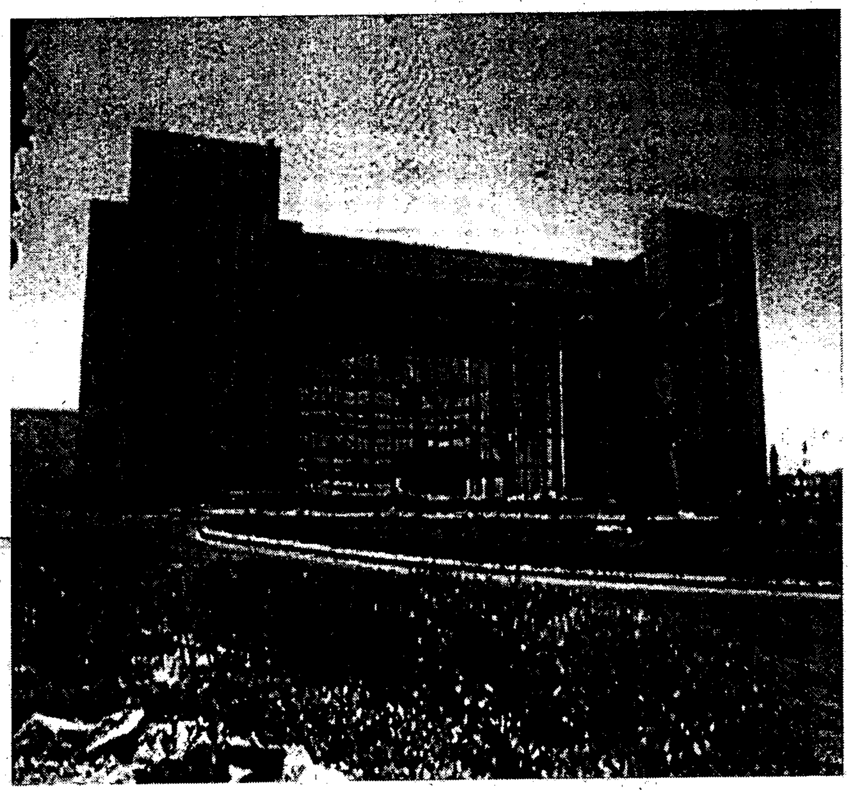
Presentation Outline

- History of PV Energy in Saudi Arabia
- Major PV Applications in The Kingdom
- PV Manufacturing
- Obstacles of PV Widespread
- Conclusions and Discussions

History of PV Energy in Saudi Arabia

- 1960 French Company Installed Photovoltaic Powered Beacon at Small Airport.
- Systematised Major R & D Work For Renewable Energy was Started by the Establishment of KACST in 1977.
- 1980s KACST Entered Into International Joint Research Programs.
- 1988 Establishment of ERI

King Abdul Aziz City for Science and Technology (KACST)



Energy Research Institute ERI

Objectives of ERI

- Identifying energy-related problems and propose appropriate solutions.
- Transfer and development of energy technologies that are socially and environmentally suitable for the Kingdom.
- Preparing related studies on energy conservation and its utilization.
- Assessing renewable energy sources in the Kingdom.

Objectives of ERI Cont.

- Supporting the private sector to achieve efficient energy uses in various applications.
- Contributing to the development of manpower in the field of energy technologies.
- Promoting public awareness in the field of energy sources and utilization.

Major PV Applications

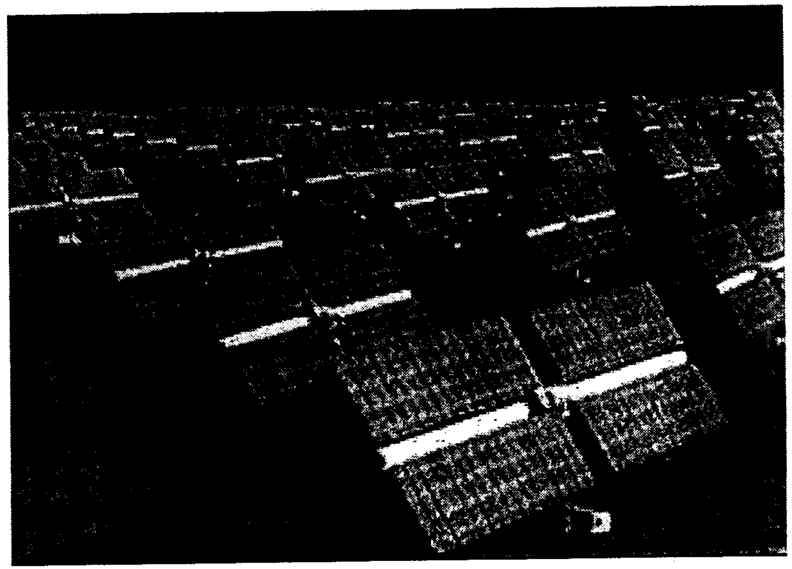
- Research Development and Demonstration (RD & D) PV Applications
- Industrial Applications

Research Development and Demonstration (RD & D) PV Applications

- Solar Village
- HYSOLAR Project
- PV water pumping and desalination
- PV Greenhouse Project
- Solar camp
- 6 kW PV grid –connected
- Tunnel Lighting

Solar Village

- 350 kW PVPS, completed in 1981, 1st in size and complexity
- Supplied 1 to 1.5 MWh/ day to three villages
- Experiences acquired contribute significantly to technology development
- Establishing the Solar Village test facility (thermal-sun simulator, Spectro Lab & others installation)

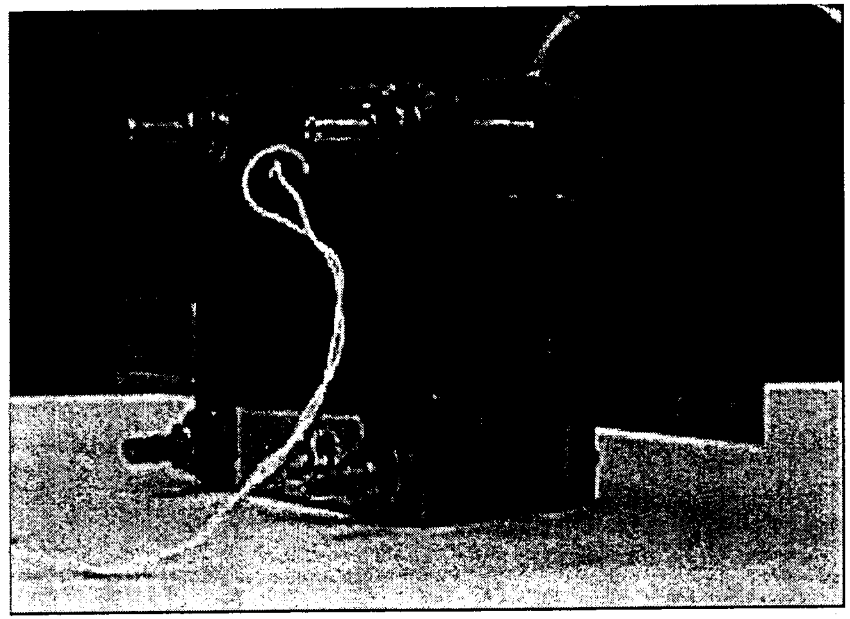


HYSOLAR Project, Saudi-German Joint Program

- 60 M Deutsche marks funded jointly by the two countries, 1986-1995
- Objectives:
  - Gaining the basic scientific and technical knowledge in hydrogen production using solar energy.
  - Prediction of technical and economics of solar hydrogen technologies.
  - Design, installation and safe operating for the solar hydrogen production plant.

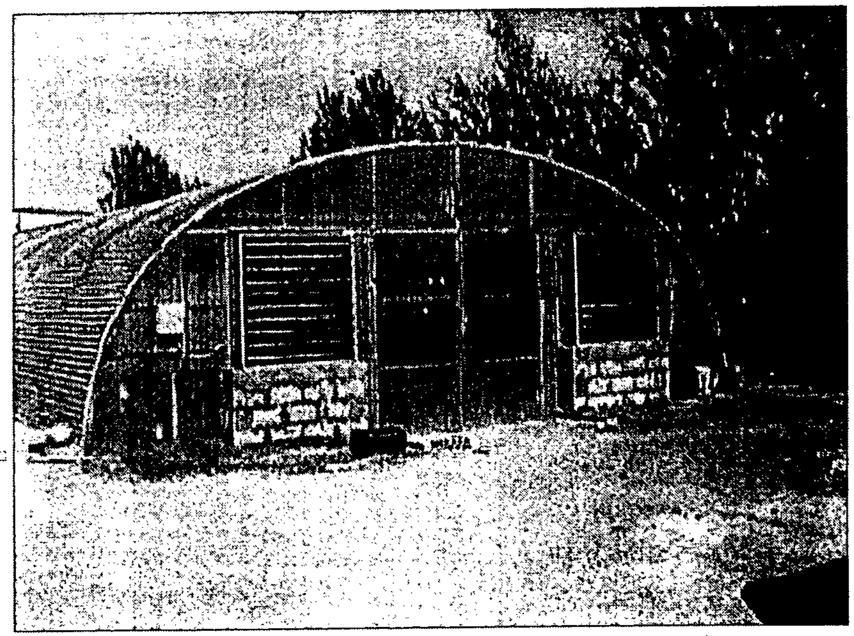
HYSOLAR Major Technical Achievement

- Fuel Cell R&D
- Real example of hydrogen utilization
- Offer high efficiency (75-80%).
- Modularity and good environment characteristics.
- Development of PAFC half cell, mono cells, 100, 250, 1 kW stacks

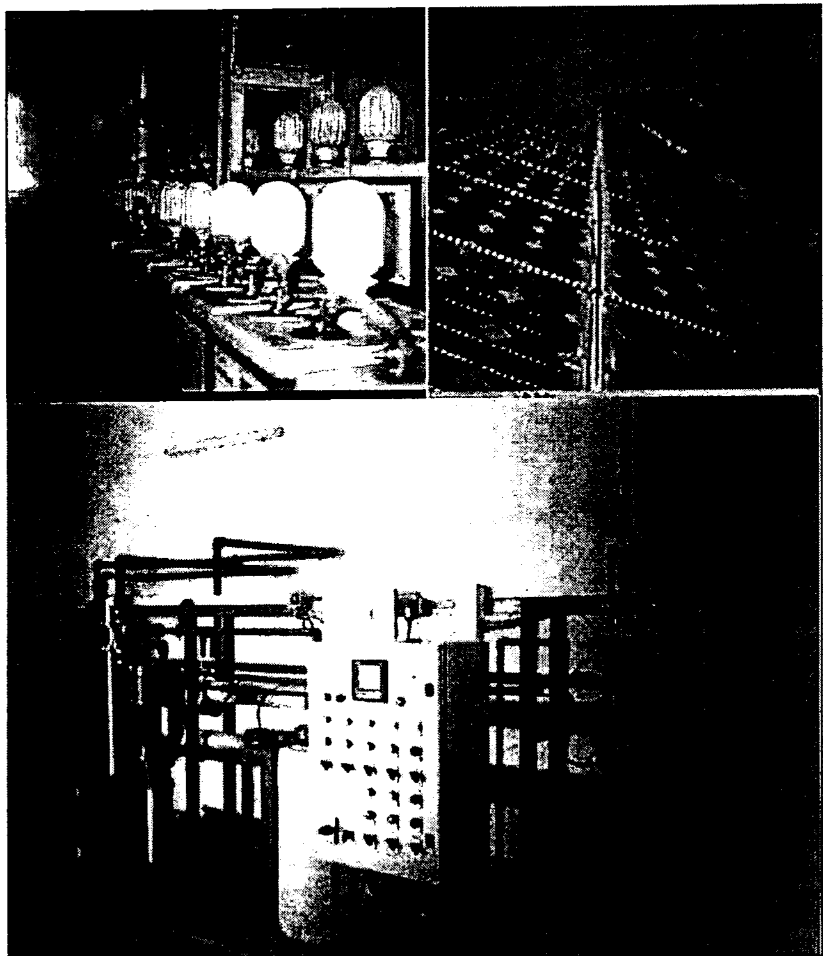


PV Greenhouse Project

- Established in 2000
- 92 SANYO manufactured modules, 160 Watt capacity each. Total of 14.72 kW
- 60 deep charged batteries. Total of 3000 Ah (350 kWh)
- 15 kVA SunPower with 15 kWp MPPT and 120 V
- the project aimed for optimization of the use of PV power system for desert climate



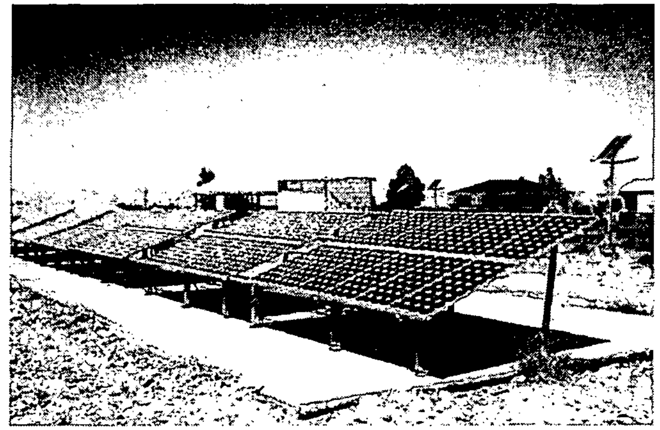
PV Water Pumping & Desalination



- Design and operation of 11.3 kW PV powered plant for water pumping and desalination
- 10.08 kWp PV for RO & 980 Wp for pumping
- 50 m deep well & ~7000 ppm
- Produce 600 lt/h in Phase 1 and 24 M^3/Day in Second Phase
- Calculating the mathematical relation between the amount of pure water and incident solar radiation.

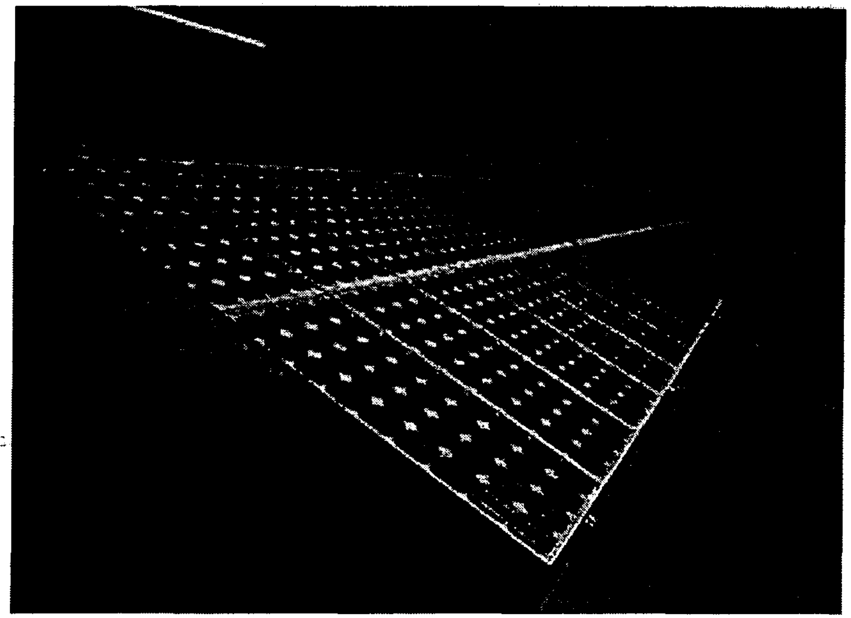
Solar Camp

- Established in 1997
- 6 Arrays, 12 Modules per array total of 5.4 kW
- Storage System 60 Batteries (2 V, 1200 Ah)
- Project Demonstating Solar Applications to puplic
- Stand Alone PV cooling and Lighting
- Solar Thermal Heater (Solar Collectors)



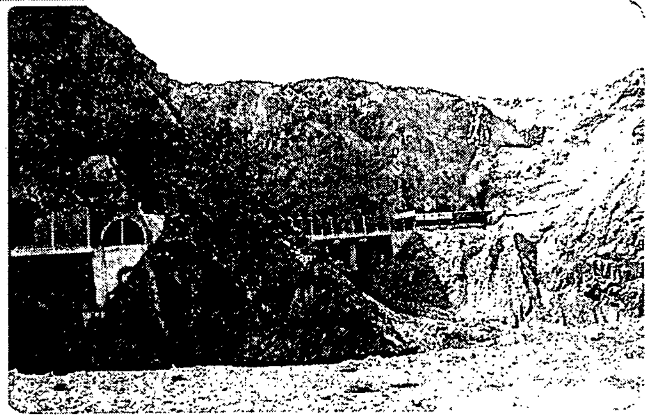
PV Grid Connected System

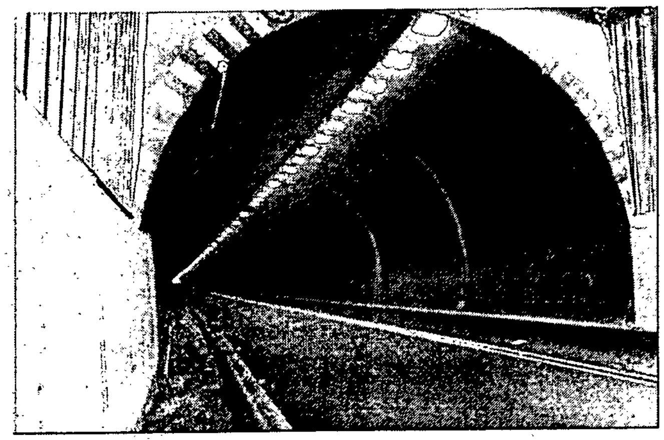
- Established in 1996
- 6 Arrays, 1Kw per Array, Total System Size is 6 kW
- No Storage System, Cost Reduction by 40%.
- Project Suggested a Mathematical Equation for the Payback Period.
- Some Solution for Peak Load Shaving.



PV-Powered Highway Lighting

- Project Sponsored by KACST in collaboration with the ministry of communication
- include two remote tunnel lighting of 240 m & 546 m and 48 & 57 kWp
- Batteries sizes were 6000 4900 Ahr



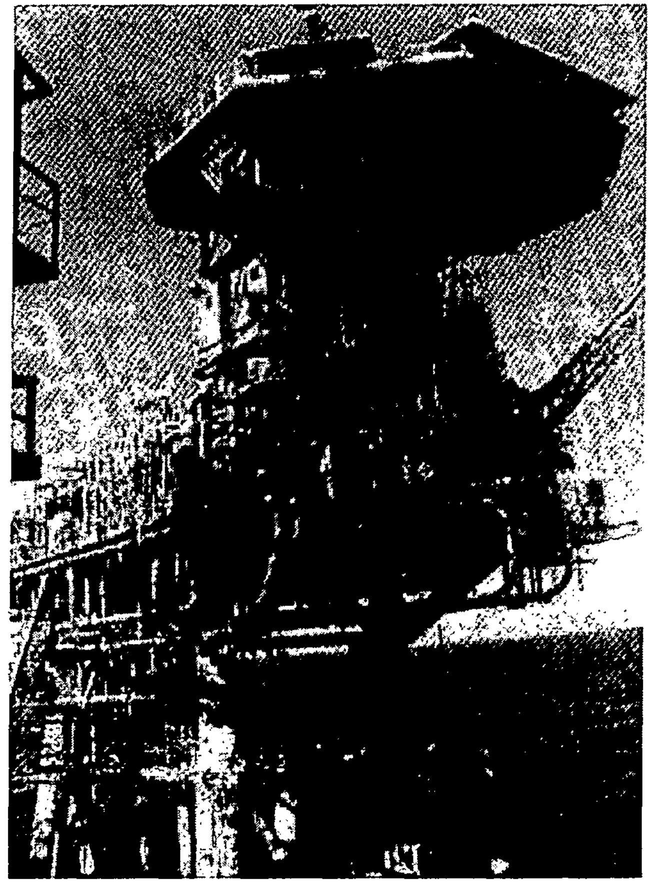


Industrial Applications

- PV applications in Saudi Arabian Oil Company (ARMCO)
- Saudi Telecom (STC) PV power Applications
- Saudi Consolidated Electricity Company (SCECO)
- Miscellaneous PV Applications:

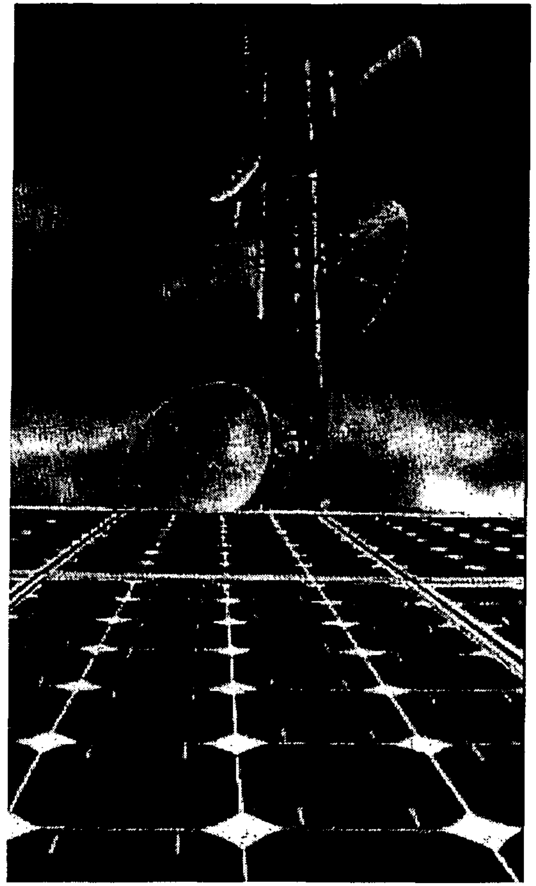
Saudi Aramco

- Offshore telemetry and instrumentations
- Cathodic protection
- Wireless and Radio communications



Saudi Telecom (STC)

- PV powered systems for microwave repeaters
- Rural communication
- Coin phones

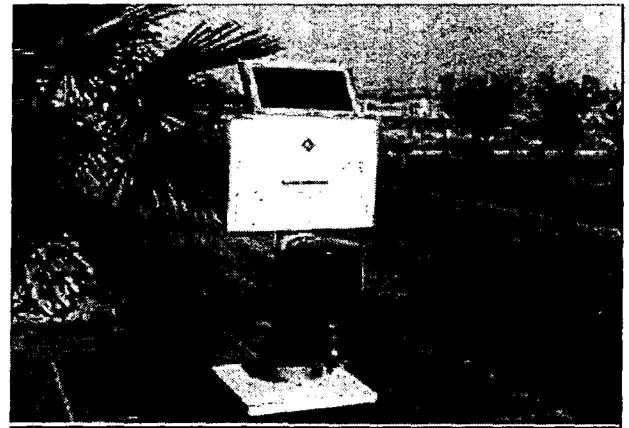


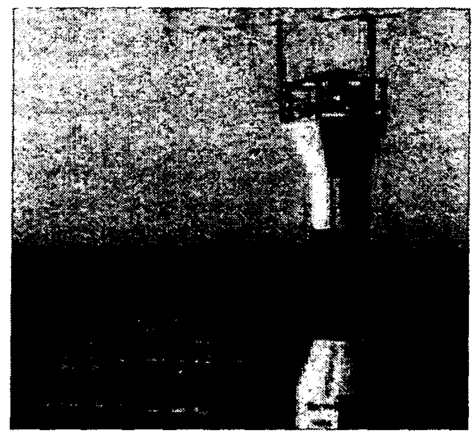
Saudi Consolidated Electricity Company (SCECO)

- PV powered systems for microwave repeaters
- Rural communication
- Coin phones

Solar powered highway devices

- 54 kW telecommunications PV System for the ministry of defence and aviation (MODA).
- 20 kW PV powered system for communication repeaters built by the ministry of interior.
- 22 telemetry purposes PV systems for the ministry of agriculture
- Solar powered highway devices





Obstacles of PV Widespread

- Higher cost of such systems as compared to subsidized utility power
- Lack of public awareness of the potential of solar energy amongst the general public
- Some promising PV application need to be explored.
- Lower governmental support and legalization.
- Researching technical and economical problems.

Summary and Conclusions

- RD & D and industrial activities in the Kingdom have confirmed that PV energy has a multitude of practical uses
- Interaction between research centers and the local industry for mass production of experimentally and seasonally tested PV energy technologies
- PV energy education and training programmes are needed for increasing public awareness
- Governmental legalization for the large electricity users
- Some technical and economical problems like PV degradation and maintenance need to be reserched

Report on Activities of Photovoltaic Applications in Kuwait

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ABSTRACT

In the state of Kuwait, there is one research institute, which conducts research on fundamentals and applied photovoltaic cells. The research institute is called Kuwait Institute for Scientific Research (KISR). A Japanese's Oil Company, the Gulf Oil Company, established the institute in 1967 in order to assist local industries in Kuwait to find solution approaches for industrial problems throughout conducting research. The main industrial problems were related to the oil production, petrochemical refineries, and water desalination in Kuwait. Throughout the recent year, KISR are involved in the following research projects relating to the applications of photovoltaic cells:

1- Controlling the illumination of traffic signals by solar cells for the traffic department of the Ministry of interior.

2- Controlling Cooling and Heating of buildings by solar cells. The project was conducted in collaboration between KISR and a research institute in the kingdom of Saudi Arabia.

3- Controlling the corrosion of pipelines by a cathodic protection method, using an external impressed current from solar cells in the desert of Kuwait. The project will be conducted in collaboration between KISR and with a local oil company in Kuwait.

4- Modeling of Photoluminescent phenomenon of porous silicon-Light Emitting Diodes (LED's). This R&D is on going idea in the Materials Science Laboratory of the Department of Advanced Systems of KISR.

Details examples on the above applications of the photovoltaic cells will be given in the presentation.

Report on Activities of Photovoltaic Applications in Kuwait

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1-Electricity production by solar photovoltaic and solar thermal systems as compared to the conventional (fuel) electricity production in the state of Kuwait.

1.1-The cost of the electricity production by conventional and solar systems will give in the presentation.

2-Water production by solar photo-voltaic and solar thermal systems as compared to the conventional water production, either by Multi-Stage Flash (MSF) or Reverse Osmosis (RO) desalination systems, in the state of Kuwait.

2.1-A figure of water production of different systems will be given in the presentation

2.2-The cost of water production by conventional, MSF & RO, and solar systems using MSF and RO techniques will be given in the presentation.

2.3-The cost of the water production by conventional and solar systems using MSF technique will give in the presentation.

-2.4The cost of the water production by conventional and solar systems using RO technique will given in the presentation.

3-Cooling production by solar photovoltaic and solar thermal systems as compared to the conventional cooling production in the state of Kuwait.

3.1-A figure of cooling production of different systems will be given in the presentation

3.2-The cost of the cooling production by conventional and solar systems using vapor compression cooling (VCC) and vapor absorption cooling (VAC) techniques will given in the presentation.

4-Modeling of photolumenience phenomenon of porous silicon-Light Emitting Diodes (LED's) & Modeling of photo-voltaic systems of porous silicon structures. This R&D are on going ideas in the Materials Science Laboratory of the Department of Advanced Systems of KISR.

Detail examples (8-10 figures) on the above applications of the photovoltaic cells will be given in the presentation.

SOLAR APPLICATIONS IN JORDAN

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Jordan depends entirely, on imported energy and pays more than 10% of its GDP to meet its energy needs. The total area of the country is 89206 Km^2, where only 3% of the total population in Jordan occupy about 41% of the above-mentioned area. This land area represents the rural and desert part in the country, which lacks electricity.

Jordan lies in the so-called earth-sun belt area, and possesses high potential of solar energy, where the annual daily average of solar radiation on a horizontal surface is about 5.5 kWh/m^2.

Since the conventional energy resources discovered locally are limited, and considering the big burden that the imported energy has on the national economy, the Government of Jordan gives special attention to renewable energies, for the purpose of assessing, developing and planning of the local energy demand.

In this regard, Jordan has pursued intensive programs for promoting renewable energy. This involves systematic monitoring and assessment of technological developments, implementation of appropriate know-how and execution of demonstration, and pilot projects since the early seventies. Consequently, Jordan, among other countries in the region, has reached a reasonable stage in the utilization of renewable energies especially in the following areas:-

1. SOLAR APPLICATIONS

Photovoltaics Systems

The use of renewable energy systems especially photovoltaics as decentralized systems to meet the essential needs of the remote and rural areas for electrification, water pumping and other social services. There are more than 80 stations operating in this field with a capacity of 176 kW peak, as follows:

- 23 photovoltaics pumping systems with a total peak power 110 kW. The yearly average output of these pumping stations is 1541(m^3/day), the target groups are Bedouins and their herds in remote rural areas and desert regions.
- 13 photovoltaics communication stations with a total peak power 19 kW.

- 19 photovoltaics power supply systems for remote police stations with a total peak power 17 kW.
- 14 photovoltaics power supply systems for remote schools with a total peak power 4 kW.
- 5 isolated and remote clinics electrified by photovoltaics power supply systems with a total peak power 6.5 kW.
- 3 remote mosques electrified by photovoltaics power supply systems with a total peak power 750W.
- 6 systems for other general applications with a total peak power 18 kW.

As a result, these PV-systems are now working for more than 10 years under the hard climatic conditions. To date, no power supply interruption occurred and generally it can be said that the PV-power supply systems are highly reliable and working very satisfactorily. Also, the operation of these systems indicates that the major equipment (PV) are operating as expected, some problems occurred with other components of the systems such as the storage batteries, inverters or charge controller and water pumps.

<u>Solar Thermal Systems</u>

Utilization of solar energy systems for water heating (industrial and domestic), where 30% of the houses are equipped with these systems, saving about (70) thousand tons of oil equivalent annually, and contributing about 1.5% of the energy consumption.

The use of solar energy for the production of Potash at the Arab Potash Company in Jordan, where about 1.2 million tons of Potash per year are produced by utilizing solar radiation to evaporate 90 million cubic meters of salt water, saving about 4 million tons of oil equivalent annually. Without the use of solar energy, this project would not be feasible.

2. WIND ENERGY

Wind energy in Jordan is used mainly for electricity generation. There are two wind farms, one with a capacity of 320 kW, established in co-operation with a Danish Firm and considered as the first pilot project. The other most recent one

has a capacity of 1.2 MW, established in co-operation with the German Government under the so-called ELDORADO program.
Wind energy is also used intensively for water pumping in remote areas of Jordan, using locally manufactured mechanical windmills.

3. **BIOENERGY**

In the field of Bioenergy, Jordan is now executing a pilot project on the utilization of municipal solid waste for electricity generation through landfill and biogas technology systems. The project is funded by the Global Environment Facility "GEF" and considered the first of its kind in the region. The total capacity of this project is 1 MW for electricity generation.

4. Rational Use of Energy

Through many workshops, questionnaires and direct contact with the different economic sectors in Jordan, barriers preventing the implementation of energy efficiency measures in Jordan were identified, which are:

1. Lack of incentives and financing.
2. Lack of information.
3. Lack of technical expertise.
4. Lack of Management commitment, policy and organizational structure supporting energy management.
5. The needed equipment and retrofits are not available in the local market.
6. Non-existence of laws and regulation to promote energy efficiency.

Most of NERC activities in the field of improving the energy efficiency in the local economy are geared towards creating the energy conservation market in Jordan through:

- Market pulls.
- Technology push.
- Improving regulatory framework.

These mechanisms are being implemented through the implementation of many projects in cooperation with GTZ, GEF/SGP, Higher Council for Science and Technology, Chambers of Industries, NGOs, Industrial Development Bank, Ministries, The General Corporation for The Environmental Protection, Jordan Engineers Association and many other local institutions to overcome the identified barriers.

In conclusion, we can say that the efforts which have been made in Jordan until now, have paved the way for the utilization of renewable energy; either for electricity production, or for remote and rural applications.

The already accomplished projects and studies in this field provided Jordan with scientific and practical experience, qualifying it for taking the lead, among the countries of the region, towards harnessing renewable energy resources and technologies for further development, entering a new phase of local manufacturing of renewable energy systems by means of cooperation and joint ventures between local institutions and foreign companies.

From Research to Investment in Photovoltaic Water Pumping Systems

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ABSTRACT

The high initial cost required to implement Photovoltaic (PV) energy projects represents a major obstacle for the dissemination of this clean and attractive technology world-wide. In the past, most applications were limited to small scale subsidised research projects Currntly, it is noticed that many applied projects are turned from research to small scale real applications. But untill now, investment and services projects are not actually wittnessed.

In this paper, economic feasibility and prospect of investment in this field are discussed. It was found that small scale PV pumping projects are economically more feasible than the traditional diesel systems. Moreover, economic figures indicated that investment and real service projects are becoming commercially viable

Keywords: PV water pumping system, Diesel water pumping system, Cost annuity per production unit, Net present value, Internal rate of return, Pay-back period

1. Introduction

As a prerequisite to this work, detailed feasibility study has been carried out based on field experience and market situation. Many PV water pumping systems that are running in the field have been selected for this study. Actual output figures are considered. Moreover, prices are taken from the market based on year 2002.

The outcomes of this feasibility study are considered as a basis for this paper. However, it is found necessary to define some parameters and to mention some facts before coming out to the results of this study.

1.1. Equivalent hydraulic energy

The equivalent hydraulic energy (m^4), which is defined as the multiplication of water output volume (V) in cubic meter by the pumping head (h) in meter, is the basic output unit for any water pumping system. This unit gives more comprehensive meaning than flow rate. In this study 1000 m^4 will be used as an output unit which is equivalent to 2.725 kWhr. Therefore, this value can be applicable to any well. By giving any pumping head, cost of the output cubic meter can be easily calculated (i.e 1000m^4 is equivalent to 50 m head * 20 m^3 of water).

1.2. Key factors of the results

In general, four methods of economic evaluations are used worldwide: two of them are static undiscounted (Payback period and return on investment methods), and the others are dynamic discounted (net present value and internal rate of return methods) Moreover, the following 3 factors are the main indicators of this study:

- Net present value (N. P. V) in US$.
- Annuity (A) in US$/year.
- Cost annuity per production unit in US$/1000m[4]

1.3. Actual interest rate

Market interest rate and inflation rate have to be considered carefully. Based on these two values, the actual interest rate can be calculated mathematically.

In this study, an actual interest rate of 5% is used as a basis for the main study.

1.4. Lifetime and salvage values

The whole study has been conducted based on 20 years lifetime. Assumed lifetime of each component is depicted in Tables 1 &2. The lifetime of the PV generator is considered as 20 years but with 20 % loss of power output at the end (around 1% per year). In this regard, output units of the systems mentioned in the tables are taken from actual data in the first three years of their operation. However, these values will be discounted with time until reaching about 80% of its mentioned values at the end of its life (after 20 years). As an average figure, 90% of the mentioned figure in the tables has been taken as a yearly output starting from year 1 until year 20.

No salvage values have been considered for any component.

1.5. Factors affecting the economic study

For executing accurate economical analysis, many parameters that affect the results directly or indirectly have to be considered. Indirect parameters like social , health and environmental aspects are not considered here because of its dependence on many other factors relating to the society where systems are to be installed. Here are the main important direct parameters:

- Field of application (electrification, water pumping, ...etc.).
- Alternatives (Diesel generators, Batteries,...etc.).
- Local location (effect of distances).
- Geographical location (effect of meteorological parameters).
- Type and size of the electric load.
- Interest rate and Inflation rate.
- Intensity of solar irradiance.
- Fuel prices.
- Installation costs.
- Lifetime of components.
- Component costs.
- Maintenance costs.
- Labor costs in case of guards, hand work, maintenance work,...etc.

2. Systems Data

5 PV pumping systems of different sizes have been selected. The technical data of the first three systems were taken from the field. The data of the other two systems have been

calculated based on the outcomes of the mentioned three systems. On the other hand, 5 comparable diesel systems have been suggested. Data were taken from field experience, manufactures specifications and from the local market. Prices of components are taken from actual competitive prices based in July 2000. These data are depicted in Tables 1 & 2.

Table 1: Technical and Financial data for PVP-systems

Specifications, items	**Unit**	**System 1**	**System 2**	**System 3**	**System 4**	**System 5**	**Lifetime**
Output equiv. Hyd. energy	m^4/year	579000	846000	1472000	2336500	3504750	
Installed PV power	kWp	2.8	4.5	6.3	10	15	
Specific module price	$/Wp	3.6	3.6	3.6	3.6	3.6	20
Specific price for structures	$/Wp	0.3	0.3	0.3	0.3	0.3	20
Total PV generator/structure	$	10920	17550	24570	39000	58500	
Inverter cost	$	2000	3000	4000	6000	8000	10
Cost of submersible pump	$	450	600	900	1100	1300	10
Cables, wires, fittings...etc.	$	280	450	630	1000	1500	10
Pipes cost	$	200	300	500	600	700	10
Cost of installation	$	600	800	1100	1300	1500	20
Storage tank cost	$	1500	1500	1500	1500	1500	20
Basement for PV modules	$	512	823	1152	1829	2743	20
Fence (instead of operator)	$	700	800	900	1000	1100	20
Total initial investment costs	***$***	***16462***	***25023***	***34352***	***52329***	***75743***	
Operator (if needed)	$/year	/	/	/	/	/	
Maintenance (yearly)	$/year	400	600	900	1200	1400	
Total operating costs	***$/year***	***400***	***600***	***900***	***1200***	***1400***	

For diesel pumping systems, 5 comparable cases are considered. Technical data are taken from manufacturer specifications and expertise. Table 2 briefs these details.

Table 2: Technical and financial data for proposed diesel pumping systems

Specification/item	Unit	System 1	System 2	System 3	System 4	System 5	Life time
Output equiv. Hyd. energy	m^4/year	579000	846000	1472000	2336500	3504750	
Nominal power of D. engine	KVA	3.5	4.5	6.3	10.0	15.0	
Efficiency of D. engine	%	25	28	32	36	40	
Efficiency of generator	%	75	78	82	85	85	
Efficiency of pump-motor	%	40	43	46	50	55	
Overall efficiency	%	8	9	12	15	19	
Specific Hyd.equiv./ lit. fuel	m^4/L	275	345	443	561	686	
Specific fuel consumption	L/1000 m^4	3.6	2.9	2.3	1.8	1.5	
Flow rate	m^3/hr	10.3	7.2	7.4	10.5	13.6	
Total pumping head	m	24	50	85	95	110	
Hyd. energy discharge	m^4/h	248	362	630	1000	1500	
Diesel consumption	L/h	0.9	1.1	1.4	1.8	2.2	
Yearly diesel consumption	L/year	2104	2455	3323	4161	5107	
Diesel generator set price	$	2000	2500	3200	5000	6500	7
Submersible pump cost	$	450	600	900	1100	1300	10
Cables & wires cost	$	40	70	100	150	170	10
Pipes cost	$	200	300	500	600	700	10
Price for installation	$	400	400	400	400	400	
Storage tank cost	$	1000	1000	1000	1000	1000	20
Total investment costs	$	4090	4870	6100	8250	10070	
Fuel+transportation cost	$/L	0.2	0.2	0.2	0.2	0.2	
Fuel + transportation cost	$/Year	421	491	665	832	1021	
Lubricant	$/Year	50	60	80	120	150	
Operators	$/Year	5000	5000	5000	5000	5000	
Maintenance	$/Year	200	300	400	500	600	
Total operating costs	**$/Year**	**5671**	**5851**	**6145**	**6452**	**6771**	

Dynamic economic indicators

After collecting all necessary data for the economical study, it has been analyzed by using computer software (Microsoft Excel 2000). The results are briefed in table 3 and table 4

Table 3: Dynamic indicators for PV water-pumping systems

	Unit	System1	System2*	System3**	System4**	System 5**
Net present value	$	23,665	35,785	50,041	73,743	101,458
Annuity	$/year	1,899	2,871	4,015	5,917	8,141
Cost annuity per 1000m4***	$/1000 m4	3.28	3.39	2.73	2.53	2.32
Cost annuity per 1000m4****	$/1000 m4	3.64	3.77	3.03	2.81	2.58

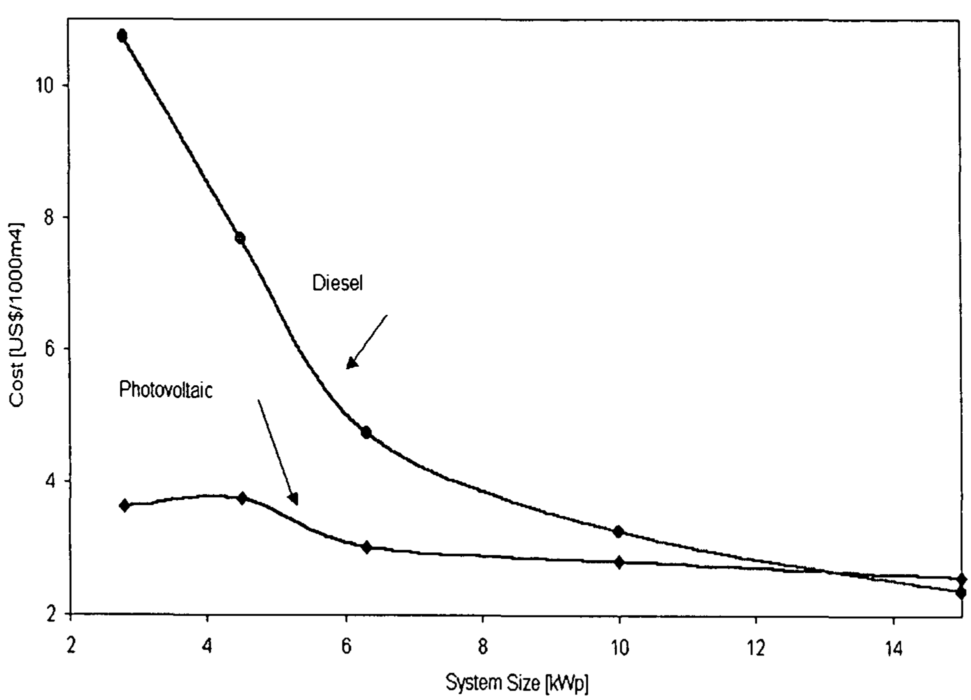
* System is not well designed
** System is well designed (Tandem system)
*** No degradation
**** With 90% of the output

Table 4: Dynamic indicators for diesel water-pumping systems

	Unit	System1	System2	System3*	System4*	System5*
Net present value	$	82,068	86,294	93,027	102,482	111,232
Annuity	$/year	6,585	6,924	7,465	8,223	8,926
Cost annuity per 1000 m4	$/1000 m4	11.37	8.18	5.07	3.52	2.55

Cost annuities per production unit in the last two tables are depicted in figure 1. It is concluded from this figure that PV pumping systems are more economical than diesel pumping systems in the range lower than 13 kWp. In other way, systems of equivalent hydraulic energy less than 3 * 10^6 m^4/year (8200 m^4/day) has better economic feasibility if driven by Photovoltaic energy rather than diesel generators. This is valid for regions of solar radiation values greater than (6 kWh/m².day).

FIG. 1: OUTPUT UNIT COST FOR BOTH APPLICATIONS



3. INVESTMENT PROSPECTS IN PV WATER PUMPING

In this study, a unit cost of \$3.7/1000m^4 is considered as a base. This figure is taken as an average unit cost systems 1&2 since small scakle systems are the most popular in the market nowadays.

3.1 Effect Of Water Tariff And Pumping Head On the main economic indicators

Water tarrif and pumping head are the main factors that affect the outcomes of the economic study. These factors are variable based on the well head where the system to be installed and on the water price to be sold for customers.

Based on the results of figure 1, it becomes clear for investors to determine the price of water which is to be supplied to the consumer to achieve the required profit. As a demonstrative example, system 1 is considered with 3 different water tariffs (0.2, 0.45, 0.7) \$/ m^3 and 10 different values for well depth (10, 25, 40, 55, 70, 85, 100, 115, 130, 145) m.

Effect of these factors on the main economic indicators are breifed in table 4 and the figures of the following items:

Table 4 : Net present value, unit cost, internal rate of return, and pay - back period at different water tariffs and pumping head

Water tariff \$/m³	Head m	Yearly water output m³	Net present value (\$)	Cost annuity per unit \$/m³	Internal rate of return (%)	Pay-back period (Year)	Revenue \$ / Year
	10	57900	142171	0.04	56.5	2.1	11580
	25	23160	37424	0.09	23	5.9	4632
	40	14475	11237	0.15	13.1	12.8	2895
	55	10527	-673	0.2	7.7	-	2105
	70	8271	-7472	0.26	3.9	-	1654
0.2	85	6812	-11874	0.32	0.9	-	1362
	100	5790	-14949	0.37	-	-	1158
	115	5035	-17226	0.43	-	-	1007
	130	4454	-18975	0.48	-	-	891
	145	3993	-20362	0.54	-	-	799
	10	57900	360395	0.04	123	0.9	26055
	25	23160	124714	0.09	51.1	2.4	10422
	40	14475	65797	0.15	32.5	4	6514
	55	10527	39007	0.2	23.5	5.7	4737
	70	8271	23705	0.26	18	7.7	3722
0.45	85	6812	13800	0.32	14.2	11.8	3065
	100	5790	6880	0.37	11.2	14.8	2606
	115	5035	1755	0.43	8.9	18.4	2266
	130	4454	-2195	0.48	6.9	-	2004
	145	3993	-5316	0.54	5.2	-	1797
	10	57900	578618	0.04	190.8	0.6	40530
	25	23160	212003	0.09	78.1	1.5	16212
	40	14475	120357	0.15	49.7	2.4	10133

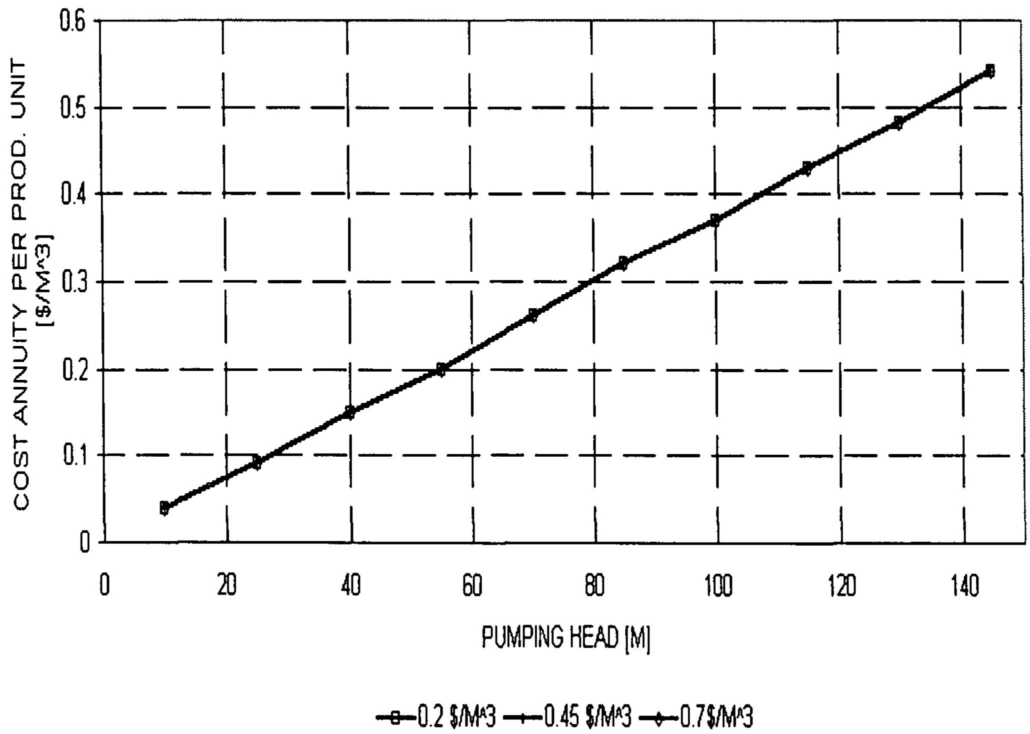
0.7	55	10527	78687	0.2	36.6	3.5	7369
	70	8271	54882	0.26	28.9	4.6	5790
	85	6812	39474	0.32	23.7	5.7	4768
	100	5790	28695	0.37	19.9	6.9	4053
	115	5035	20735	0.43	16.9	8.3	3525
	130	4454	14599	0.48	14.5	11.5	3118
	145	3993	9730	0.54	12.5	13.4	2795

3.1.1 Cost Annuity Per Production Unit,

To demonstrate the effect of the well depth on the cubic meter cost, figure 2 has been depicted depending on the following criteria:

1 m^3 cost ($/$m^3$) = cost of 1 m^4 ($/m^4)* head (m)

FIG.2: COST ANNUITIES PER PROD.UNIT FOR PVP SYSTEMS AT DIFFERENT WATER TARRIFS



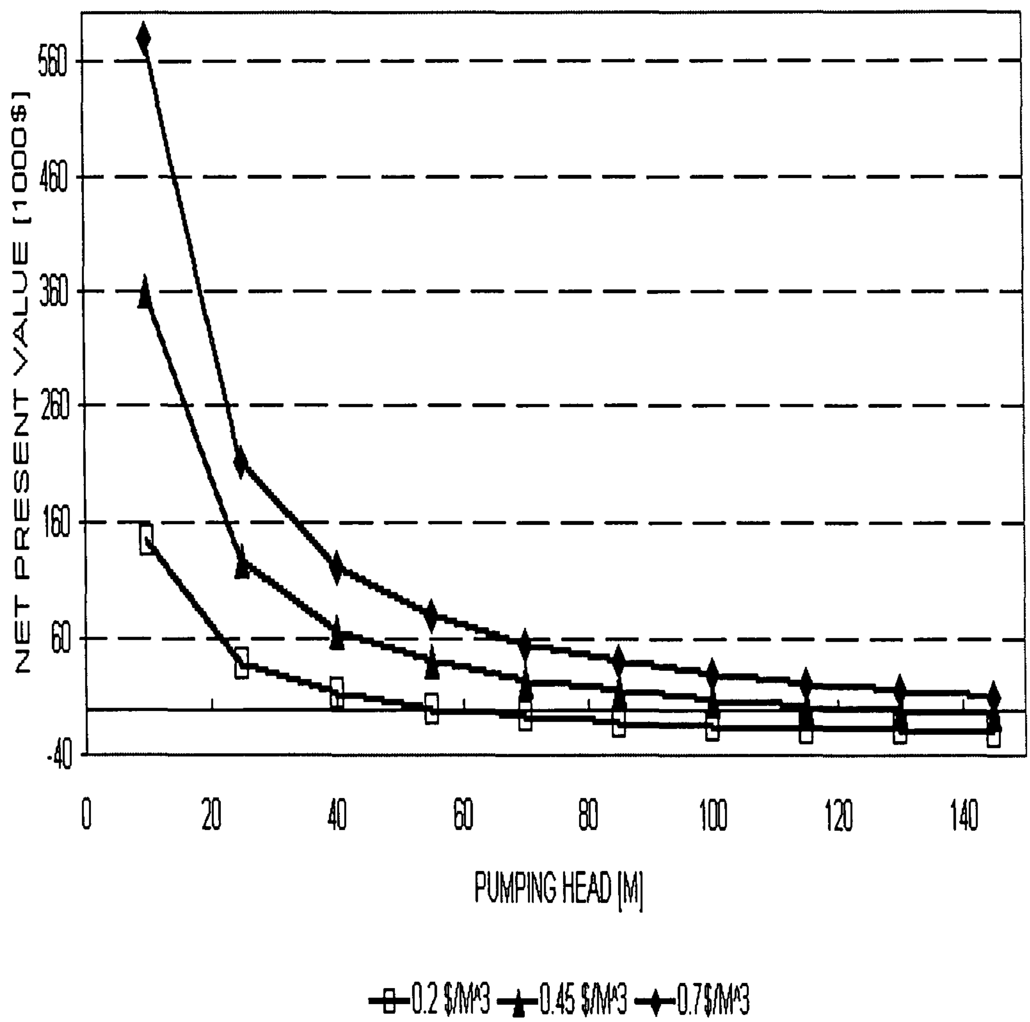
Considering the equivalent hydraulic energy cost equals to 3.7 $/1000 m4 (i.e. 0.0037 $/m4). the equation becomes: 1 m3 cost ($/$m^3$) = 0.0037 * head (m)

It is concluded from this figure that

- Unit cost is proportionally increased with increasing pumping head
- Water tarrif has no effect on the unit cost since we speak about cost not revenues
- This figure is mostly valid for a system of fixed size (kWp)
- This figure may be shifted up or down for different system sizes as stated before

3.1.2 Net Present Value

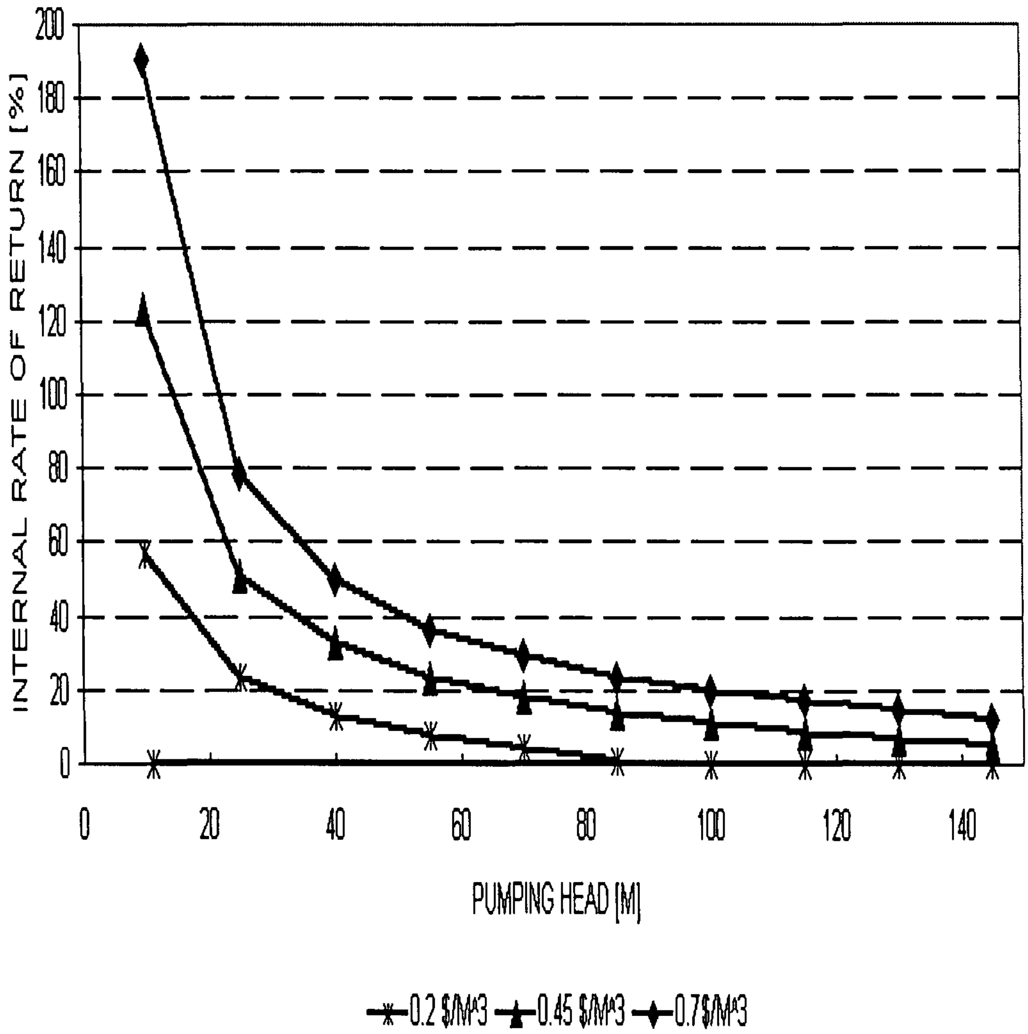
FIG.3: NET PRESENT VALUES FOR PV PUMPING SYSTEMS AT DIFFERENT WATER TARRIFS



For the three different water tariffs (0.2, 0.45, 0.7) $/m³, the system is critically balanced (net present value =0) at the following pumping head 54, 120, more than 150 m respectively.

3.1.3 Internal Rate Of Return

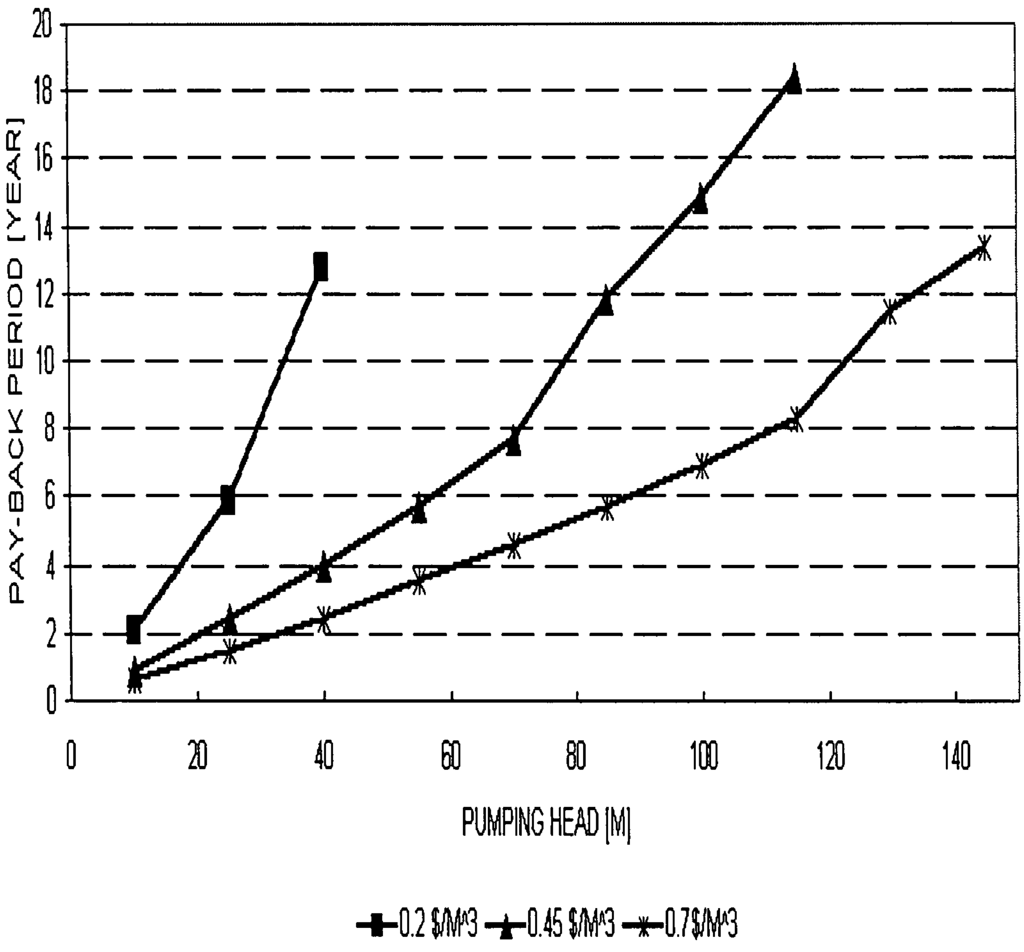
FIG.4: INTERNAL RATE OF RETURN FOR PV PUMPING SYSTEMS AT DIFFERENT WATER TARRIFS



To achieve a minimum internal rate of return = 20% at water tariffs = 0.2, 0.45, 0.7 $/m³ the following pumping head should not be exceeded (30, 65,100) m respectively.

3.1.4 Pay-Back Period

FIG. 5: PAY-BACK PERIODS FOR PV PUMPING SYSTEMS AT DIFFERENT WATER TARRIFS



To achieve a pay-back period of 6 years at water tariffs = 0.2, 0.45, 0.7 $/m³ the following pumping head should not be exceeded (25, 57,92) m respectively.

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PHOTOENERGY CENTRE
AIN SHAMS UNIVERSITY

CAIRO , EGYPT

COUNTRY REPORT
SOLAR PHOTOVOLTAIC APPLICATION IN MALI

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For the Workshop on
« PV Applications »
27-29 Mai 2002
Cairo, Egypt

Sponsored by:
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INTRODUCTION

Mali is a very big unlock country of 1,250,000 km^2 with a population of 10,000,000 inhabitants. The population density is about 1 to 5 people per Km^2 and the main activities of the population are agricultural, cattle and fishing.

The energy sector is characterized by the big proportion of wood Energy for about 90 %, against only 10 % for the others forms of energy. The big part of the electricity production came from the thermal for more than 70%, the renewable energy is insignificant for less than 1% of the total energy used in Mali.

The renewable energy and mainly the Photovoltaic (PV) had been used in Mali since the the years 1964. The solar equipment had been introduced mainly by the governmental sector for experimental and demonstration purposes and had been financed supported by the international and technical cooperation and international research centers.

In 1964, the first solar energy institution in west Africa 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, many private 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).

1 EXISTING POLICY

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

This policy is based on :

*Valorize the important potential of the hydroelectric power (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 $kWh/m^2/d$ annual mean for an irradiation of about 6 to 9 h/d)

*Contribute efficiently to the regional, sub-regional and international Energy program.

1.1 INSTITUTIONAL

-Ministry of Mining, Energy and Water is in charge of the solar energy program and policy ;
- National Direction of Energy (DNE) is 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 of promoting the sector.

To promote the energy sector in Mali, the government associate many national , regional and international organizations :

- 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 power of the Senegal River and others.

In Mali there are many local structures for the development and the promotion of solar energy :

- the training structures like high schools and university (ENI, ENSup, ECICA)
- National association of private solar energy business ;
- Regional professional association in solar energy.

-

- 1.2 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.

- decret 02-26 of 31, January 2002 to suspend the taxes on renewable energy equipment.

2. CAPACITIES (SERVICES ET PRESTATIONS)

In the field of research, studies, installation and uses of solar PV, Mali had very big experiences. About 95 % of the human and financial resources are concentrated in Bamako.

2.1 RESEARCH-DÉVELOPMENT 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 of the solar energy program in Mali. The cnesoler have also in charge to promote, to advise, to implement and to organize the renewable 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 world;
- More than 600 documents and microfiches are available on the field of solar energy in Mali

2.2 COMMERCIAL SERVICES :

The private sector is well installed and established 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..

2.3 ORGANIZATIONS AT THE VILLAGE LEVEL:

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

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. This kind of organization can be found almost in all the village.

2.4 NON GOVERNEMENTAL ORGANIZATION (NGO)

In Mali we had more than 200 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 conservation. They are also very active for the transmission of information about the characteristics, the advantages and the limit of the use of technologies.

2.5 FINANCIAL STRUCTURES :

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

The immigration (mostly from village located in the West of the Sahel of Mali) 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 in association and help a lot for the use of solar energy in their villages.

2.6. 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 cheaper to pay a component then to fabric .Actual Mali had no production unit of PV components

3. PV APPLICATIONS IN MALI (INFRASTRUCTURES ET EQUIPMENTS)

3.1 PUMPING :

More than 700 SPV(Solar Pumping System) are installed in Mali since 1977, for about more than 700 kWp. The most important equipment are 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, Public Lighting Project (PEPLS) had been installed from 1998 to 2002 ,15 pumping systems. A projection of installation of more than 250 solar pumping system is expected before the year 2010.

3.2 LIGHTING

More than 25.000 SPV are installed in Mali since 1977, for more than 300 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 more 15 thousand of systems . Some projects have installed systems for schools, medical center, cultural center, public places etc.....From 1985 to 1999, the RSP had installed 33 systems for lighting and charging batteries, from 1998 to 2000 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..

From 1998 to 2000, the Project « Women and Renewable energy » (FENER) had installed 113 lighting systems for the communities centers.

The aim for the future project in PV should be able to install around 5000 lighting systems ,1000 street lighting before the year 2010. The program concern the private, the individual, the NGO and the government sectors.

3.3 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. In ours days, all the telecommunication are almost equipped in solar PV systems.

3..4 REFRIGERATION

Approximately 120 SPV are installed in Mali since 1977, for 22 kWp mainly for the medical center. The aim for the future project in PV should be able to install around 5000 lighting systems ,1000 street lighting 120 refrigerator before the year 2010. The program concern the installations from the private, the individual, the NGO and the government sectors

3..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. The aim for the future project in PV should be able to install around 100kWp of miscellaneous before the year 2010. The program concern all kind of miscellaneous by the private, the individual , the NGO and the government sectors

4. ACTUAL OFFER OF MATERIALS AND SERVICIES

4.1. STATUT

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

- Formal which is conducted by the know official sectors (private, governement, NGO etc....) with all necessary know how and services ;

- Informal which provide materials from any where at any time . It is characterized by the bad quality of the equipment, a bad quality of the installation, the bad sizing and without any available spare parts in the market for maintenance

4.2 MATERIALS ET SERVICES OFFERT

Table of materials et 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.)

5. EVALUATION OF THE MALIAN EXPERIENCE

5.1 ÉCONOMICAL AND FINANCIAL ASPECTS

5.1.1 ECONOMICAL ASPECTS :

The Malian experience had been evaluated in many times and the main coming out results are :

- 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 had been improved with some very good result and actually the installing price is around 5.000 to 10.000 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 15 000 to 20 000 FCFA. Most the programs are using the solar refrigerators for the conservation the medical product of the medical center.

5.1.2 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 . .

The best financial mechanism can be supported by the system of credit guaranted.

- Financial mechanisms of running:

The most use system for charging the running cost is the collections, the payment of the services, and the donation 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 systems shown that the PV are economically better than the others conventional systems for the same services. In the remote area the PV is economically better. According to some studies, you pay 100% more for the conventional energy services for 50% less quality of services.

5.2 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 guaranteed life time of the module can go for at least 15 years, the others components are from 2 to 7 years

5.3 SOCIO-ORGANISATIONAL ASPECTS :

5.3.1 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..) are well trained to solve the technical, financial and social problems.
- the account opened in a bank to keep the money for the system replacement and maintenance ;
- the services for local 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.

5. 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 program of the energy sector, the technicians and the commercial will be installed in the remote area. The involved organisms for the improvement of the rate of energy in the rural are 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.

5.3.3 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, who 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.

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 which need less maintenance ;
- very low cost material and systems;
- an adapted systems to the remote area use ;
- an availability of the spare part every were at every time ;
- an availability of the local technicians.

PV APPLICATIONS WORKSHOP

Estimated need for a village of 500 people

	locàl	Estilmated Need (Wh/d)	Installed Powe in Wp	Approximative Cost in §US	Approximative Time of Rei	Amount of Rei/mo	Real Wp	Cost in $US	% of items
2.1	Water Pumping	2965	741.25	5930	15	32.94	741.25	5930	4.80
2.2	LIGTHING								
2,2,1	Individual (family)								
	Rich Individual lighting	2009	502.25	4018	5	22.32	5228.42	41827.38	33.87
	Medium individual	484	121	968	5	5.38	7351.96	58815.68	47.63
	Poower Individual	244	61	488	5	2.71	1318.82	10550.56	8.54
	Very Power Individual	100	25	200	5	1.11	180.25	1442	1.17
2,2,2	Schools	400	100	800	5	4.44	100	800	0.65
2,2,3	Medical Center	460	115	920	5	5.11	115	920	0.75
2,2,4	Mosses	200	50	400	5	2.22	50	400	0.32
2,2,5	Street Light	350	87.5	700	5	3.89	87.5	700	0.57
2,2,6	Cultural Center	200	50	400	5	2.22	50	400	0.32
2.3	Cold Production								
2,3,1	Medical Center	200	50	400	5	2.22	50	400	0.32
2,3,2	Cultural Center	200	50	400	5	2.22	50	400	0.32
2.4	Others uses								
2,4,1	Telephon Center	200	50	400	5	2.22	50	400	0.32
2,4,2	Batteries charging center	200	50	400	5	2.22	50	400	0.32
2,4,3	Miscellaneous	50	12.5	100	5	0.56	12.5	100	0.08
	Partial total		2065.5	16524		91.80	15435.70	123485.62	100.00
	Total for a village		1324.25	10594.00					

	500				
Individual	10.41	52.05	502.25	26142.11	209136.9
Rich Indidual	60.76	303.8	121	36759.80	294078.4
Meduim Indidual	21.62	108.1	61	6594.10	52752.8
Poor Indidual	7.21	36.05	25	901.25	7210
Very Poor Indidual					
		500	709.25	70397.26	563178.1

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« PROJECT OF SOLAR PHOTOVOLTAIC APPLICATION IN MALI »

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The University of AIN SHAMS

INTRODUCTION

After many years of research and development, it is possible now to give an appreciation of the orientations of the rural electrification in Mali. Mali is a very big country of 1,250,000 km^2 with a population of more then 10 millions. Due to wideness of the country, it is impossible to have the same king of strategy for the rural electrification for the whole country. For this, many considerations have to be integrated according to the realities of the population of the areas. Inside this document, I will explain a strategy for one village of 500 people. According to the national statistics, in Mali we have approximately 12,500 villages and more than the half of them have less than 5,000 people, it means that the strategies which will be developed in this document can be applied to the half of the villages in Mali by extrapolation and considerations of local realities. According to the studies, we find that, the main needs of the village are concentrated around :

- water ;
- light for schools, individual , medical center, mosses, street and cultural center ;
- cold for medical center and cultural center (refrigeration) ;
- energy for rural telephone center and others miscellaneous (batteries charging)

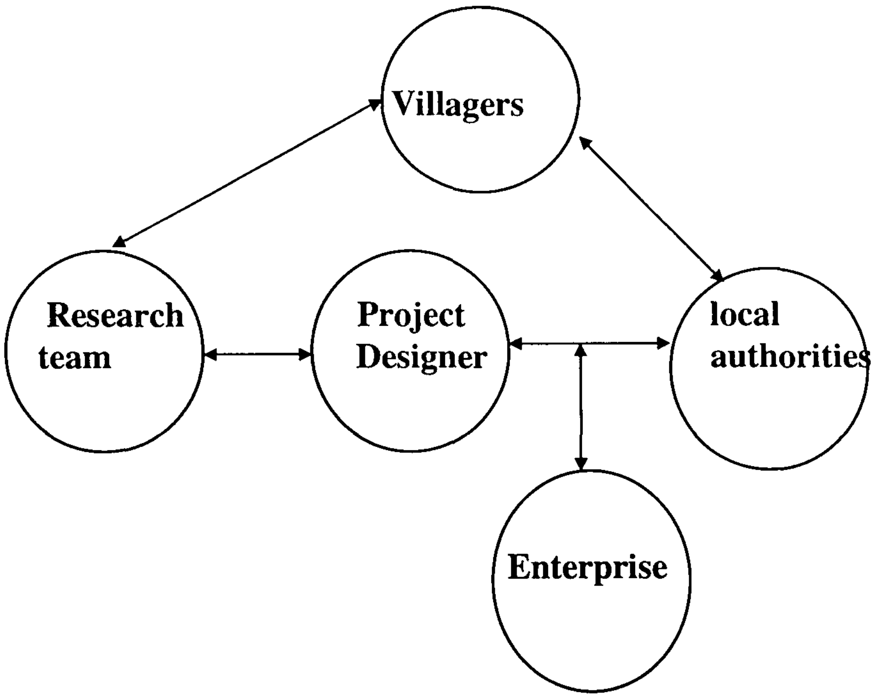
It will be consider that, the village of 500 people will have 10 person per family (100 family for the village) and the need for the individual are by family.

I OBJECTIVES OF THE PROJECT :

The aim of the project is to tray to satisfy the need of the community and some individual need. For this work we had obtained from the studies in some rural area the unit need of the energy by categories of users. To satisfy the need we have to consider the village organization, the village structures and the associations of the village. We should insist that the equipment should be use to generate resources for the community and for the individual users. The equipment should be paid, their will be no 100% gift of material or services. According to the localities, it will be necessary to increase the energy demand of certain structure (telephone center, cultural center, medical center etc...). In this case the cost of the project will increase and the reimbursement also.

II PRESENTATION

According to the studies and to aim to be obtained for this project, we had tray to use the photovoltaic to satisfy the most urgent need of village. For this a very tithed relationship should permanently between the involved structures.

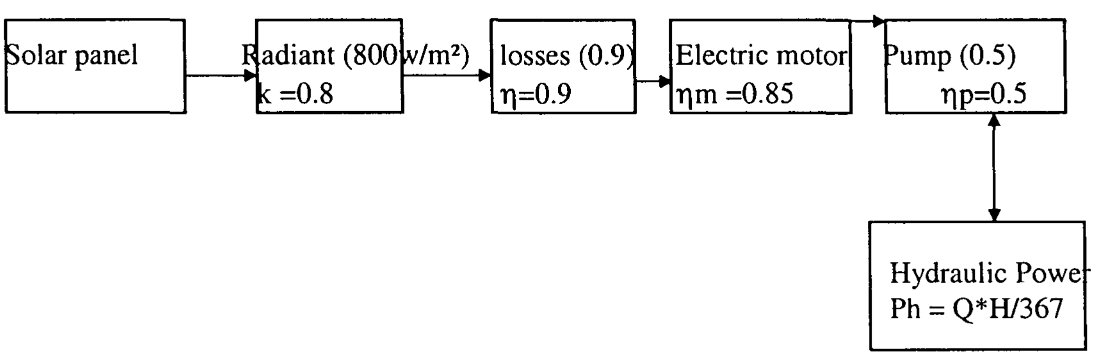


All the concerned partners are important. The research have to be done in order the solve the real problems of the village. The project have to be designed for the village from the coming data of the research team. The local authorities have to work in relationship with the data of the research team and the realities coming from the population of the village. The villagers have to discuss and to decide their real need and possibilities before given the data to the local authorities and to the research team. The entrepreneur have to work with the given data from the research team and from the local authorities. The contract have to be respected in conformity with the law of the country and with the real possibilities of reimbursement.

2.1 **Drinkable Water** :

According the studies we did, the all need of the village will be around 50 l per person an per days. This 50 liters of water must be used for people, animals and others.
We hope to have in the village a very good bore hole (or well) for less than 15 m of deep with a total head of 20m..

Example : For a village of 500 people, we have a total need of $25m^3$ per days.



where Q is the need of the village in m^3 per hour ;
H is the total head in m (20m)

With an centrifugal pump which has a maximum flow ;
$Qmax\ (h) = Q\ (days)/6 = 25/6 = 4.16\ m^3\ /hour$

The necessary Hydraulic Power :
$P(KW) = Qmax * H / 367 = 4.16 * 20/367 = 0.227KW$

The necessary Mechanical Power is :
$Pm = PH/\eta_p = 227/0.5 = 0.454\ KW = 454W$

The necessary electric motor power (the efficiency of the motor is 0,85:

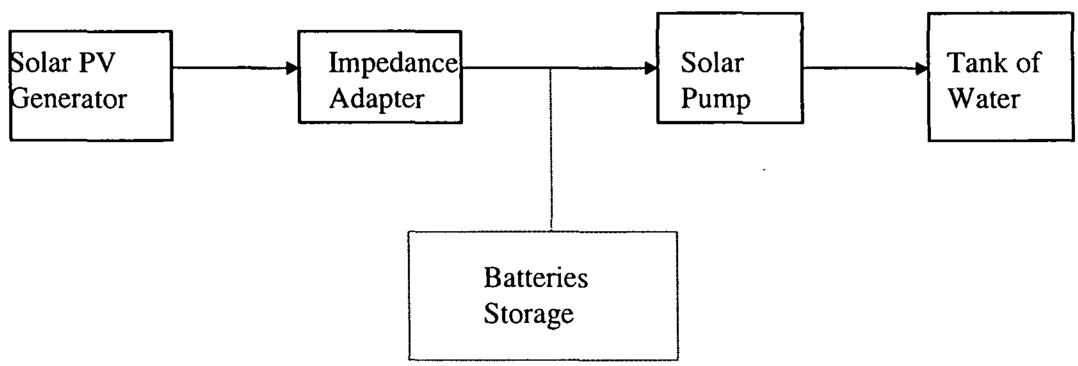
$Pel = Pm/\eta_m = 454/0.85 = 534W$

The generator power at e radiant of $800W/m^2$ in considerations of the losses due to the temperature, the dust, the cable etc..

$Pg = Pel/0.9 = 534/0.9 = 593W$

Peak power of the generator :
$Pp = Pg/0.8 = 741.25\ Wp$

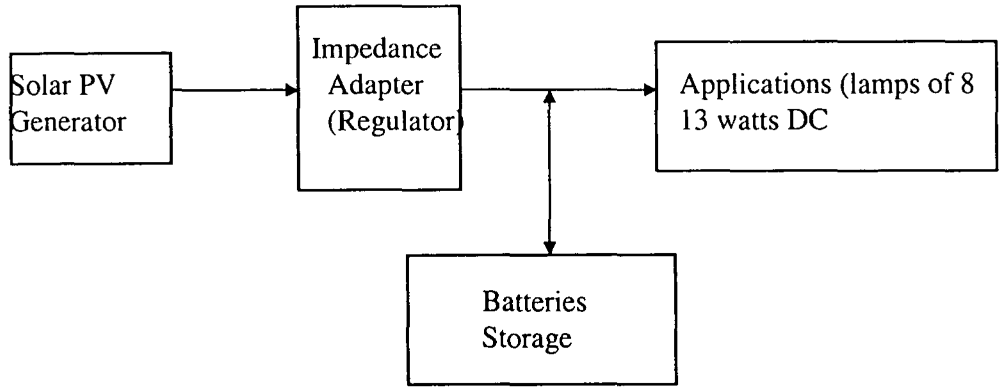
According to this small calculation, we can see that approximately , for the pumping system in this case it will be necessary to consider a power peak **of 1.48Wp per person or 8.88wh per person per days**.



General Presentation of the Solar Pumping system

2.2 **lighting**
For a village, « the light is the live ». When you put a lamp in a rural village, it means that you bring this village to the level of a small town. From my small experiences of lighting, it is

possible to increase the educated people by 10 in five years in village by given light to the schools, to reduce the mortally due to some diseases by given light to the medical center and give the possibility of storing some very simple medicine by 3 to 5 etc...



General Presentation of the Solar lighting system

2.2.1 Individual

According to the studies we find four categories of individual :

- Rich individual for about 10.41 % of the population of the village;
- Medium individual for about 60.76% of the population of the village ;
- Poor individual for about 21.62 % of the population of the village;
- Very poor individual for about 7.21% of the population of the village.

As a village consider, a family will have around 15 persons and we accept that 1Wp will give around 4wh per days of normal radiant

For the energy need to be satisfy by photovoltaic we find :

- Rich individual will need a total of 2009.0 wh of energy per days with 360wh per days for lighting, 268 wh per days for radio, 580wh per days for television and 700wh per days for the ventilation;

- Medium individual will need a total of 484 wh of energy per days with 240wh per days for lighting, 244 wh per days for radio and television (Black and white TV) .

- Poor individual will need a total of 244 wh of energy per days with 120wh per days for lighting, 124 wh per days for radio and others ;
- Very poor individual will need a total of 100 wh of energy per days with 70wh per days for lighting, 30 wh per days for radio and others .

2.2.2 Schools

According the studies and to the need of the village, we find out that the considering village have a maximum of nine (9) classroom. In Mali more of the village have six (6) classroom. In any case the light will be useful for only those who have to past to the 6th level and to the e 10th level. Link to the principle we choose to give electricity for two (2) classroom where there are six (6) classes and four (4) where there are nine (9) classes . We decide also to have two (2) lamps of 8 to 13 watts per class, one (1) lamp of 11 watts for the external where we have 6 classes and two (2) lamps of 11W for the external where we have 9 classes.

By analyzing this all proposition , we came out with a PV kit for each case (one kit for the schools of 6 classes or two (2) kits for the schools of 9 classes) which should be able to produce 200wh per days and per kit.

2.2.3 Medical Center

As in this kind of village we have a small structure for the sanitary services, the need in light has been estimated at 460wh per days.

2.2.4 Mosses

According to the village, we have 2 to 3 mosses and an estimated energy have be made for 200wh per village.

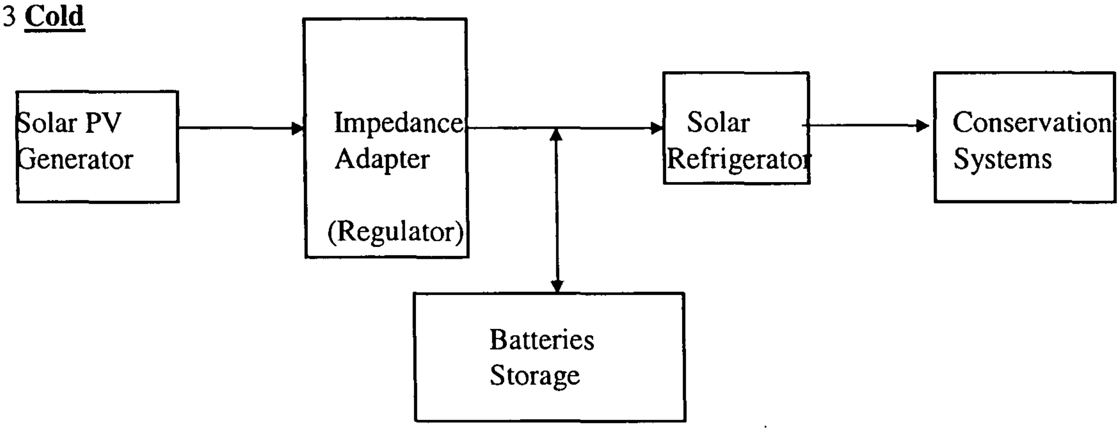
2.2.5 Street light

For rural area, an according to the village we find maximum of on (1) street lighting per 300 people. Each street lighting systems will need 350wh per days.

2.2.6 Cultural Center

For rural Cultural Center the need had been estimated at 200wh per population of 500.

2.3 **Cold**



General Presentation of the Solar Refrigeration system

How can we store medicine in a village located a 150 to 200 Km from the big center ?

2.3.1 For Medical Center

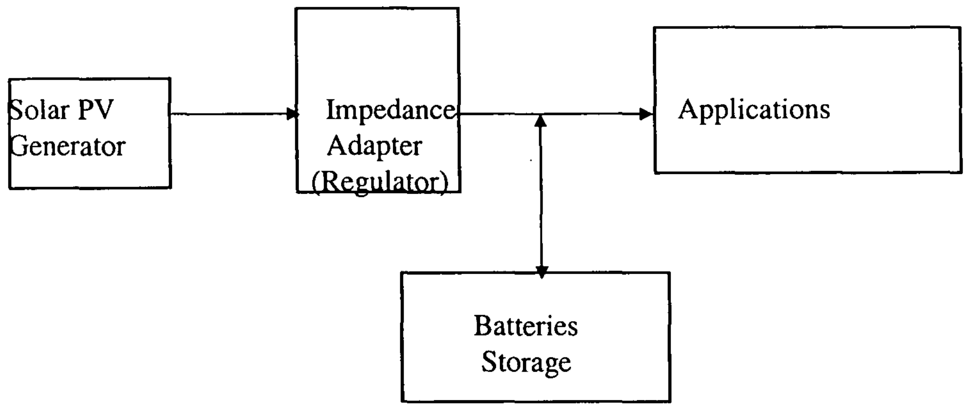
For the rural medical center, we had estimate a small refrigerator of maximum need of 200wh per population of 300

2.3.2 For Cultural Center

22

For the rural the Cultural Center, we had estimate a small refrigerator of maximum need of 200wh per population of 500

2.4 **Others uses**



General Presentation of Solar uses for others systems

2.4.1 Telephone Center

For rural Telephone Center the need had been estimated at 200wh per population of 500.

2.4.2 Batteries Charging Center

For rural batteries Charging Center the need had been estimated at 200wh per population of 700.

2.4.3 Miscellaneous use of PV

For rural use, it will be necessary to thing about the solar lamp, the lantern and others small gadgets which can be useful in the village level. All this need had been estimated at a maximum of 50wh per days for a population of 300.

PV APPLICATIONS WORKSHOP
CAIRO 2002 - Egypt

Estimated need for a village of 500 people
(100 families)

N°	local	Estilmated	Installed Power	Approximative	Approximative	Amount of
		Need (Wh/d)	in Wp	Cost in §US	Time of Rei	Rei/mo/equip
2,1	Water Pumping	2965	741,25	5930	15	32,94
2,2	LIGTHING					
2,2,1	Individual (100 families)					
	Rich Individual lighting	2009	502,25	4018	5	22,32
	Medium individual	484	121	968	5	5,38
	Poower Individual	244	61	488	5	2,71
	Very Power Individual	100	25	200	5	1,11
2,2,2	Schools	400	100	800	5	4,44
2,2,3	Medical Center	460	115	920	5	5,11
2,2,4	Mosses	200	50	400	5	2,22
2,2,5	Street Light	350	87,5	700	5	3,89
2,2,6	Cultural Center	200	50	400	5	2,22
2,3	Cold Production					
2,3,1	Medical Center	200	50	400	5	2,22
2,3,2	Cultural Center	200	50	400	5	2,22
2,4	Others uses					
2,4,1	Telephon Center	200	50	400	5	2,22
2,4,2	Batteries charging center	200	50	400	5	2,22
2,4,3	Miscellaneous	50	12,5	100	5	0,56
			2065,5	16524		
	Total		**15435.70**	**123485.62**		

Rei = reimbursement

III STRATEGIES

The project we had describe bellow had some very important information about the part of the users. About 91.21 % of the project is for the lighting and inside the lighting about 33.87% are for the rich individual families, 47.63 % are for the medium rich individual, 8.54 % for the poor and only 1.17 % for the very poor.

The project need about 15,435.70 Wp for a cost of 123485.62 $US (without running cost and miscellaneous cost) .

Without the benefit and with a projection of 5 years of reimbursement, the poor individual will pay only 1,1 $US per month per family and the rich individual will pay about 22,32 $US per month. For 15 years of reimbursement, the community pay 32,94 $ US per month for the water pumping system.

To get the project describe to be run in a village, you have to put together some very important an acceptable strategies for each village. It means that you have to go the villagers and discuss with them about the best way of running the project. According to ours discussions, we came to two big suggestions at the government level and at the private sector level:

A- At Government Help

1) the authorities (government and local authorities) have to contribute for 50 to 70 % for of the cost of the equipment of the community uses (water pumping, street lighting, schools, medical centers, cultural centers, telephone centers etc..) ;
2) the authorities have to facilitate to obtain the PV kit by credit for 2 to 3 years for the others uses (individual, etc..) and to help and facilitate the work of the others partners in the village.
3) the authorities (government and local authorities) have to help and to guaranty a private enterprise to get money to realize the project. The partner of the project which are going to be the local authorities and the population should sign a contract with the enterprise and should have 5 to 10 years for the reimbursement of the value of the equipment for the community uses (water pumping, street lighting, schools, medical centers, cultural centers, telephone centers)
4) the authorities have to help and to facilitate to obtain the PV kit by credit for the others uses (individual, etc..). The individual will have to sign a direct contract with the enterprise and they have to negotiate for the conditions they can respect.

B - At Private Help

1) the research teams (whose who have in charge to size and to adapt the systems to the need of the users);
2) the project managers (whose who have in charge to execute the project, to install and to maintain, to give service and send back information to the research teams);

CONCLUSION

From the lesson learn from the different project, it came out that it is possible to make rural electrification based on the real need by the use of solar energy. For this the following partners have to work together :

1) the financial partners (whose who have in charge to help for financial support and to advise after analyzing the cost and the conditions of reimbursement and to study the financial conditions of the village and the villagers);
2) the government (whose who have in charge to look if the project is running according the engagement of the partner and if there will be problem for the running of the project, to supervise and to control the correction execution of the project);
3) the local authorities (whose who have in charge to help, to facilitate, to contribute, to supervise and control the project execution in the village);
4) the villagers (whose who have to analyze the benefit their will have, to inform the others partners, to propose improvement if necessary and to diffuse the information to the others villagers);.

- For each level a document should be signed between partners to avoid problems and imperfection
- According to all it will be possible to make rural electrification by using the solar PV systems. We have to find a loan for 5 to 10 years and to guaranty the loan for the rural villagers.
- From this study, it came out that with 30.87 Wp per person, we can make a rural electrification program for a village of less than 5,000 people. For the success of the project each person of the village should paid approximately 250 $ US.

ICS - INTERNATIONAL CENTER
FOR SCIENCE AND TECHNOLOGY

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« SOLAR PHOTOVOLTAIC APPLICATIONS »

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For the Workshop on
« PV Applications »
27-29 Mai 2002
Cairo, Egypt

Sponsored by :
ICS – UNIDO and The Government of Egypt

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The University of AIN SHAMS

Introduction :

The aim the presentation is to give some information about the solar radiation, the material and the application of the PV systems . :

I - **SOLAR RADIATION** :

Solar radiation arrives on the earth at a minimum flux density of about 1 KWm^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 **habitated** areas, received fluxes vary widely from about 3 to 30 MJ/m^2day, depending on the place, time and weather. The quality of the radiation is characterized by photon energy of around eV as determined by 6000K 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 earth atmospheric and surface temperature are also of order of 1 KW/m^2, but occur in a wavelength band between about 5 to 25 μm, called long wave radiation, peaking 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 absorption by water vapor

The internal radiation is absorbed in the inner passive layers which are heated to about 5800K and become a source of radiation with a relative continuous form of spectral distribution.

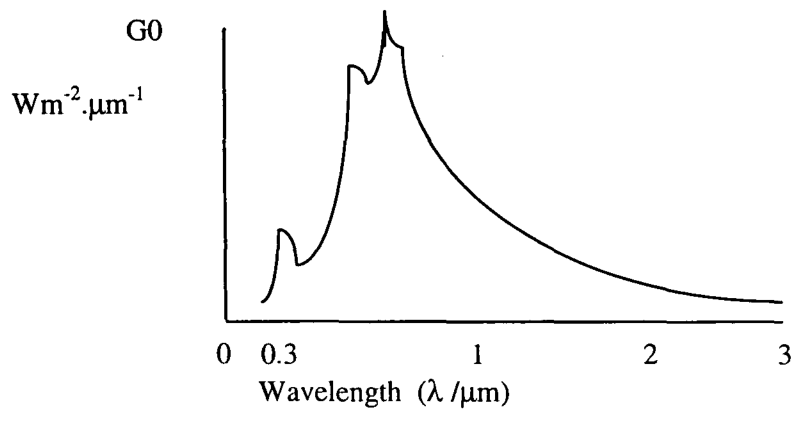


FIG 1

Fig 1 shows the spectral distribution of solar irradiant at the earth's mean distance, uninfluenced by any atmosphere. Note how the distribution is like from a black body at 5800K in shape peak wavelength and total power emitted. The area beneath this curve is solar constant $G^*o = 1367\ Wm^{-2}$

This is radiant flux density (RFD) incident on a plane directly facing the suns rays, above the atmosphere at the distance of 1,496 x 10^6 km from the sun (i.e at the earth's

mean distance from the sun . The RFD actually received by the top of the atmosphere differs from the solar constant by less than + or - 1.5% because of fluctuation is suns radiant output and by the + or - 4% through the year because of the predictable changes in the sun -earth distance arising from the earth's slightly elliptic path.
The solar spectrum can be divided into three main regions :

1. Ultraviolet region ($\lambda < 0.4\mu m$) : for 9% of the irradiant
2. Visible region ($0.4\mu m < \lambda < 0.7\ \mu m$) 45 % of the irradiant
3. Infrared region ($\lambda > 0.7\mu m$) : 46 % of the irradiant

The contribution of the solar radiation flux from wavelengths greater than $2.5\mu m$ is negligible , and all three regions are classed as solar short wave 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. Fig 2 is a sketch of how this happens

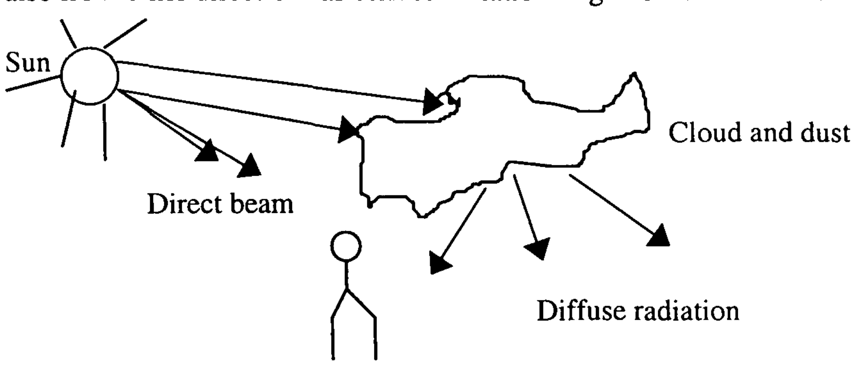


Fig 2

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

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

II - **ESTIMATION OF SOLAR RADIATION**

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 device, it is possible to calculate the size of the collector.
Ideally, the data required would be several years of measurements of irradiation on the proposed collector plane. This is very rarely available, so the required (statistical) measured have to be estimated from meteorological data available at the site or at some nearby site, which appears to have the similar irradiant.

To estimate the solar radiation , it will be possible to do it by three ways :

- calculate by using the formula ;
- measured the data from some years ;
- estimate from the data of a similar site.

To install a solar collector it is important to consider :

a) the statistical data variation (monthly means of daily insolation) ;
b) the sun shine hours ;
c) the proportion of beam radiation (K_T value of 0.8 is very good) ;
d) the effect of **inclinaison** (transformation of the data from the horizontal plane)

PHOTOVOLTAIC

I- **PRINCIPLES OF SOLAR CELLS**

The cells are optoelecronics components which allowed the transformation of the light to electricity. They are made by semiconductors materials, which has proprieties between **insulators** (very low conductivity) and **conductors** (high conductivity).

1.1 **Material**

The more used photocell is the silicone, which is very common in his form of **silice** ( ) but which has to be hardly work to get the **monocrystal** form.

The operating system of the cell is based on the proprieties of the silicone when the atoms in small numbers (impurities) are substituted in a crystal row (**doping**) :

- when the atoms of impurities have more electrons than the silicone, the material will have some more free electrons : it is said that the material is an « n » type (which can accept the phosphorous for example with 5 electrons - pentavalent). This kind of material is called a donors (Antimony (Sb) , arsenic (As) etc..)
- when the atoms of impurities have less electrons then the silicone, the material have a deficit of electron, it will be called a « p » type (which can accept the boron with 3 electrons). This kong of material is called an acceptors (Aluminium (Am) , Galium (Ga) etc..)

1.2 **Photovoltaic effect**

The photovoltaic phenomena is the interaction between the light and the atoms. For this interactions, the light can be consider as composed of particles : photon which energy varies according to the wave length ($E= h*c/\lambda$) were :

E : is the Energy in Joules :
h : Planck constant : $6.62*10^{-34}$ j.s
c : celerity of the light : $3 *10^{8}$ m/s
λ : wave length (m)

A photon of sufficient energy which across an atom can pick an electron and transmit a certain speed. If there are no specially precaution, all the created electron can recombine.

It will be possible to get a solar cell by making a junction between two opposed type (PN Junction). Near the appear an electric field which can maintain the separation of the positives and the negatives charges

When a material is excited, the taking electron will be accelerated by the electric field and came to the N type area, the positive charge obtained by the atom will be propagated to the « p » type. So the electric Voltage appear between the two face of the Junction and if they are linked by an outside circuit, a current will flow. The photon energy is converted to electrical energy.

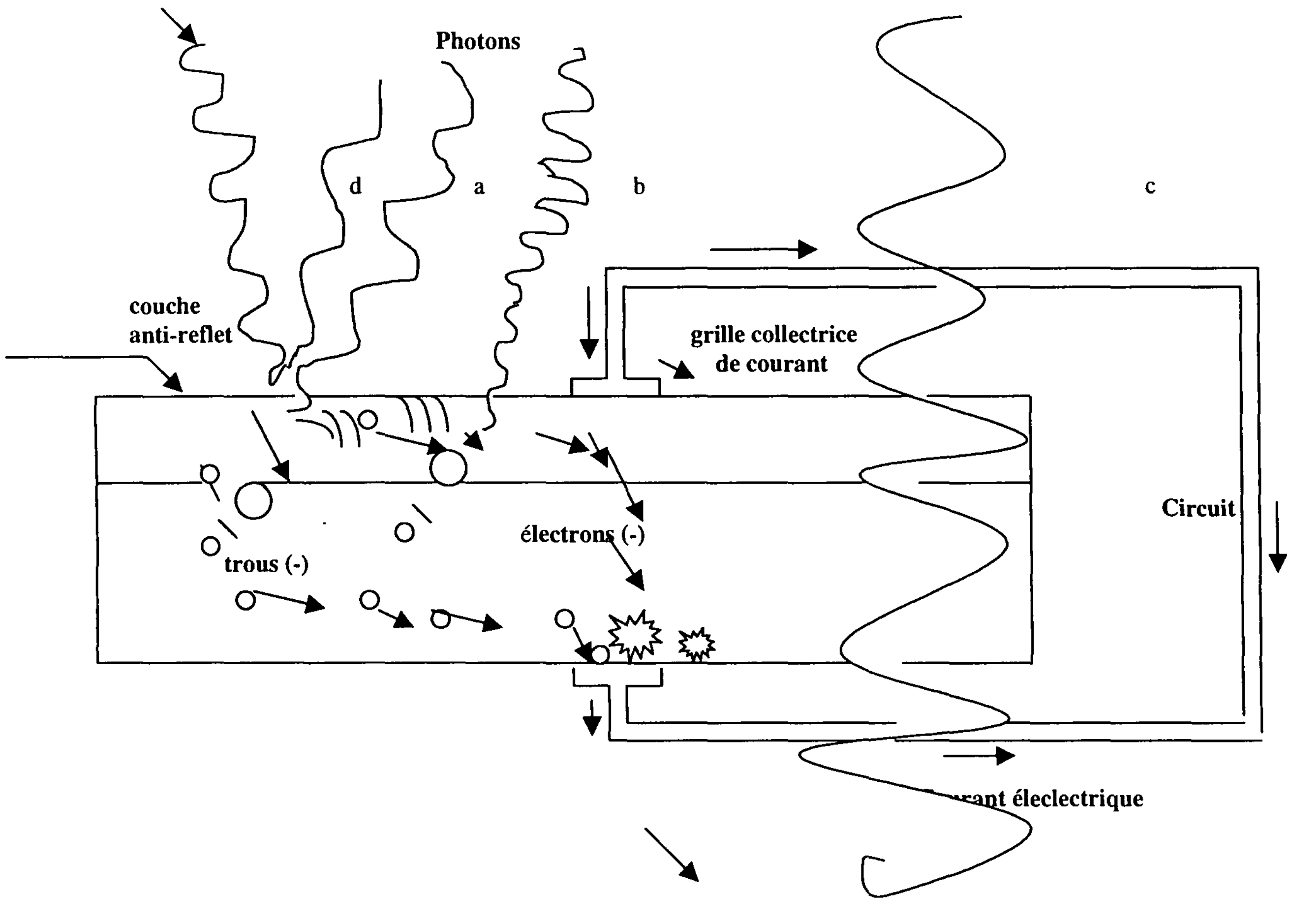


FIG 3

1.3 **Efficiency**
The efficiency of the solar cell is the ration between the electrical energy given and the solar energy obtained on the all area..
We have to know that all the light from the solar can not be transformed to electricity.
- Some photons are reflected on the face before attending the cell (d)
- Some don't have enough energy to take an electron (E<Eg). For the Silicone the necessary energy for taking an electron is at the wave length of 1.1μm ; that means the infrared spectrum is not useful (c)

Only the photon which have enough energy (E>Eg) are absorbed and create the electron-hole, the surplus of energy is given as a form of kinetic energy which is lost and will be transformed in heat.
- More electrons created will be recombined before having a chance of producing useful energy

By considering this different actions which act for reducing the efficiency, the theoretical efficiency of a solar cell (Silicone **monocrystal**) is around 22 %. In practice, the more used cells for economical and practical reasons have an efficiency of 12 to 14 %.

a)
b)
c)
d)

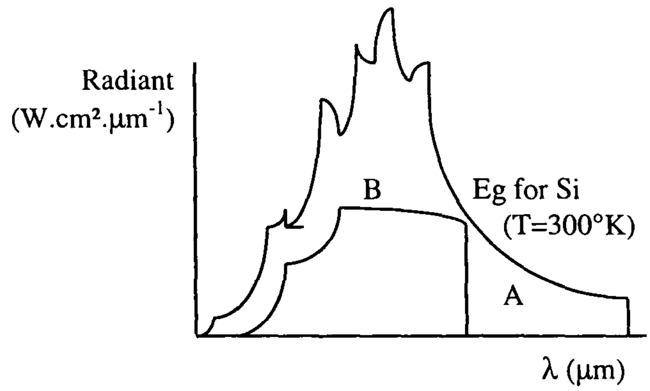


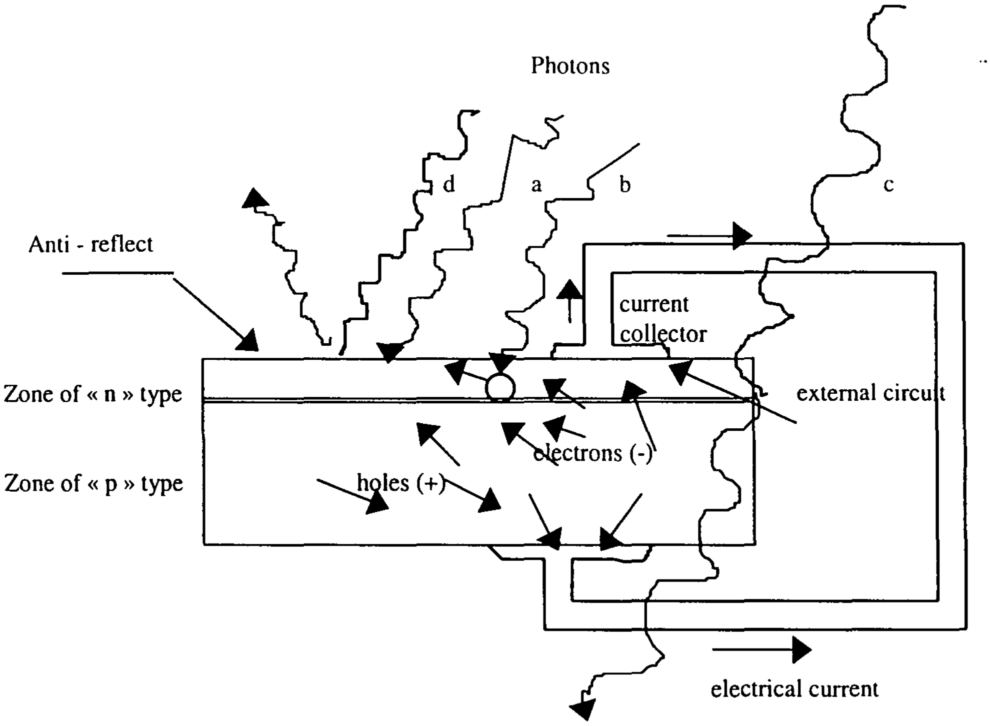
FIG 4

II - EXPLOITATION OF THE SOLAR SPECTRUM BY THE SI SOLAR CELLS
- the area A corresponding to the lost energy due to the no absorbed photons
- the area B corresponding the excess of energy, not used due to the photons of higher energy (

2.1 Collecting Current

The collecting current is made by the recuperation of the electric charges which have across the junction by the back face and the front face.
- the front face is made by a material which allowed to collect the negatives charges and let the light going in (negative pole)
- the back face is cover with a metallic contact which collect the positives charges (positive pole)

The cell is actually produced as a form of fine plaque of many cm^2 and which give an electric direct current throw two cables.



2.2 **Different types of Cells**
The major solar cells used in ours days in the word are cilium **monocristal**. The **polycristal** (with an efficiency of 9 to 10 %) and the amorphous cells (with an efficiency of 4 to 7%)are also used.

Added to the silicone, the Gallium arsenic (with an efficiency more than 20%) and the association of the CU2S - CDs are also very well used presently in the world.

III- SOLAR CELL

3.1 **Cell in the dark**
The solar cell in the dark ins not an active component. It will look like a PN junction, like a simple diode. It will not produce any current and any voltage.

If we connect an external circuit, the theoretical laws shown, the equation of the diode for the voltage and the current.

$Id = Is * \exp. [(q*V)/(\eta*k*T) - 1]$ where
Id is the current throw the junction ;
Is is the reverse current
V is the voltage across the junction
k*T/qis equal to 26mV at 300°K (27°C)
η is the ideal coefficient of the diode.

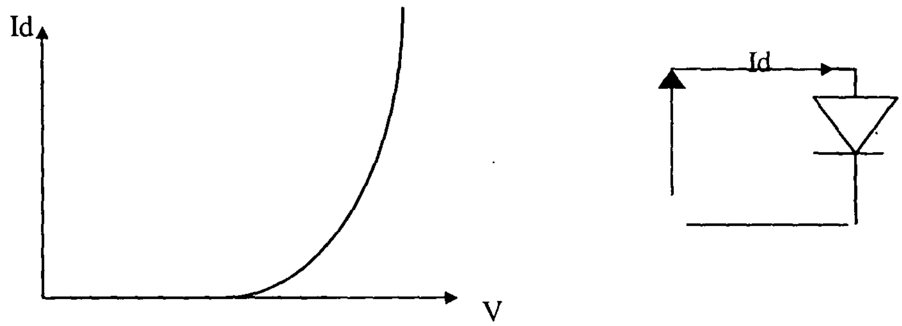


Fig 4 Characteristics of the diode Symbolic representation of a diode

3.2 **Cell in the light**

3.2.1 Generator

If the cell is in under the light, it will create a **current** (Iph) due to the solar radiance
The Iph will appear at the borders of the PN junction and will be directly proportional to the flux (ø) : Iph = Kø

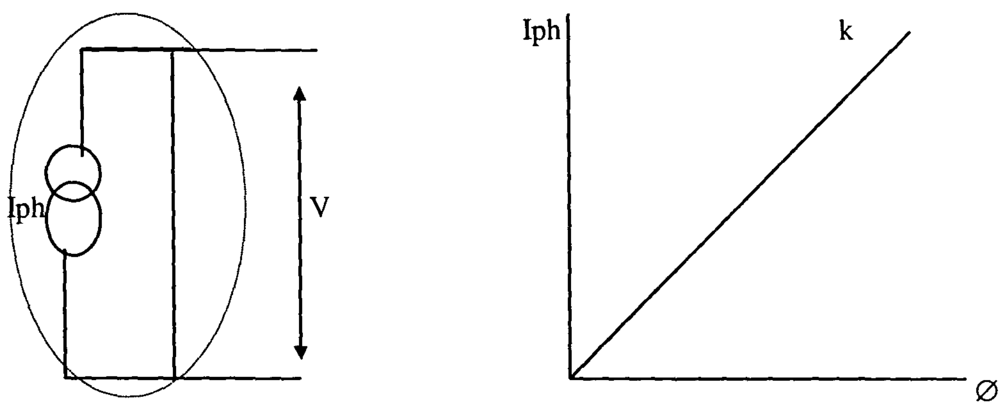


Fig 3.2.1 Current generate by the illuminated cell

The current generate by the solar cell is I and is given by the formula :

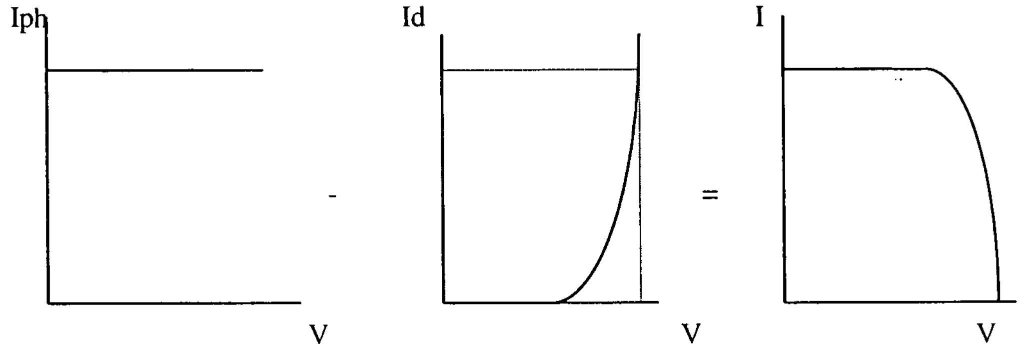
I = Iph - Id where I is the available current (A)
Iph is the current generate by the cell (A)
Id is the diode current (A)

or

$$I(V) = Iph(V) - Is*\exp[(q*V)/(\eta*k*T) - 1]$$

a) Current and Voltage characteristics (IV Curve)

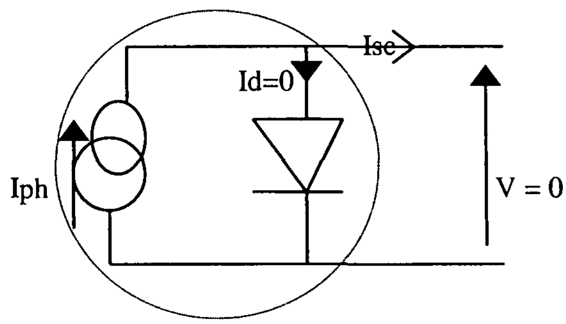
The I characteristic is simple given by the subtraction of the Id(V) and the Iph (V) curves



Iph (V) curve   Id (V) curve   I (V) curve

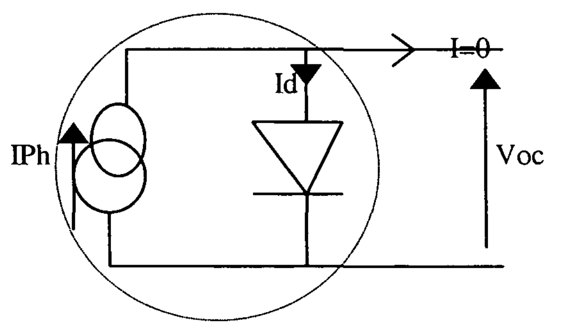
Fig 2.2.1 a)

b) The short circuit current (Isc)



The short circuit is given when the voltage is zero, V=0 , Id =0 and Isc = Iph
This result means that the short circuit is directly proportional to the solar radiation (Icc = K*ø)

c) The open circuit Voltage (Voc)

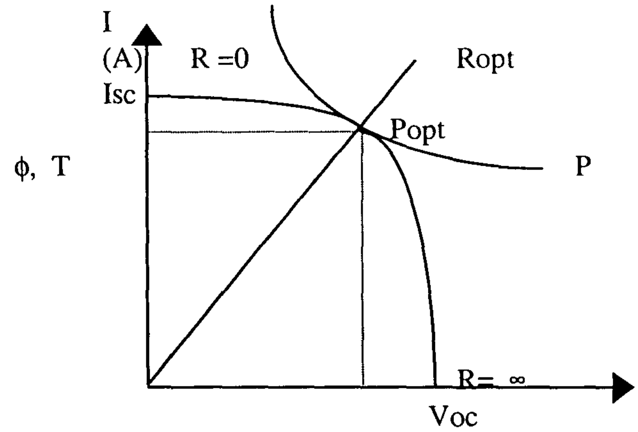


The open circuit voltage occurred when I=0, which means that

$$Iph = Id = Is*[\exp (e*V)/(n*k*T) -1]$$

The open circuit voltage is equal to the junction voltage when this is across by the cell current Iph

d)The power curve



If we consider a power of the solar cell characterized by the I =f(V) for a solar radiation ø and at a fixe temperature T, and we connect a variable resistor R, the functioning point will be determine by the interconnection of the I=f(V) curve and the line I= V/R :

- the power obtain is a function of the variable resistor ;
- the maximum power is obtain when R= Ropt which is consider as a optimum point of the power at an optimum point of the resistor, the voltage and the current :

$$Ropt = Vopt/Iopt$$

e) Characteristics of the generator

There are three kinds of characteristics :

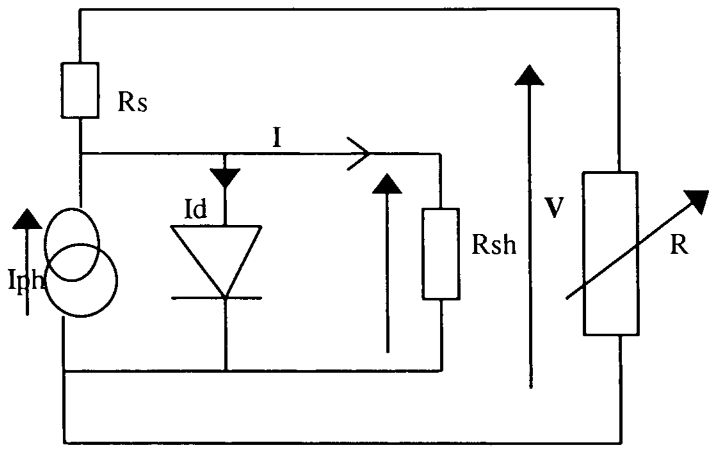
- if the flux and the temperature are constants, the cell characteristics is the same as the fixed I = f(V)
- if the load R is variable, the cell will work in the area of MN, it means that the constant current is practical equal to the Isc current.
- if the load R is important, the cell will work in the areas of PS and the constant voltage is practical equal to the Voc.

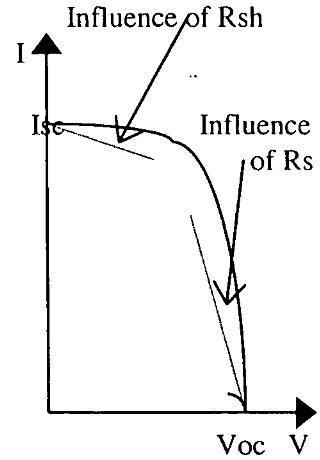
f) Real Cell

In reality the cell contain a shunt resistor and a serial resistor due to the technology of fabrication.

- the shunt resistor is due to the lost current at the level of the junction and it depend on how the junction had been made ;
- the serial resistor is link to the **resistivity** of the internal connections.

This figure give the real description of the solar cell

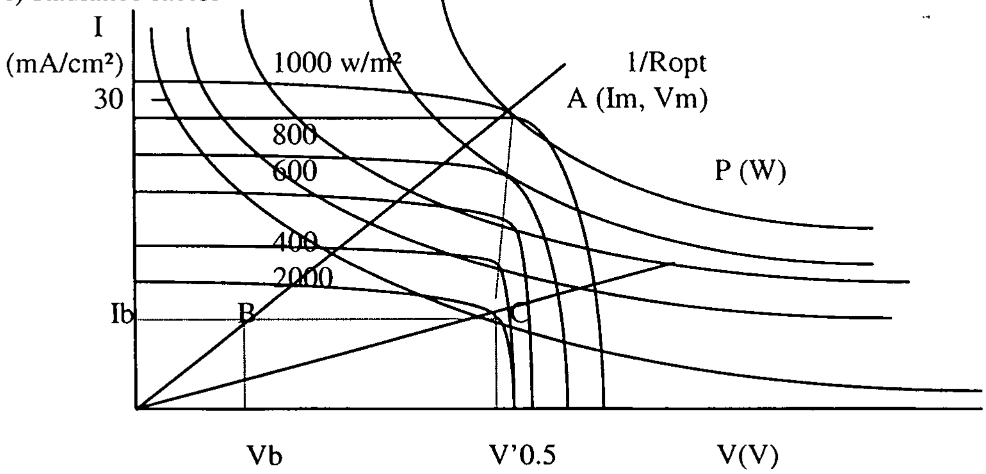




Graphical , the serial and shunt resistor will modify slightly the form of the characteristic of the cell curve I = f(V)

- the incidence of the serial resistor will be translated by a diminution of the voltage ;
- the incidence of the shunt resistor will be translated by diminution of the current

f) Radiance factor



If we consider the Iph, the Id(Vj) for the junction, thee current can be given by a formula :

$$I = f(V) = Iph - Id(Vj)$$

This curve can be draw for many radiation

If we consider that the Isc is proportional to the radiation (it means that the serial resistor is neglected), we can say that I = 30mA/cm2 with an radiation of 1 KW/m2 for the Si **monocristal** (Tj = 25 °C) this is called the NOCT (Normal Operating Cell Temperature)

We know also that the open circuit voltage will dropped when the radiation is going up, is not a function of the areas but link to the material, and for the Si **monocristal**, the Voc is equal to 590mV at the NOCT.
With these conditions, it will be possible to get the different power of a solar cell according to the solar radiation.

g) Temperature factor
The temperature is very important at the level of the I=f(V) curve.
It is important to know that when the current increase with the temperature (0.1 % per °C or 0.03mA/°C)
The diode current Id (Vj) various quickly with the temperature t.
In practice :
1) the Voc will be reduce by 2mv/°c
2) the maximum power available will be reduce by 0.35 % per °c

This reducing value are very important when you have to size a PV system.

h) DEFINITIONS :
Peak Power (Wp): is the power obtained in the NOCT conditions

Conversion efficiency : is the ratio between the optimal electrical power of the cell and the solar radiation

Fill Factor (FF) : is the ratio between the Peak power in Wp measured and the product Isc x Voc. The ratio is translated by the rectangular form of the characteristic of the I =f(V) curve.
The value of the fill factor is around 0.7 for the good cells. The incidence of the serial and shunt resistor will be seen directly by the drop of the fill factor..

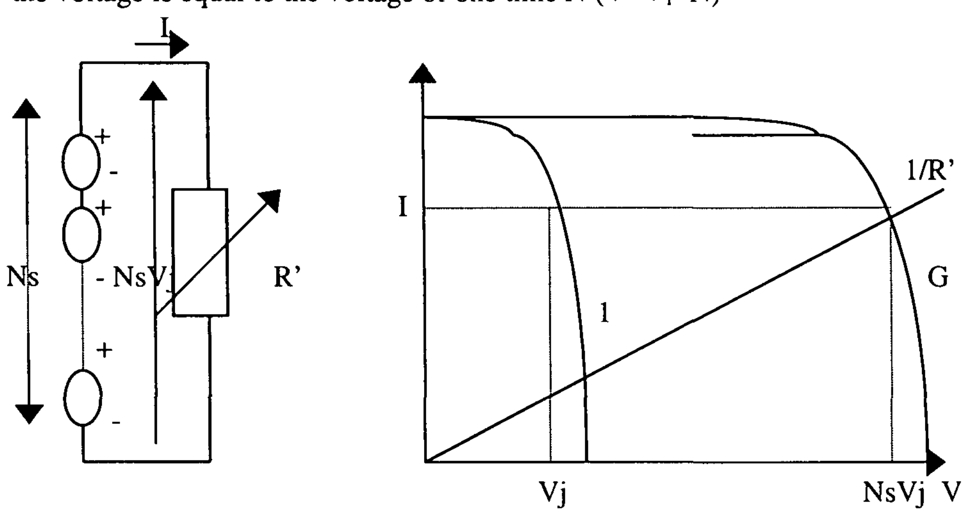
FF = (Iopt*Vopt)/ (Isc*Voc)

IV **PHOTOVOLTAIC MODULE**

The very low voltage and the thickness of the solar cell impose the association of the solar cells

The solar module (photovoltaic module) , standard useful element have two function :
- association of cells to obtain interesting current and voltage for applications ;
- protection of cells against the atmospheric conditions in odder to give then a significant life time (very important for the use of the photovoltaic).

4.1 **Association of cells** :
4.1.1 Cells in series :
a) Identical Cells
When you put together N identical cells you will have :
- the same current for the rest of the circuit ;
- the voltage is equal to the voltage of one time N ($V=V_1*N$)



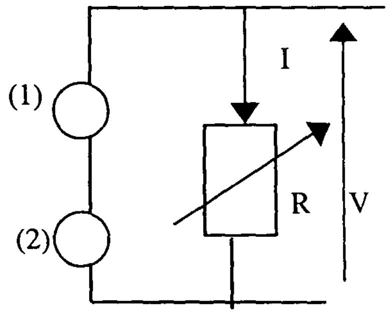
b)Different Cells

If we put together, two cells with different characteristics, and if the cell (1) is more efficient than the cell (2), we will have a characteristics resultant for the voltage by addition of the two cells.

For an impedance R<Ro, the cell (2) will be a receiver (I_2>0 and V_2<0)

For example R=0, I_1 = I2 and $V_1 = - V_2$

The two cells will have the same voltage but in the opposite direction

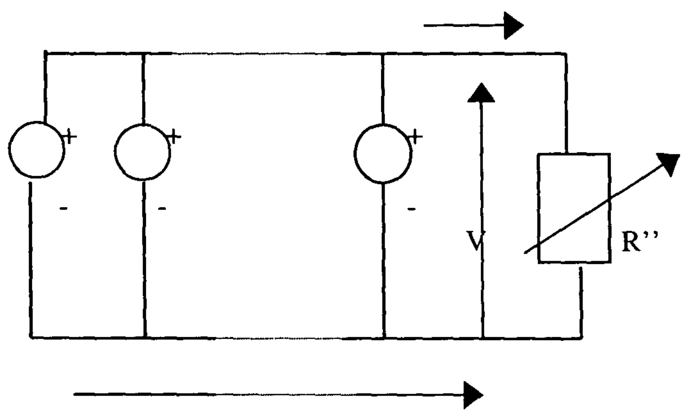


4.1.1 Cells in parallel

a) Identical cells

When you put together Np identical cells in parallel, you will have :

- the same voltage across the circuit ;
- the current will be Np times the current of one cell ($I = I_1 * Np$)



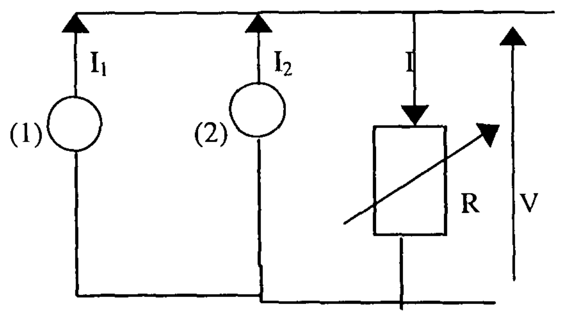
b) Different Cells

If you put together in parallel two cells, and if the cell (1) is more efficient than the cell (2), we will get a resultant characteristic by addition of the current I = f(V)

For an impedance of the load R>Ro, the cell (2) will be a receiver (I_2<0 and V_2>0)

Exple : in the short circuit , you will have : $V_1 = V_2$ and $I_1 = - I_2$

The more efficiency cell will give current to the feeble one.



4.2 **Association of modules** :

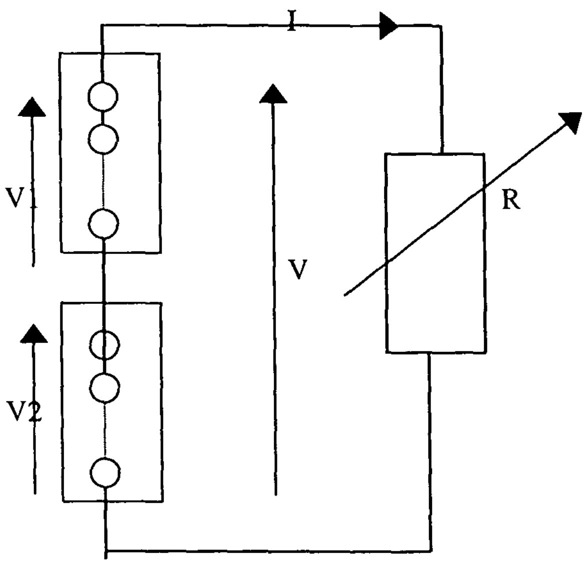
The association of cells give the solar module or photovoltaic module.. As seen for the cells according to the applications, the module can be mounted in series, in parallel or in series and parallel. The module should be protected against the atmospheric conditions and the temperature.

4.2.1 Modules in series :

If we put together, two modules with difference characteristics, and if the cell (1) is more efficient than the cell (2), we will have :

- a characteristics resultant for the voltage I = f(V) by addition of the voltage of the two cells.
- for an impedance R<Ro, the module (2) will be a receiver ($I_2>0$ and $V_2<0$)
- in the critical case, the short circuit, R=0, I_1 = I2 and $V_1 = - V_2$

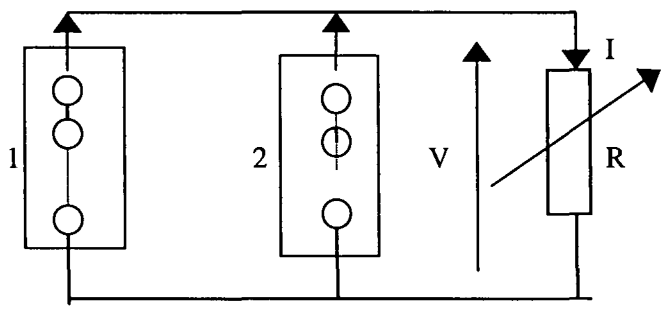
The two cells will have the same voltage but in the opposite direction



The dissipated power by the module (2) (P2 = V2*I2) can be of tens of Watts. This dissipated power can create a punctual heat called also the « hot-spot » and can destroy the module.

To avoid the heating of the module (2), it will be better limit the reverse voltage by putting a by-pass diode of protection in parallel.

4.2.2 Modules in parallel



If you put together in parallel two modules , and if the modules (1) is more efficient than the cell (2), we will get

- a resultant characteristic by addition of the current I = f(V)
- for an impedance of the load R>Ro, the cell (2) will be a receiver (I_2<0 and V_2>0)
- for the critical case, open circuit, R = ∞ , I = 0 , you will have : $V_1 = V_2$ and $I_1 = - I_2$

The more efficiency module will give current to the feeble one.

A big dissipation of power can happened and can be dangerous for the feeble module.

To avoid a feeble to be came a receiver for the higher power one, it will interesting to put a diode in serial in each branches. The solution is a good one if the dropped voltage across the diode is very small compare to the voltage of the other module. In fact you should know that a current will across this diode, in normal functioning , that will introduce a permanent power losses.

4.3 **Modules in series and parallel**

An association of modules can be called a panel or a generator

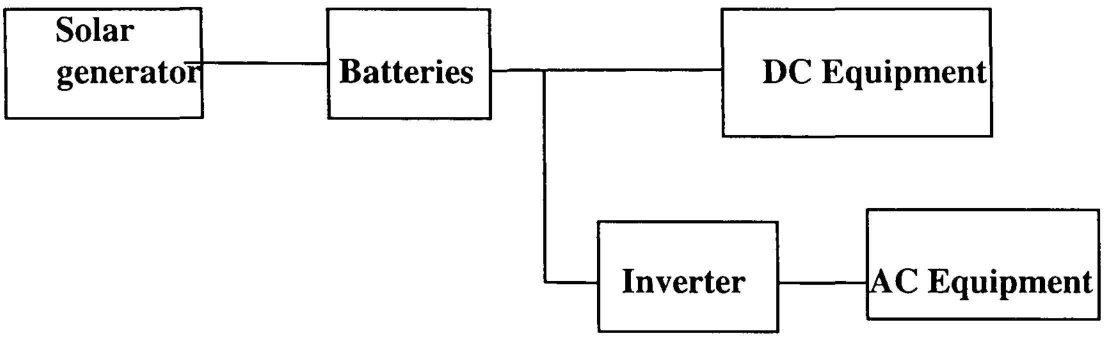
A power of a solar panel is determine by the sizing and need an association of modules In this case according to the need, you have connect the need modules in series and the needed panel in parallel.

To protect the panel you will need a diode in series for each serial branch and the by-pass diode for the parallel group of modules

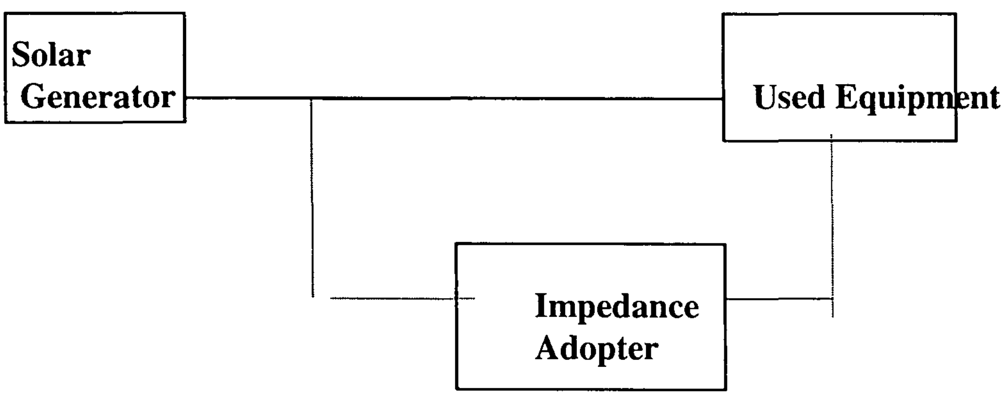
PHOTOVOLTAICS SYSTEMS

For the use of the energy coming from the sun by PV sources we can have many applications. The m

ore current systems used for applications can be by the PV systems - by electrical storage (batteries) which can have a DC current applications or an AC current applications by inverters.



- by the direct coupling without batteries. In case the used equipment are connected directly to the solar panel with in some case an impedance adopter



For the systems without batteries storage, it will possible to have an other kind of storage for example by the tank of water for the pumping systems or the cold by the refrigeration systems.

For the use of the photovoltaic systems , the more studies should be done on the adaptation of the load which can be the batteries, the others kind of load (resistor).

WORKSHOP ON PV APPLICATIONS

CAIRO - EGYPT FROM 27 TO 29 MAY 2002

REPORT PREPARED BY

AMOR OUNALLI, ANER - TUNISIA

PHOTOVOLTAIC APPLICATIONS IN TUNISIA

EXPERIENCE AND PROSPECTS

CONTENTS

CHAPTER A

TUNISIAN PROGRAM OF RURAL ELECTRIFICATION BY PHOTOVOLTAIC SYSTEMS

1. Introduction:

The development of the rural environment requires to surmount the difficulties bound to the provision of households, the schools, the centers of cares with energy.
The rural population basis needs in energy touch essentially to the cooking of the meals and bread, to the heating, to the lighting, to the pumping of water and to its transportation, to the access to the audiovisual medias and a complementary manner to the needs in energy for the appliances and especially the refrigerators.

To limit the pressure exercised by the rural population on the forests, by saving fossil energy and seen the abundance of the solar energy in Tunisia, it becomes obligated to try to improve at least some needs of energy, by the use of the renewable energies : photovoltaic, wind energy or biogas.

Photovoltaic solar energy can be produced to satisfy basis needs of in energy of the rural population: lighting , audiovisual devices (television and the station of radio cassette). And this is how projects of rural electrification by photovoltaic systems have been achieved since about ten years.

During this last decade, about 10 000 rural households have been electrified by photovoltaic systems, corresponding to a total PV power installed 1,1 MWp.

2. Projects of demonstration:

Since the beginning of the years 1980, public institutions have achieved some projects in the field of the photovoltaic electricity. These realizations concerned essentially the electrification of a village situated in the northwest of the country (village of Hammam Biadha in the Gouvernorat of Siliana) by a small independent photovoltaic power plant 30 kWc, some border stations of the army, of the forest ranger's stations, the maritime Armée,...

Since its creation in 1985, the AME (Agency for saving energy, named presently National Agency of Renewable Energies - ANER) achieved a certain number of projects in the field of photovoltaic rural electrification.

These demo programs concerning photovoltaic rural electrification followed each other since the beginning of the years 1990 and passed by different levels of maturity.
The photovoltaic powers used for the electrification of the rural homes evolved from 50 Wp to 70 Wp and finally reached 100 Wp.
The used equipment permits to supply in direct current under 12 volts, three lights, a television in black and white and a radio cassette.

Among these projects we can mention:

2.1. Tuniso-Spanish cooperation project:

This project have been achieved in 1990, in the village of Ouled Nouaouia, in the Gouvernorat of Kairouan in the center of the country. The PV systems permitted the electrification of 48 homes and 2 schools. The installed total power is 3 kWp.

2.2. Tuniso-German cooperation project :

In the frame of the Special Program of Energy, launched by of the German cooperation, 90 isolated rural homes as well as 37 rural schools have been equipped with photovoltaic systems in 1991 and 1992. These realizations corresponded to a phase of demonstration of the photovoltaic activities of the project. The installed total power is around 14 kWp.

2.3. Tuniso-French Cooperation project :

In 1993, fifty rural homes and one primary school belonging to the village of Dhokara, in the Gouvernorat of Bizerte in the north of Tunisia, have been electrified by photovoltaic systems in the frame of this project. The installed total power is 2,7 kWp.

3. Pilot projects :

The realized projects of demonstration in the field of the photovoltaic rural electrification have been followed quickly by more important pilot projects. Among these projects we can mention those that have been achieved in the frame of the German cooperation and those that have been financed by the state.

3.1. Electrification of the rural schools project:

Having acquired a better knowledge of the photovoltaic systems used for the rural electrification, the ANER launched in 1991 a program of diffusion of these systems to electrify 155 rural schools located in the Gouvernorats of Kairouan, Béja, Kasserine, Sidi Bouzid and Siliana in the center and in the Nord West of Tunisia. The installed total power is 33 kWp.

3.2 German cooperation :

From the results given by the first projects of demonstration, some approaches permitted to identify a strategy to set up in 1994 a first project of the electrification by photovoltaic systems, 1 000 rural households belonging to the Gouvernorat of the Kef, in the west north of the country. The installed total power is 70 kWp.

4. National program:

The projects of demonstration and the pilot projects achieved in the field of the rural electrification by photovoltaic systems showed that :

-This technology can contribute to satisfy the needs of basis electric energy needs of the dispersed rural homes that won't be connected to the grid, in the next future (lighting, audiovisual);
-The individual photovoltaic systems are adapted better to the electrification of the households dispersed than the other solutions as the centralized photovoltaic, the biogas and possibly the grid;
-This solution allows the state to limit the enormous expenses in case of connecting rural zones to the electric grid.

To the continuation of these encouraging results and seen the particular interest granted by the state for the improvement of the conditions of life of the rural families, a national program of rural electrification by photovoltaic systems has been established.

4.1 Programming and partnership :

4.1.1. Rates of electrification by the national electric grid :

During these last years, Tunisia made remarkable efforts concerning rural electrification by the national electric grid. If the rate of electrification reached 100 % in the urban area at the end of the 8th five-year plan (1992-1996), the same rate reached about 73 % in the rural area. At the end the 9th five-year plan, in the year 2001, this rate has reached 90 % in rural area.

4.1.2. Potential of the homes to electrify by the photovoltaic solar energy :

The different sources generally considered for the assessment of the potential of use of the photovoltaic systems for the rural electrification take into account the date of the National institute of Statistics (INS), the results of the investigations achieved by the Tunisian Company of electricity and Gas (STEG) and essentially from the recommendations of the strategic survey for the development of the renewable energies, achieved in 1995, that advances a number of 70 000 rural households that would not be electrified by the national electric network by the year 2010. Indeed, according to this survey, the rate of electrification in this date would be 97 % in the rural area and the 3 % remaining of the rural households could be equipped by photovoltaic systems.

4.1.3. Complementarity of the programs to achieve by the grid and by the photovoltaic:

In the achievement of the national programs of rural electrification as well by the national electric grid that by the photovoltaic solar energy, it is important to insist on the character of complementarity between these two programs. The photovoltaic facilities get in place to the contrary of the grid and to the places most distant of him. It is rather about complementary programs and in no moment competitors. Also, the development use of the rural electrification by photovoltaic systems represents a very interesting solution to supplying with energy the dispersed rural zones that won't be electrified by the national electric grid to mean and to long terms.

4.1.4. Preparation of the development five-year plans concerning rural electrification by photovoltaic systems:

The ANER as a public Institution applying the politics of the state in the field of the promotion and the development of the renewable energies, pushed, since its creation to use these technologies to electrify the scattered and distant rural homes of the national electric grid.

The main objective of the ANER is to contribute in the national effort aiming to reach a rate of global electrification of 100 % on the horizon 2010.

To this deadline, the STEG intends to electrify 97 % of the homes and the 3 % remaining will be electrified by the photovoltaic systems.

Of this fact, the ANER planed its programs of the 8th and 9th five-year plans the installation of 10 000 photovoltaic systems for every plan.

4.1.5. Preparation of the yearly national program of rural electrification:

The realization of the national programs of rural electrification takes into account priorities that can be of financial and political order, in link with considerations of economic and social development in all regions of the country. After knowing the yearly demands emanating from the regional authorities and showing their needs concerning rural electrification by photovoltaic systems and to better plan the achievement of the national programs of rural electrification that are very expensive, the concerned national institutions meet within a commission to establish the national programs of rural electrification and to coordinate between the different partners concerned by the national electric gird or by the photovoltaic solar energy.

The coordination of the national programs of rural electrification takes place currently to the Ministry of the industry, to the office of the General Direction of the energy in presence of the representatives of the Ministry of the inside affairs, of the Ministry of the Economic Development, of the Ministry of the environment, of the Fund of National Solidarity, the STEG and the ANER.

While taking into account the forecastings of the five-year plan of economic and social development, the needs and related costs to the investment, the commission plans a yearly national program of rural electrification.

For every Gouvernorat, it will be established the zones of intervention of each of the two institutions to achieve the national program of rural electrification (ANER, STEG) as well as the number of households to electrify in every zone.

The report also specifies the mode of financing of the electrification of every site.

With regard to the program of rural electrification by the photovoltaic, its financing essentially comes from the FSN (Fund of National Solidarity), of the credits of the World Bank (line BIRD 2735 TUN), of the credits and outside grants, of the budget of the state and the contributions of the beneficiaries.

The report established by the National Commission of rural electrification, accompanied by a note of presentation is submitted to the approval of the Government.

The national program of rural electrification by photovoltaic systems is achieved according to a strategy archived in collaboration with the concerned authorities defining the role and the assignments of every partner or national or regional institution implied in the execution of the programs.

4.2. Financing of the national program of rural electrification:

The realization of the rural electrification program by photovoltaic systems is very expensive and require the procurement of big budget.

The Tunisian program of rural electrification is subsidized until more that 90% by the state. The user pays 100 DT/systems, the rest of the cost of the system (about 1800 DT/system) is financed by the following sources:

4.2.1. Funds of National Solidarity (FSN):

It is a fund created by the President of Republic in December 1992, whose main assignment is to improve the conditions of life in the poor rural zones named " zone of shade ".

This fund is essentially collected by contributions given by the citizens and societies, the associations,...

This fund financed the electrification of about 950 households by photovoltaic systems. It also participated in the financing of the electrification of about 1 000 other households by the same technology.

4.2.2 Regional Program of Development (PRD):

This program financed, through funds given by the state to the profit of the regional authority.

On the other hand, this program participated at the rate of 200 DT/ system in complement of the projects financed by the ANER through the budget of the state or by foreign credits.

The number of the homes electrified by this diagram of financing has reached about 5 000 households.

4.2.3 Integrated Regional Development Program (PDRI):

It is a special program that generally finances specific projects in the poor zones. It is directly managed by the Regional Council of the Gouvernorat.

This program financed the electrification by photovoltaic systems of about 20 households.

4.2.4 Foreign credits:

4.2.4.1 Credits of the world bank:

The world bank, through the credit line BIRD 2735 TUN, financed the realization of a project of electrification of 1250 rural households and the acquirement of the necessary material for the electrification of 1000 other homes by photovoltaic systems.

4.2.4.2 Credits suppliers:

To face the expensive rural electrification by photovoltaic systems, the state judged useful to benefit from credits State " to State" granted by the foreign suppliers of the photovoltaic facilities.

These credits, allowed the ANER to finance the electrification of 5 000 rural households by photovoltaic systems.

4.2.5 Non Governmental Organizations (NGOs):

The national or international NGOs financed the electrification of about 350 homes by photovoltaic systems.

4.3 Achievement of the national program :

4.3.1 Sizing of the systems:

The photovoltaic systems installed in Tunisia in the frame of the national program are sized to satisfy the basis needs of the users in electricity for the lighting (3 lamps of 18W) and the audiovisual (black and white television set of 20 to 30W and a cassette radio set) and that, for one period of active use of 3 to 5h/day.

The sizing of the systems will also take into account the conditions of sunshine of the month of December that is the most unfavorable month and for an autonomy of 3 to 5 days.

The systems installed in this program have the following minimal specifications:

-Photovoltaic panel in crystalline silicon : 100 Wp ;
-Tubular plates battery : 200 Ah- 12 V ;
-Charge/discharge Regulator: 12V/15A ;
-Lights 12V/18W with fluorescent tubes ;
-Voltage Adapter for radio : 12V/9 ;7.5 and 6V ;
-Outlet 12 V for the connecting of the television.

4.3.2. Preparation of the specifications:

The specifications of the relative realization of the rural electrification program by photovoltaic systems take into account the rural environment characteristics, of the results of the preceding experiences rural needs of energy, the quality of the services,...

The specifications require the use of facilities presenting good qualities and performances, to avoid breakdowns and expenses of maintenance.

4.4 Setting up of the programs:

4.4.1 Sensitization of the beneficiaries and decision-makers:

For the majority of the regional decision-makers and users, the electrification by photovoltaic systems is not very known.

In this way, action have been achieved to explain to the future users of the photovoltaic and the decision makers, how the systems run and the services that can offer.

4.4.2 Identification of the households:

The Gouvernorats communicate the lists of the users in accordance with a model specifying the user's name, the region and the sector to which it belongs, the remoteness of the line of the electric grid, average tension (MT) and low tension (BT) and the cost of the interconnecting of its home by the national electric grid.

After that, the ANER make an identification door-to-door of the homes having a cost of interconnecting to the grid superior to the limit fixed by the National Commission of rural electrification.

This identification takes place in narrow collaboration with the regional authorities.

4.4.3 Contributions collect of the users:

These contributions are to be payed directly by the users to the regional council of the Gouvernorat.

After the completion of the collection of the users contributions and the Gouvernorat's contributions, the amount will be transferred to ANER, to finance this program.

4.4.4 Different parts Commitment:

4.4.4.1 ANER's Commitment:

The ANER, as a company responsible of the execution of the national program of rural electrification by photovoltaic systems is charged of:

-To launch call for tenders and to choose the facilities, the suppliers and the installers;
-To communicate to the installers the lists carrying the names of the users that paid their contribution;
-To assure the follow-up and the control of the installation works;
-To assure the follow-up of the progress of the maintenance and the after-sales service during the period of guarantee ;

4.4.4.2 The regional Council of the Gouvernorates Commitment :

The regional Council of the Gouvernorat, responsible of the development of their regions, will participate in the execution of the national program of rural electrification by photovoltaic systems as follows:

-Collection of the contribution of the users belonging to the zones of intervention defined by the program;
-Communication to the ANER of the list of the users that paid their contribution;
-Creation of the auspicious conditions to facilitate the task of the representatives of the ANER and of the installers;
-Payment for the ANER, the contributions of the Regional Council of the Gouvernorat and users and that, before the starting of the installation works;

4.4.4.3 The users Commitment:

Since the photovoltaic systems installed in the frame of the national program is extensively subsidized by the state, the users of these systems are held to:

-To bring a contribution of hundred dinars (100 DT) by system as involvement to the financing of the program;
-To assure the good maintenance of the system as well as its maintenance after the period of guarantee;
-To commit to not to transfer or to not to sell the system;
-To commit to hand back to the ANER, the system in case of connecting of his home to the national electric grid..

4.4.5 Training :

To improve the quality of the service provided by the societies active in the domain of the photovoltaic, the ANER organized sessions of training on a regional and national level.

These sessions which last three to five days aim the training of local technicians in the goal to improve their know-how concerning installation and maintenance of the photovoltaic systems.

The sessions of training are enlivened by the engineers of the ANER or by foreign trainers in the frame of the bilateral cooperation. About 200 technicians have been trained.

4.4.6. Maintenance of the systems during the period of guarantee:

In addition to maintain the systems in good operation, the installer must do at least two visits of maintenance of the installation during the period of guarantee which lasts two years.

4.4.7. After-sales service after the period of guarantee:

The installer must assure a permanent presence in the regions concerned by the project. It is for this reason that the ANER requires that at least a member of every installer's team had to be recruited of every region of the project.

And in the goal to accomplish the after-sales service during and after the period of guarantee, the installer must assure the availability of the necessary spare parts for the maintenance.

5. Assessment:

5.1 Choices of the users:

The programs of the ANER take delay so that between the date of definition of the zones of intervention of the photovoltaic by the National Commission of rural electrification and the moment of the installation, the configuration of the land changes, since the electric grid advances and it doesn't try to avoid the zones of intervention of the photovoltaic projects. This delay that can reach 2 to 3 years is essentially owed to the time taken by the research of the financing of the program and to the means limited of the ANER.

And therefore, it has been noted that in about 20 % of cases, electric grid arrived at users of the photovoltaic in a periods of 3 months to one year after the installation of the systems.

To limit the useless expenses according to this duplication of money to face the rural electrification, it is essentially to do as follows:

-To choose the users while electrifying sector by sector according to a long-term electrification rate by the national electric grid ;
-To assure a systematic identification of the homes to verify their remoteness from the grid;
-To review the consistence of the rural electrification projects by photovoltaic systems in agreement with the logistical capacities of the ANER;

-To review the programming in the time of the projects to assure their management as foreseen.

5.2 User's satisfaction :

The passage to photovoltaic powers progressively from 50 Wp to 70 Wp and then finally to 100 Wp permitted to offer a sufficient energy to the users. Otherwise, the technical follow-up as well as the investigations achieved by the ANER or by other institutions reveal that the recourse of the users to the lighting lasts about 6 hours per day. In the same way the television runs 5 at 6 hours per day and the radio cassette is used about 3 hours per day. A consumed energy is satisfied completely by the proposed photovoltaic energy which is 300 Wh/day.

Since the chosen facilities are distinctly more reliable than those used in the first projects, the cuts of current are reduced and the systems fill their role completely while giving sufficiently energy.

However, for the projects whose damaged composants have not been replaced in time in the frame of the guarantee, the breakdowns and the cuts are frequent and the users are unsatisfied .

Otherwise, there is grounds to note that the needs in lighting increase in winter whereas the solar energy is relatively weak. Of this fact, the user tends to adapt his needs according to the available sun energy.

Of another point of view, some users of the photovoltaic systems of rural electrification wish that the systems could offer them the possibility to have the refrigeration as the customers of the STEG. For that, it will be necessary to offer them a complement of equipment and by continuation more of photovoltaic power. The engineering solution exists but the national program of rural electrification doesn't support to cover more costs bound to the refrigeration.

5.3 After-sales service:

No project in the field of the renewable energies can succeed if it doesn't take into account the maintenance and the after-sales service. The good working of the photovoltaic system intended to the rural electrification requires some maintenance, repair, change of components,...

During the first two years of working, these operations are covered by the guarantee and are in charge of the supplier.

Beyond, the maintenance it would be better if the user could find close to his region necessary spare parts and the technicians specialized in the domain.

5.4 Social aspects:

It will be interesting to present some advantages bound to the use of the photovoltaic systems of rural electrification in comparison with the traditional uses.

5.4.1 Repercussion on health:

Especially with regard to the lighting, the advantages bound to the use of the photovoltaic systems are neat. With the replacement for the lighting of the traditional sources oil lamps and candle by fluorescent tubes, the pollution by smoke disappears.

5.4.2 Education of the children:

There is grounds to notice the convenience that is also offered to the children to prepare their lessons in the evening.

5.4.3 Access to the medias:

The photovoltaic systems of rural electrification gives the opportunity to the users to have a television and a radio cassette that allow them to be informed of the events that happen in the world that surrounds them and to feel less isolated.

5.4.4 Improvement of the incomes:

It is important to underline that the woman is relieved of the tasks that she assumes for the working and the traditional maintenance of the home, bound to the use of the oil lamps. The use of the lighting by the photovoltaic systems avoids them some tasks and give them free time as well as sufficiently to have lucrative occupations as the texture. Indeed, the sale of the products of the texture can generate improvements of income.

The lighting by the photovoltaic can permit to have the activities that generate some incomes but these incomes remain modest in comparison with thus which could be offered by the national electric grid offering much better possibilities when it allows to supply some motors (pumping, mills, shops,..).

5.5 Promotion and sensitization:

In the domain of the promotion and the sensitization, the main tasks of the ANER are :

- The development and the diffusion of sensitization supports;
- The organization of symposia, exhibitions, seminaries, days of information,...

In this frame, days of information and sensitization have been organized in the regions for the decision-makers attention. During these days, interventions presenting the experiences acquired in the domain of the renewable energies permitted to value and to establish some recommendations for the success of the rural electrification projects by photovoltaic systems.

Days of informations have been organized also for the attention to the users to allow them to appreciate the technology of electrification better by photovoltaic systems.

5.6 Assessment of the program management:

5.6.1 Technical performances:

The follow-up and the assessment of the projects achieved in Tunisia in the field of the rural electrification by photovoltaic systems permitted to clear some observations:

5.6.1.1 Power of the systems:

It has been recorded that the current cuts in the month of December, January and February for the first systems installed of 50Wc.

It brought the ANER to increase the power of the photovoltaic panels to 70 Wp in a first step to arrive to 100 Wp.

5.6.1.2 Performances of the facilities:

5.6.1.2.1 Photovoltaic modules:

The photovoltaic silicon modules installed in Tunisia didn't present any techniques failing.

The guarantees granted by the suppliers for this type of equipment vary between 10 and 25 years.

5.6.1.2.2 Batteries of storage:

Battery cars are used in the beginning of the program they have a short life time (12 months to 24 months).

The studies and tests took place in collaboration with the local manufacturers of batteries and the Technical Center of the Mechanical and Electric Industries (CETIME) to improve the technical performances of these components succeeded in a first step to the use of the batteries with thick plane plates and finally to the use of batteries with tubular plates that would bear an important number of charge/discharge cycling .

5.6.1.2.3 Other components :

The technical performances of the charge/discharge regulators, of the lights, of the transformer for Radio, the cables and the accessories of installation evolved in a considerable way with the program's advancement.

Indeed, the ANER tested several types of these components. The majority of the equipment used in the projects of demonstration, the pilot projects of popularization and the first projects of widened popularization presented technical failings due to the absence of international norms (for the charge/discharge regulators and the voltage transformer for radio) and to the bad quality of manufacturing.

While taking into account these technical failings in the development of the specifications, the performances of the electronic and electric components, some photovoltaic systems reached during the last projects a very satisfactory degree of maturity.

5.6.2.4 Works of installation:

In spite of the sessions of training organized by the ANER in the field of the installation of the photovoltaic systems, the quality of the installation works requires more improvements to the level of the connections, the location of the equipments and the care of the wiring.

5.7 Economic aspects:

The costs of the photovoltaic system installed is currently on average of 1 900 dinars. The costs cover only the expenses bound to the initial investment. Their details are as follows:

Components	Costs Dinar Tunisien/Unit
Photovoltaic panel 100 Wp	800-900
Charge/discharge regulator	100-200
Tubular battery 200 Ah	300-350
Lights (3)	120-200
Small material	100-150
Installation	150-250
Maintenance visits (2)	40-80
TOTAL :	**1610 – 2130**

PS. 1US$ = 1, 45 DT.

For a working life time of the photovoltaic module, 20 to 30 years, it will be necessary to consider the costs corresponding to the renewal of the facilities and the maintenance. The life time of the components is estimated as follows:

Components Life time	Years
Photovoltaic module	20-30
Charge/discharge regulator	5-10
Plane battery	1-2
Tubular plates Battery	5-7
Lights	5-10
Voltage transformer for radio	5-10

During the life of the equipment, financial costs of the electric energy produced by the photovoltaic systems installed are situated between 1 and 2 DT/kWh, which is very expensive in comparison which costs of the kWh produced everywhere by the STEG, close to 0,100 DT/kWh and this even in the rural zones, in application of the adjustment of the prices.

However, there is grounds to notice that for the period of the 8th and for the 9th economic and social development five-year plan, the electric national grid advance respectively for costs of 1 500 to 2 200 DT, or even 2 500DT for the programs of the National Solidarity fund.

During the same periods, the national program of rural electrification tries to equip the households which cost of connecting to the grid is the most elevated first (a few thousands of dinars) and that corresponds at the most distant zones of the electric grid.

Of this fact, the rural electrification by photovoltaic systems present a complementarity seen its application for zones completely distant of the grid. In the case or the zones are nearer, there is risk of interference between the two technologies.

Even though the solar energy is interesting, the homes that have been equipped with photovoltaic systems risk to be connected to the national electric grid some months after.

To avoid the double investment to the state as well as the discontent of the users, there is grounds to give the priority to the grid.

5.8 Financing :

For the present programs managed by the ANER, the diagram of financing of every photovoltaic system installed at the user is as fellows:

-100 DT in charge of the users;

-200 DT in charge of the Regional Council of the Gouvernorat;

-The rest, amount of 1 600 DT, in charge of the state (Budget of the ANER, outside financing, international cooperation, FSN);

In most cases, the costs are covered by the budget of the state for more than 90 %. The involvement of a household has always been considered like a contribution proving the user's interest for the system and his capacity to face the expenses of the maintenance in case of breakdowns or renewal of equipments.

In fact, when it is about maintenance, the user often considers that the system belongs to the state, in case it is covered by the guarantee or outside of the period of guarantee. In this way if the ANER doesn't assure the maintenance the system remained in breakdown. And this is how since 1997, the ANER instituted a budget to face the maintenance.

From this point of view, it becomes possible to review the financing of the systems. Some possibilities, can be considered:

-One way is, to make increase the contribution of the user. The amount of 100 DT represented in 1990, date of starting of such programs, 20 % of the total costs of the proposed system at this time. Currently the proposed system amounts to the ANER 1 900 DT, either to a cost nearly four times more elevated than the costs of 1990 that were around 500 DT;
-To foresee a budget of maintenance, to be included since the departure in the costs of the system;
-To longer term, the user who feels the utility to install such a PV system, gets it directly by the supplier and the ANER encourages him with a subsidy that would cover 40 to 60 % of the costs with a ceiling of 1 000 DT.
-In the same way, the ANER will assume completely its national coordinator role in the field of the rural electrification by photovoltaic systems and while bringing all its expertise concerning preparation of the specifications and its technical assistance to the regional authorities and to the users themselves.

5.9 Realizations:

During the periods of the 8th and 9th five-year plans, the realizations in the domain of the farming electrification by photovoltaic systems reached about 10 000 systems, corresponding to 50 % of the forecastings.

6. CONCLUSION:

Of the Tunisian experience, the main advantages bound to the rural electrification by photovoltaic systems present themselves as follows:

-The rural electrification by photovoltaic systems is considered like a minimum public utility returned by the state to the rural population ;
-The rural electrification by photovoltaic systems has a non negligible effect on the development of the population ;
-These programs could have an influence on the limitation of the rural exodus ;
-The photovoltaic energy is in harmony with the kindness of the environmental aspect ;
-The Tunisian experience in the domain of the rural electrification by photovoltaic systems can be judged positive, of this fact it can be strengthened for its credibility.

CHAPTER B

SYSTEMS OF PUMPING PHOTOVOLTAIC

The introduction of the use of the photovoltaic pumps since the years 1980 had leaned on a problematic that is bound to provision in water of the rural population while taking advantage of the abundance of the solar energy in Tunisia.

1. Setting of the projects and regions:

In Tunisia, the inhabitants of the rural environment represent about 40% of the total population. Wells of surface and the deep wells provide the drinking water for these populations whose dwellings are often very scattered. As a rule, some motor diesels serve to pump water. The reliability of such systems is often essentially reduced by frequent problems due to the lack of spare parts and to provision in diesel. So the use of the photovoltaic pumping systems offer advantageous possibilities for economic competitiveness and reliability.

Since the beginning of the years 1990, forty (40) photovoltaic pumps have been installed in Tunisia and that, through the projects of demonstration introduced by the ANER (National Agency of the Renewable Energies) and through the programs of the regional water authorities for supplying rural aereas with drinking water (the CRDA: Commissariat Régionale au Développement Agricole). The total power installed with this application is 100 kW.

The first project of demonstration initiated in 1992 by the ANER in Tunisia, has been achieved with the GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit), organ of German Technical Cooperation, and this in association with the CRDAs of the four regions: Kairouan (region situated in the center of the country) and Médenine, Tataouine as well as Kébili (regions situated to the South of Tunisia).

This program had the following objectives:

-Provision of potable water in rural areas;
-Demonstration of the technical maturity of PVP systems;
-Clarification of limiting conditions for economic operation;
-Definition of conditions of the further developed and the promotion of PVP systems in Tunisia.

Thus, in the frame of this program, 14 photovoltaic pumps have been installed: 7 in Kairouan, 2 in Kébili, 3 to Tataouine and 2 in Médenine.

The second project of demonstration in Tunisia also initiated by the ANER to achieve a photovoltaic pumping installation to supplying " the Solar" village of Ksar Ghilène, situated in the desert, in the South of Tunisia with drinking water. The project has been carried through in its conception and its financing, with the support of the Spanish cooperation (IDAE).

It is noted that after at least one year of running, the ANER yielded the responsibility of the management of the photovoltaic pumping systems to the concerned CRDAs.

The CRDAs, satisfied of the results of these demonstration projects, integrated in their choices the solution that uses the photovoltaic systems. The CRDA of Kébili installed 11 photovoltaic pumps by its own means. The CRDA of Médenine 11 other photovoltaic pumps and the CRDA of Tataouine 2 other photovoltaic pumps (under realization).

2. Solar energy resources:

The National institute of the Meteorology (INM) collects measures of solar energy in about 26 sites on the whole territory. This institute treats data and analyzes them, to take out the intensity of the sunshine, its duration and its distribution.

As an example, the total duration of sunstroke is 3 000 h/years for Kairouan. The average of the global radiance on a plane surface, 5 kWh/m²/d, with pronounced seasonal variations: 2,9 kWh/m²/day for the month of December and 8.4 kWh/m²/j for the month of June.

With regard to the regions of Kébili, Tataouine and Médenine, being at the South, to distances superior to 300 km of Kairouan, the sunshine is again a lot more important. The duration of sunstroke in these regions are located between 3400 and 3600 h/d. in the same way, the annual average of the global radiance on a plane surface is 6 kWh/m²/d.

3. Administrative structures of the regions:

The Tunisian territory is subdivided in 24 administrative regions, said Gouvernorats. Every Gouvernorat is subdivided in about ten administrative units named Delegations. Each of these Delegations is herself subdivided in smaller units, called Sectors.

In the head of the regional administration there is the Governor. He represents the superior regional authority as a president of the Regional Council of the Gouvernorat. In the same way, in each Gouvernorat, the Ministry of agriculture is represented by the Commissariat Regional Development Agricole (CRDA), which is in charge of water management of the rural population. The CRDA is in charge of water provision, water resources, rural engineering and maintenance.

4. Associations around the points of water:

Besides the tasks of CRDA, the operation and maintenance of the drinking water supply (DWS) network is realized in general by users associations called AIC (Association of Common Interest). Each AIC is created by the GIH (Hydraulic Interest Groumpment), which is located in each Gouvernorat Council.

The AIC management is assured by an administration council composed of 3 to 9 members. One president and one treasurer are usually elected among the members.

Tow manners are used for water sales :

- Monthly fees which varies from 1.2 to 3.35 US Dollars per family ;
- Cubic meter sale which varies from 0.100 to 1 US Dollars per m^3 ;

Water cost covers nearly DWS network maintenance and operation costs. But big failures are still supported by the Government.

5. Decision criterias of the sites for the first project of demonstration:

The choice of the appropriated sites for the of photovoltaic pumping systems is made according to technical and economical aspects order. The main criterias for the choice of a village for the installation of a photovoltaic pumping system are as fellows:

-The daily demand of water for human and animals. The range of daily pumped water should remain within 1800 m^4/day;
-The sufficient productiveness of the well (Dp < ¾ D nom);
-The distance to the national grid (> 5 km);
-The readiness of local administrative unions, so-called Association d'Intérêts Collectifs (AIC), is appreciated ;

6. Maintenance:

When all facilities were under guarantee, the supplier faced the maintenance of the photovoltaic pumping systems and this with the help of its local representative. There were at the disposal of the project spare parts that permitted to cope very quickly to the breakdowns that could occur at the level of the photovoltaic modules, the inverters, the pumps and the motors.

The CRDAs have the budgets that depend on the central administration while having a certain autonomy of management of their programs and activities.

For the accomplishment of the maintenance of photovoltaic pumping systems we meet three kind of management cases :

6.1 Curative maintenance case by case:

The example is given by the CRDA of Kairouan that faces the curative and preventive maintenance in subcontracting the operations of intervention (spare parts, labour) by the supplier's local representative. The CRDA of Kairouan undertook in 1999, an operation of preventive maintenance after having had a budget to this effect. This operation was the subject of a market with the local representative of German supplier.

For the essential, the consistence of the maintenance is resumed as follows:

- The replacement of the pumps;
- The change of the columns;
- The acquirement of the emergency facilities and small materials;
- The supply of the submersiblepumps

6.2 Subcontract of the follow-up and the maintenance:

The example is given by the CRDA of Kébili that concluded a service contract of preventive maintenance with a local enterprise having operated already in subcontract for the account of the local representative of the German supplier. This same enterprise has also been charged by the long-term consultant GTZ, responsible of the setting up of the project in Tunisia, to assure the follow-up of the photovoltaic pumping systems. In the frame of the maintenance agreement concluded with the CRDA of Kébili, this society, assures regular visits, every 4 months.

6.3 Maintenance assured by the CRDAs:

The example is given by the CRDAs of Tataouine and Médenine that estimate that they know enough about PVP systems, allowing them to face the possible breakdowns by their own means.

In a general manner, the CRDAs have some teams constituted of engineers who supervise some technicians (mechanics, electricians), having a car and tools which permit then to intervene to repair the breakdowns.

7. Training:

The sessions of training in the field of the photovoltaic pumping system have been organized to the advantage of the engineers and technicians and this abroad and in Tunisia. A big know-how has been acquired therefore locally (ANER, High schools). Concerning, although to the to the level of the CRDAs which are more specialized with the techniques of the hydromécanique and less with the renewable energies and the systems of computer measures. There is a handicap that hindered the acceptance of the photovoltaic pumping and it has created difficulties in the setting up coherent politics of maintenance and follow-up of the performances of these systems.

It is recommended therefore to make follow the technicians and engineers of the CRDAs, more deepened training and complete their knowledge photovoltaic techniques as well as the follow-up system and measures .

8. Acceptance of the photovoltaic pumping systems:

A better acceptance of the photovoltaic pumping systems has been noted by the CRDAs of the arid and semi-arid regions of Kébili, Tataouine and Médenine. The conditions of the choice of the sites are appropriated more than those of the region of Kairouan.

In these regions of the South of Tunisia solar energy is already more abundant. Otherwise, the scattering of the rural population (or nomads) living around the point of water, having more difficult access and more costs of provision in diesel, accept more easilly PVP Systems than CRDA of Kairouan.

9. Everlastingness of the photovoltaic pumping systems:

The follow-up of the working of the photovoltaic pumping stations showed that the adopted technology (solar generator, inverter, submersible motor-pump, integrated follow-up system, storage of water in a reservoir of good capacity) is interesting for its reliability. Indeed, except the problems met on the modules, very few breakdowns have been noted on the others composants of the systems. The technology is also interesting for its autonomy of running, without surveillance, without provision of fuel and without batteries. Installed in zones distant from the urban comforts (electricity, asphalted roads,...), in arid zones, the systems of photovoltaic pumping provide water to satisfy the needs of the rural population, nomad, as well as to their livestock, with continuity and abundance.

The management of these systems by the CRDAs has been well integrated to their activities, for the same reason as the classic facilities of water pumping. However, some actions remain to undertake. These actions present some variable degrees of emergency. They can be as well in relation with the CRDAs, as with the supplier as well with other institutions implied in the success of the photovoltaic pumping projects (ANER, GTZ, DG/GR, Schools of engineers...).
For an everlastingness of the photovoltaic pumping systems, there is grounds to undertake the following actions:

9.1 Replacement of the photovoltaic modules:

For the project achieved with the German cooperation concerning the setting up of 14 photovoltaic pumps, 600 modules have been installed. Among these modules, 260 have been replaced in the frame of the guarantee and this because of the loss of power noted. This phenomenon continues to occur and it risks to harm to this application of photovoltaic pumping a lot. Of this fact, it will be recommended to intervene vigorously at ASE, the supplier of the modules, to replace all remaining modules, either 350 modules. The ANER, the DG/GR (General Direction of the Rural Engineering, department of Ministry Agriculture) .

9.2 Funding of the follow-up and the maintenance:

The systems of photovoltaic pumping operate an autonomous manner but it will be recommended to exploit the system of follow-up incorporated to the installation, to control its good working. This approach also permits to warn the breakdowns and to detect some anomalies, beforehand especially those that are bound to the performances. Indeed, the losses of power of the modules can be detected by a follow-up system.

10. CONCLUSION :

The use of the photovoltaic pumping systems in Tunisia, as well through the projects of demonstration of the ANER or through the projects of the CRDAs, showed that the technology bound to these systems is mature. It also has demonstrated the efficiency of the system that assures the pumping of water with solar energy, and its storage in a big reservoir and this while using only a photovoltaic generator, an inverter and a motor-pump.

This use proved that the technology is reliable since the rate of breakdown on the different components is admissible. Except the shortcomings of photovoltaic modules, the breakdowns met on the inverters and the motor-pumps are minimal. But it will be necessary to remain heedful in the future to insure constantly that the solar generators don't lose their performances with time.

These are there advantages in favor of the use of photovoltaic pumping systems in the desert zones where the notions of efficiency, of reliability, of autonomies running, without surveillance are so much useful for supplying drinking water.

CHAPTER C

SYSTEMS OF TELECOMMUNICATION

1. Introduction:

The systems of telecommunication are frequently used in the isolated regions, notably for :

- The emergency calls, the collection of meteorologicals data;
- The information exchanges: telephonies, relay, radio, telecommunications;

Data concerning the first applications are limited. In following, only will be described the photovoltaic systems implanted by Tunisia Telecom to promote the rural telephony.

The photovoltaic applications for the sector of the telecommunications represents a big interest for the development of the rural telephony in Tunisia. Indeed, this application began to be developed itself since 1976. The first programs that concerned this activity had as objectives to get a telephonic density of 88 lines for 1000 inhabitants in 1991. To this effect, Canadians and French enterprises have been consulted to install two types of systems in 1995: 16 systems using 7 photovoltaic modules each and 55 systems using 14 modules each.

At this date, 1153 photovoltaic modules of 50 Wc each has been installed, corresponding to a total power of 45 kW. Besides, the fast extension of the national electric grid is going to allow supplying the rural telephony devices by the grid instead the by the photovoltaic systems.

2. Technical specifications of the systems

Two proposed system designs are configured to fully the local specifications :

System A : Consists of :

-A 357 Wp PV array panel comprised of 7 kyocera 51Wp modules, arranged on a single 7-module ;
- Photocomm model PW 12-30 controller, housed in a enclosure ;
-A single lockable steel battery enclosure housing a 57 Ah battery bank comprised of 6 Johnson control , 6V, 190 Ah modules, configured as two in series for 12 VDC and three in parallel.

System B : Consists of :

-A 714 Wp array comprised of 14 kyocera 51 Wp modules, arranged as two 7- modules ;
-A IPC model TS2C-4 controller and 12 Johnson controls 6V battery modules in the same steel enclosure as used for system A, with a total capacity of 1140 Ah.

CHAPTER D

ELECTRIFICATION OF THE RURAL SCHOOLS

In the frame of its activities of promotion of the renewable energies and support to the improvement of the conditions of life and teaching in the rural area, the ANER has electrified by PV systems about 215 schools. Generally the schools are distant of the electric grid of some kilometers to more than 10 kilometers, what justifies their equipment by PV systems. This approach is strengthened by a project that makes intervene as well as the ANER as the regional council of Gouvernorat as the regional representative of the primary education. The financing of the acquirement and the installation of the PV systems is normally shared by the ANER and the council of Gouvernorat, with large contribution of the ANER.

In its design, the PV installation is conceived as fellows:

- Every class room is PV powered with 100 Wc, to supply 3 lights ;
- The installation of 100 Wp by canteen ;
- The installation of 100 Wp by lodging of teachers ;
- The installation of an independent circuit of cable, in the class rooms, the canteens and the offices of the directors for supplying an electric plugs : DC-24 V ;
- The classrooms, the office of the director and the canteens are supplyed by DC 24 V;
- The lodgings of the teachers are supplyed by DC-12 V .

Thus, the class rooms are sufficiently powered to offer a good lighting early, in the morning, especially in winter and late in the evening. The school can also use educational appliances (color Televisions, video) by using an inverter 24V/220V that is put at the disposal of the school.

The mean PV power by school is around 600W. And the total PV power installed in the frame of these projects is equal to 50 kW.

CHAPTER E

SOLAR STREETLIGHT

The ANER have developed the use of the solar streetlights in a "solar" village: Ksar Ghilène, situated in a desert region in the south of the country. This project consists of the installation of 10 solar streetlights. equipped with PV modules which power is 100Wp.

The ANER have installed also 10 solar streetlights in the natural park of Ennahli, close to Tunis, having the same features as the precedents. ANER has also achieved a project of installation of 20 solar streetlights on the beaches of Ouedhref and Metouia, in the South East of the country.

The total power installed according to all these realizations is 4 kW.

CHAPTER F

MARITIME BUOYS

For its needs, the army of sea have installed maritime buoys running with photovoltaic solar energy.

The systems consists on the use of a PV module 51 Wp, a charge/discharge regulator, a battery, a clock that allows the lamp to blink (ignition 1/3 of the time and extinction 2/3 of the time, the night). Recently the army has purchased 400 maritime buoys, corresponding to 2kWp.

CHAPTER G

BORDER STATIONS

The army positioned at the border or in other places of the national territory, are generally distant of the electric grid from the STEG. And it is often that they resort to PV solar energy to cover their needs in lighting, in transmission using radio stations, to have audiovisual facilities as well as refrigeration.

In a general manner the necessary photovoltaic generator to cover these PV needs has a power of 3 kWp.

The available electric energy can be used directly to supply the lights and the radio station or through an inverter, in alternating current (220V, 50Hz) to supply the refrigerator.

CHAPTER H

POTENTIEL

After having described the photovoltaic applications in Tunisia, the present chapter intends to value briefly the perspectives of development of the photovoltaic systems.

The main concerned applications are:

- The rural of the households ;
- The rural electrification of the schools ;
- The streetlights ;
- The pumping water systems ;
- The maritime buoys ;
- The electrification of the border stations.

1. The rural electrification :

The use of the photovoltaic systems for the rural electrification knew a high development in Tunisia during the last years. In the same moment the rural electrification by the electric grid is knowing more important developments.

The survey achieved by the STEG in 2001 showed that the rural households that are not electrified again by any system and that won't be electrified by the grid, by the year 2010, don't exceed the 20.000 homes. This number represents the maximal potential of the relative photovoltaic application to the rural electrification.

As the present national programs have installed only a power of 100 Wp by home. The total potential would be 2 MWp.

This potential market could double if would be applied the recommendations of the ANER, which have proposed to increase the power of the PV systems from 100 Wp to 200 Wp.

In this case, the potential would be of 4MWp.

2. Photovoltaic pumping:

The installation of photovoltaic water pumping systems constitutes one of the most important applications and this for the following reasons:

-The rarity of water in the desert multiplies its importance again in these regions ;

-The reliability of the technology and its working in an autonomous manner with the solar energy to provide water regularly, grant more importance to the pumping of water by the photovoltaic systems.

According to the 1990 underground water table exploitation, the total number of surface wells is estimated to 100.000 wells, disseminated through 196 underground water tables. The situation of the equipped wells per energy source is a follows :

TOTAL WELLS	1 EQUIP. WELLS						NON EQUIPPED WELLS	
	G.E	%	G.D	%	Dalou	%	Number	%
98140	15703	16	41752	43	18848	19	21837	22

GD: Diesel motor **DE:** Electric motor **Dalou :** 40 Litres

The table above shows :

- Non equipment and simple equipment wells (seal, dalou, etc.) represent 61% of the total wells (41 000 wells);
- Wells equipped with Diesel pumps represent 43% of the total wells (42 000 wells).

The number of wells which might be equipped is very important. The Centre and Southern Governorats, suitable areas for PVP development, offer 10 000 non equipped wells (10% of the total number). Beside of surface wells, the country has about one hundred deep wells with characteristics suitable for PVP systems (power demand below 4 kWp). More than half of these deep wells are situated in the Centre and the Southerm areas. The potentiel of PVP systems is estimated to 2 MWp.

However, PVP systems could find another application in booster pumping which is done frequently in DWS projects (low fow, and high total manometric head).

3. Telecommunication:

Following the extension of the national electric grid, the telephonic relays will be more and more supplied by the electric current to the alternative format 220V, instead of supplying by the photovoltaic direct current. Of this fact, the needs in photovoltaic panels to supply the telephonic relays will be very weak to hopeless in the future.

4. The solar streetlight:

The local experience in this field is only to its beginnings. Insofar as it is valued, and in the case where it is judged positive and interesting a non negligible market of installation of solar streetlights exists. Beaches and the spaces between the scattered households could be illuminated with these streetlights. It is possible to foresee the installation of 50 solar streetlights annually, either 5 kW/year, corresponding to 400 kW by 2010.

5. Maritime buoys:

The army of sea have acquired these last few years 400 maritime buoys. It would seem that these acquirements corresponding to the renewal of equipment and no to new needs expressed by the department of Armée. It would appear that the market for this kind of facilities remained limited.

6. Border stations:

The army of earth and of sea continue to equip itself in PV facilities to face their energy needs on the islands that are not connected by the electric grid, as well as on the national border sites. With the progress of the electric grid, the place of the PV is more and more reduced.

THE EXPERIENCE OF THE DESERT TRACKS BEACONED WITH THE SOLAR ENERGY IN ALGERIA

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Abstact:

ALGERIA has around 3000 hours of sunshine throughout the year. The climatic conditions encourage the use of this noble and clean energy. In the saharian desert, the conventional energy was pratically non-existant.
To go from the south of Algeria to Mali or Niger, the crossing of the desert is obligatory because there is no other terrestrial way to join the neighbouring countries. The tracks in the south of Algeria know a very dense traffic by night during the hot seasons, because of the high temperature during day. Unfortunately, travelling by night presents big risks of getting lost because there are not visible mark points. To give the necessary security of persons crossing the region and to maitain a vital commercial flux exchange with the limitroph regions and the sub-saharian countries. The PV application solar energy is used for the different advantages, and a lot of tracks were beaconed. Some beaconed tracks are: from Reggane to Bordj Baji Mokhtar (700 Km),
Bordj Baji Mokhtar - Timiouaine , Aoulef - Ain Belbel , Tin Zaouatine - Ain Guezzam, etc...
Totally, 2000 Km of tracks beaconed are in the desert of ALGERIA.

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THE EXPERIENCE OF THE DESERT TRACKS BEACONED WITH THE SOLAR ENERGY IN ALGERIA.

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Abstract:

ALGERIA has around 3000 hours of sunshine throughout the year. The climatic conditions encourage the use of this noble and clean energy. In the saharian desert, the conventional energy was practically non-existent.

To go from the south of Algeria to Mali or Niger, the crossing of the desert is obligatory because there is no other terrestrial way to join the neighbouring countries. The tracks in the south of Algeria know a very dense traffic by night during the hot seasons, because of the high temperature during day. Unfortunately, travelling by night presents big risks of getting lost because there are not visible mark points. To give the necessary security of persons crossing the region and to maintain a vital commercial flux exchange with the limitroph regions and the sub-saharian countries. The PV application solar energy is used for the different advantages, and a lot of tracks were beaconed. Some beaconed tracks are: from Reggane to Bordj Baji Mokhtar (700 Km), Bordj Baji Mokhtar - Timiouaine, Aoulef - Ain Belbel, Tin Zaouatine - Ain Guezzam, etc...

Totally, 2000 Km of tracks beaconed are in the desert of ALGERIA.

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Key words : PV Application , Solar energy, Tracks beaconed, South Algeria.

1. INTRODUCTION

This study presents the following beaconed tracks : Reggane-Bordj Badji Mokhtar (700 km), Bordj Badji Mokhtar-Timiaouine (180 km) and Aoulef-In Belbel (120 km) in the wilaya of Adrar.

While Silet-Tin Zaouatine (400 km) and Tin Zaouatiné-Ain Guezzam (350 km) are located in the wilaya of Tamanrasset.

Finally El Golea-Hammam Berkane (170 km) and Hammam Berkane-Hassi Fhel (100 km) is situated in the wilaya of Ghardaia (see fig. 2).

It presents also the essential aspects such as economics, human and experimental that lead to choose the tracks in the middle of the Tanezrouft and hoggar deserts which are known as the most fearsomes deserts in the world.

Nowdays, the crossing of these deserts "of thirst and dead" does not present any danger thanks to solar energy. It is now possible to travel by night by taking as a mark-point these blinking beacons. The distance between two beacons varies from 5 to 10 kms depending on terrain topography.

2. MOTIVATIONS OF THE PHOTOVOLTAIC CHOICE

To go from the south of Algeria to Africa passing by Mali or Niger, the crossing of the desert is obligatory because there is no other terrestrial way to join the neighbouring countries.

The towns of Adrar (Lat:27°53'N, Long:0°17'W) and Tamanrasset (Lat:22°47'N, Long 5°31'E) are obligatory steps for travellers who take the risk to cross this laborious and dangerous desert, especially with bad weather.

dune of sand.

Table II gives an idea on the number of missing, finded and lost persons for the only track of Reggane - Bordj Badji Mokhtar (wilaya of Adrar) during the period of Feb.79 to Nov.87.

Table II : Lost persons in the Reggane - Bordj Badji Mokhtar track (79/87)

Periods	Missing persons	Finded persons		Lost persons
		Deads	Alive	
from 28/02/79 to 10/11/79	18	2	5	11
from 15/05/84 to 14/10/84	11	2	9	-
from 01/03/87 to 15/11/87	2		2	

Looking after persons is of great importance for the local authorities.

The search operation necessitates the mobilization of many rescue squads equipped with 4 x 4 trucks, radios, gas-oil, food etc...to cover all the suspected zone. This type of operation can last more than one week sometimes.

In some complicated cases, the intervention of the army forces with helicopters is necessary and this costs too much to the country.

In front of all these difficulties the wilayates (provinces) asked the CDER to find a solution.

After analyzing many solutions (grid, gas etc...) the idea to beacon these mortal tracks with PV solar energy imposed itself at last to be the most economic one.

This danger is increased during some periods of the year when the climate characterized by an extreme aridity varies suddenly : sandstorms, rainfalls etc...For example in winter the ambient temperature can decrease (by night) to -15°C and exceeds 50 °C in summer.

The windstorms reduce drastically the visibility and can reach sometimes a speed of 100 km per hour.

Some of the tracks in the south of Algeria know a very dense traffic by night during the hot seasons, because of the high temperature during day. Unfortunately travelling by night presents big risks of getting lost due to the absence of visible mark points. The non existence of gas oil stations along the roads complicates more the travel.

In spite of all these difficulties the desert crossing frequency increases every year.

Table I : Crossing frequency 1983-1989

Years	Number of persons	Number of vehicles
1983	777	564
1984	927	639
1985	950	650
1986	1006	757
1987	1010	760
1988	1522	952
1989	1736	1126

From table I we notice clearly this yearly increase of the number of people crossing the region and therefore the number of missing persons.

The main reason of all the disappearances is going off the track while trying to evitate an obstacle or a

3. DESIGN APPROACH

The realization of a solar beacon did not come from the first time because there was no known PV terrestrial beaconing system that we could have counted on. That is why our starting point was the blinking system of a car to which we added a flip-flop and a twilight switch to make it work by night only on one side and, to reduce the energy consumption on the other side. This has lead to the system of fig.1.

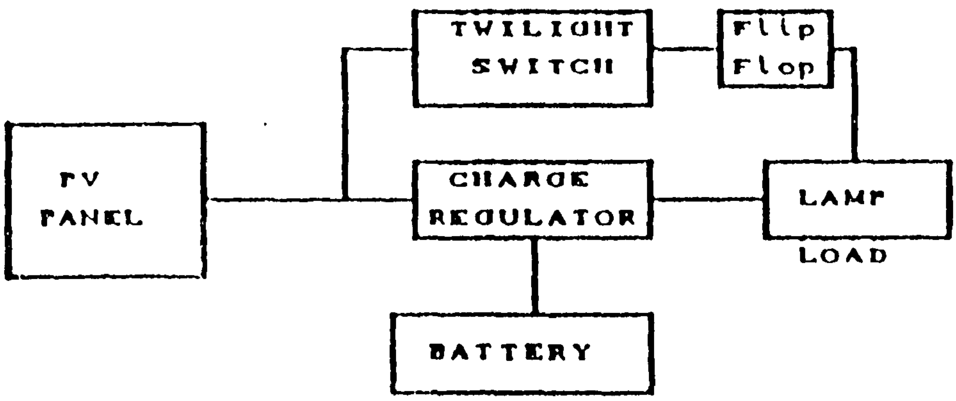


Fig.1 :Schematic diagram of the system

During day, the battery is charged by the PV module via the charge regulator which protect it against discharge or overcharge. During night, the twilight switch puts the system ON and the flip-flop lets the lamp to blink until the sunrise.

In a first time the system was composed of 2 PV modules (38 Wp each), a charge regulator, a blinking electronic system (twilight switch + flip-flop), a lead-acid battery (12 V - 150 Ah) and a car lamp (45 W).

This system has equipped only the Reggane-Bordj Badji Mokhtar track composed of 100 PV beacons (see list in Table III).

Table III : Beaconed tracks list

Tracks	Distance	Number of beacons	Year
Reggane-BBM (W Adrar)	700 Km	100	1984
BBM-Timiaouine (W Adrar)	180 Km	32	1986
Silet-Tinzaouatine (W Tamanrasset)	400 Km	45	1987
Tinzaouatine-Ain Guezzam (W Tamanrasset)	350 Km	45	1987
Aoulef-In Belbel (W Adrar)	120 Km	12	1988
El Golea - Hamam Berkane (W Ghardaia)	170 Km	16	1991
Hamam Berkane-Hassi Fhel (W Ghardaia)	100 Km	16	1991

In a second time and after analysis of the system functioning and after elaboration of a sizing program, many improvements have been brought:

- the power of the PV generator has been reduced from 76 Wp to 40 Wp (≃ 50 % reduction). This has let to use only one module
- the number of regulator entries has been also reduced to one instead of two
- the battery capacity decreased from 150 Ah to 100 Ah

As a consequence of all this, we concentrated our efforts on the following points:

1) the power lamp reduction comes down from 45 W to only 12 W, with white lamp instead of a yellow one

2) this has obliged us to improve the optic effect by using a Fresnel lens. The emitted light is in all direction but the flux is mainly concentrated in the horizontal plane.

3) the new flip-flop uses transistors instead of relays

4) the time duration rate (ON/OFF) of the lamp has been reduced to 1/3 instead of 1/2. This means that the lamp remains illuminated during 1/3 of the time.

Any beaconing system is not only

composed of the system described above but also of a candelabra (signpost) 7 m height where the module is fixed (at 6 m height) and the lamp on it's top. This candelabra is fixed on a concrete base.

The realization of a trap of 1 m^3, beneath the earth has permitted to:

- protect the battery and the electronic system against bad weather (windstorms, rainfalls, etc ...)
- maintain an acceptable temperature
- evacuate battery gases

4. ENCOUNTERED PROBLEMS

1) All the means and tools used during realization on-site where not sufficient with the extreme harsh conditions.

2) Even with police control, many vandalism acts have been noticed during some control missions (robbery of batteries and one PV module).

3) Very little interest has been shown by the local authorities.

4) Some defects have been noticed here and there for absence of maintenance.

5. CONCLUSIONS

In this paper were described the first tracks beaconed with PV solar energy in Algeria and , as for as we know, in the World. This way, 2000 kms of tracks situated in the Tanezrouft and Hoggar deserts were beaconed since 1984.

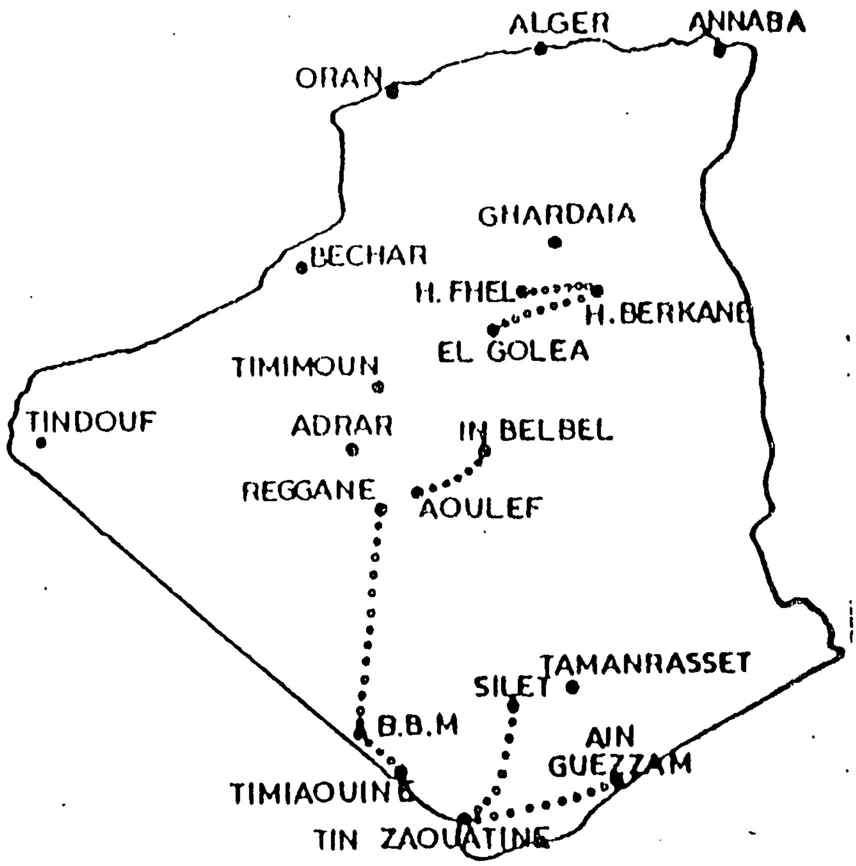
The beaconing of this tracks gave more security to the persons and vehicules. It's use is not to demonstrate again.

The experience gained during the first beacon's installation has let to many improvements of the system. It is sure that other improvements should be given in the future.

Despite all this, a difficult work remains. The local authorities and the track's users should be sensitived more in order to reduce vandalism and to assure an efficient maintenance.

ACKNOWLEDGEMENTS

The authors are gratefull to the many people involved during systems installations, per their full devotion to the work in hard conditions.



• ∘ TRACKS BEACONED WITH SOLAR ENERGY.

Fig.2 : Tracks geographical localization

THE EXPERIENCE WITH PV ELECTRIFICATION OF SOME LOCALITIES IN THE SOUTH OF ALGERIA

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ALGERIA, located in North Africa, with an area of more than 2.300.000 Km_2, 4/5 of it are arid and semi arid zones. This particular situation makes it very costly to extend the conventional energy distribution grid, mainly the villages in Sahara are scattered. Further, the average daily total horizontal radiation calculated over the year is about 6 Kwh/m2 for over 3000 hours of sunshine duration. Taking in to consideration this huge renewable energy potential, for this reason, an algerian governmental solar energy program is reteined and a tramendous effort has been done to promote the use of solar energy. The PV electrification of many localities in the south of Algeria is installed. For example: Tin Zaouatine, Ain Guezzam, Bordj Baji Mokhtar, Ain Belbel, Aoulef, Matriouane, etc...For example, in a remote saharian village in the south of Algeria, a 6.7 Kwp PV array was installed for electrification for streets and indoor lighting.

The full solar energy sulution has been chosen for the electrification of these isolated regions and to promote the living conditions, such as lighting and other applications.

At present, the PV system is running perfectly.

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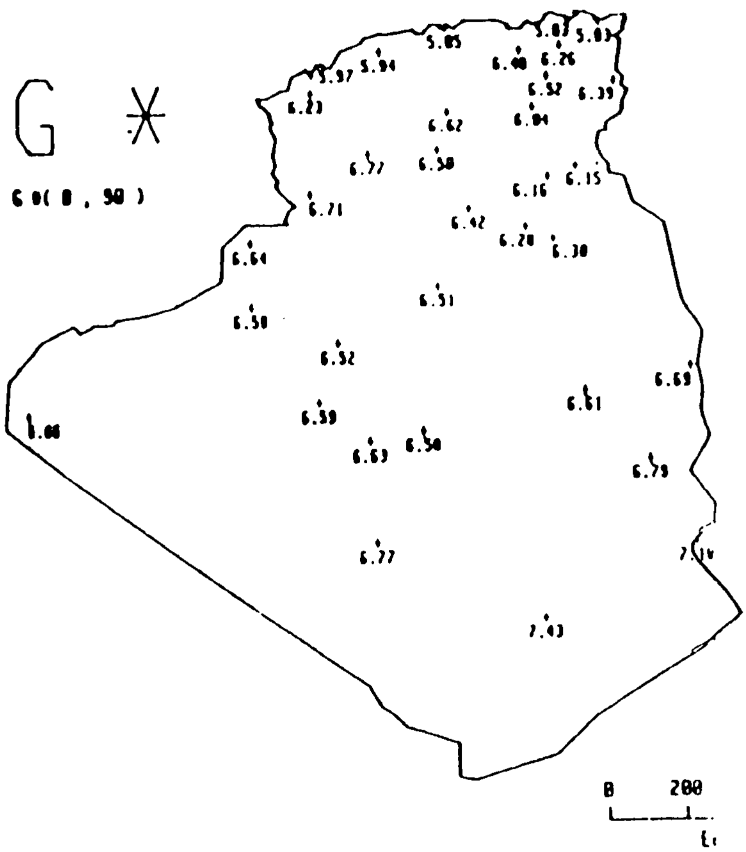

Fig 1: Average daily total horiz
radiation overa year(clearday Kw

1. INTRODUCTION

In the framework of the Algerian and Spanish cooperation, a project of rural electrification has been retained to power, by PV solar energy, a village in the south of Algeria.

Two centres are involved for the achievement of this project: CDER (Centre de Développement des Energies Renouvelables) from the Algerian side and IES (Instituto de Energia Solar) from the Spanish side. Each country contributes with it's know-how and equipments produced within its frontiers. Algeria furnishes the PV generator, the support structures, the civil engineering, the underground distribution network and the indoor electrical installations. Spain furnishes the batteries, the power conditioning systems, the electrical loads and the data monitoring system. Design, field checks, follow up and evaluation are part of the common jobs.

2. DESCRIPTION

Matriouane is a typical remote village of the south of Algéria. It is located in the Wilaya (province) of Adrar (lat: 27° 53′ N, long: 0° 17′ W, 1543 km from Algiers) on the southern edge of the Tadmait Plateau in the central part of the Algerian Sahara. Matriouane and In Belbel (10 km west of Matriouane) are the last villages non electrified in the Daira (county) of Aoulef.

Matriouane can be accessed by two principal tracks (180 kms from Adrar or 120 kms from Aoulef). The distance between Adrar and Aoulef is 240 kms (good road).

The settlement of Matriouane is on an alluvial plain of wadis between two little mountains with 50-70 m height in the North-South direction. The altitude in the center of the settlement is approximatively 400 m. The size of the oasis is not very large. The population is about 300 inhabitants (1990) and there are 57 houses including a mosque, a health centre and a school with two classrooms. Except the common services , all the constructions are built in toub (adobe) which isolate them from high external temperature and create a comfortable climate in themselves.

To the southest of the settlement there are date palm gardens. The main agricultural products of the garden are: dates, barley, vegetables and some fruits. Infortunately the production is still not sufficient for the village consumption.

Water, for irrigation and drinking purposes, is drained from open wells and foggara (old system distribution used to transport water through underground channel to a village) where the maximum depth is 7 m (1). Beyond this, the soil is formed by non-porous rocks which serve as a tank to retain the rare rainfall water.

From 1984 until 1988, the village was equiped with a 35 kVA diesel engine which supplied a numerous incandescent lamps during 4 hours per day. The villagers were organized in a way that each family pays 50 DA (4 $) per month to buy gas oil and spare parts. This let them to be autonomous from the central administration (Aoulef).

Unfortunately, since 1988 a spare part of the diesel engine was not found to repair it.

The weather in the Wilaya of Adrar is caracterized by a long and hot summer (May to October) where the mean ambient temperature can reach 44.7 °C in July (2).

During the other period, the climate is moderate caracterized by a mean ambient temperature of 17 °C. Dust storms occur regularly between February and April. They can last 08 days a year with a maximum of 12 days in April (3).

3. DESIGN APPROACH

3.1. PV plant

As it is shown in fig. 1, the system installed has an 6.7 kWp generator, a 800 Ah stationary battery (10 h discharge rate), a back-up generator powered by a 35 kVA diesel engine (manually switched) and two static inverters (4600 VA and 500 VA). A manually change-over switch of 3 positions (PV, Diesel and no charge) can be used by the operator. The PV plant delivers electricity via a 220 VAC local underground grid to water pumps, public and private lights.

Actually a 5 kVA diesel engine has been installed until the old engine will be repaired.

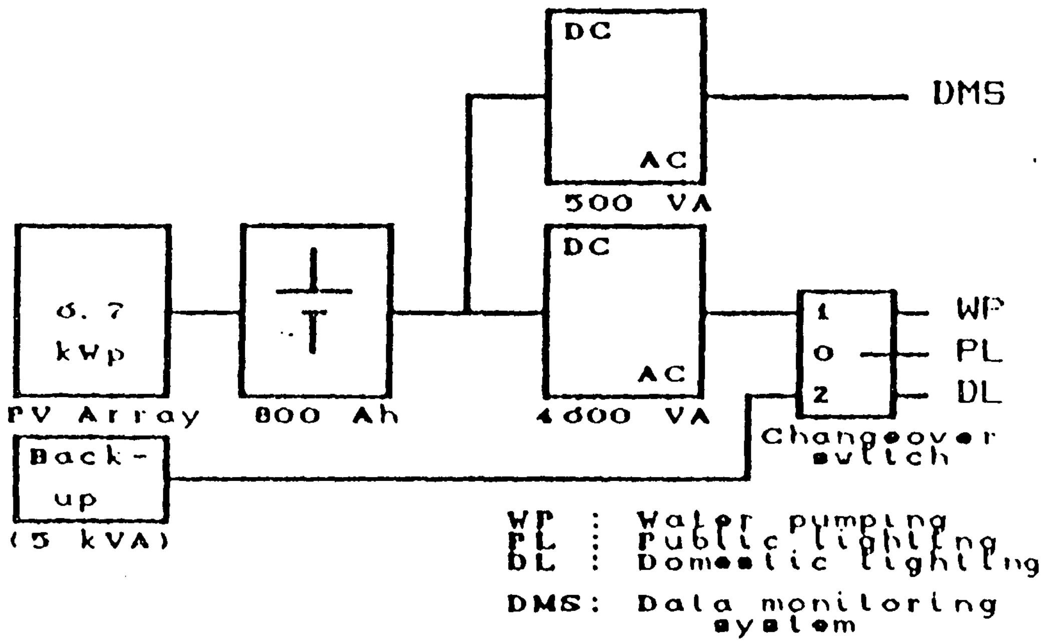

Figure 1. Schematic diagram of the system

The PV generator is composed of 135 monofacial modules (36 monocristallin cells associated in series) with a nominal value of 50 Wp of each module at STC. Each string is an association of 9 modules. The modules were selected so that the dispersion of mismatches losses due to the currents at maximum power of the individual modules would be minimal.

The battery has 60 series connected stationary elements with a nominal voltage of 120 Vdc.

Both inverters are built with high-power MOSFET of high efficiency (4). The first one (4600 VA) supplies all the loads while the second one (500 VA) supplies the data monitoring system (DMS).

The loads consist of two 0.5 HP water pumping (static head life = 7 m), six vapour sodium lamps of 35 W for public lighting and one hundred and sixty one fluorescent lamps of 18 W for domestic lighting. Twenty one of them are installed in the courtyard of the houses.

All the loads are time switched. For the protection of the system, the village was divided into three parts. Each part is protected by three or four switches 5 A/250 V each. This way, the energy is limited and permit us to localise any overcharge or short circuit.

Locations of the public lamps, the number of private lamps per family and the two open wells for pumping water were fixed after consulting the inhabitants.

All the equipments are installed in a central building who has 45 cm thick walls and built with a locally brick called BTS (Béton de Terre Stabilisée / Stabilized Cement Clay) avoiding the influence of the high ambient temperature. The BTS is composed by clay, sand and 7% of cement.

3.2. Data monitoring system

1) For evaluating the performance of the plant, an analytical monitoring system was installed according to the CEC recommendations (5). In addition, three electromechanical counters were installed to measure the AC energies supplied by the PV plant, the diesel engine and consumed by the DAS. Each day, the operator registers these three parameters and send them each month to the technical staff.

2) Due to the particular conditions of the site (high temperature during summer day, dust storms) additional parameters were included in the measuring system to provide data about the behaviour of the BTS building and the effect of dust deposition on the performance of the PV generator.

4. PROBLEMS ENCOUNTERED

1) Transportation of persons and material is a rough problem because the village is so isolated and the tracks are very difficult.

2) During transportation of material, some electronic cards of the inverters were damaged. For this purpose, the presence of the manufacturer during phase installation was necessary.

3) Living conditions on the site were too difficult and this obliged us to reduce the time intervention on site.

4) Due to some logistic problems, the two tanks of the pumps are not yet built.

5. SOCIAL ASPECTS

1) Since the first time, we noticed that the inhabitants of the village are organized and well disciplined in many domains: water distribution, house construction, gas-oil share, etc ...

2) During phase installation, the technical staff was helped by the villagers in transporting the material and the realization of the trenches for the underground distribution network.

3) PV energy has been quickly accepted and appreciated by the users. Their hope is to see the project extended to other applications such as refrigeration or TV. This last possibility can be studied if the Wilaya can install a TV repeater and an antena on the top of the nearest mountain.

4) 9 new houses are in construction since the beggining of the project

5) From the starting of the PV plant, a group of 5 persons were selected by the villagers to :

- take care of the PV system
- collect a mensual share to cover some maintenance charges
- connect and set the necessary lamps for

the new houses
- participate in the water distribution when the pumps will in function

8. EARLY RESULTS

Even if it is early to come up with conclusions and according to the data collected (72 days) so far we can say that the mean daily consumption of the village is 10.2 kWh which is to close to our estimation (10 kWh). The mean daily consumption of the DMS is about 0.7 kWh. The total consumption is shown in fig. 2.

One can notice that no energy was delivered on the 53th day. This happens during a rainy day when the operator shut down the utilization in order to evitate short circuits. This type of behaviour is justified by the inexperience of the operator. His reflex was to protect the PV installation.

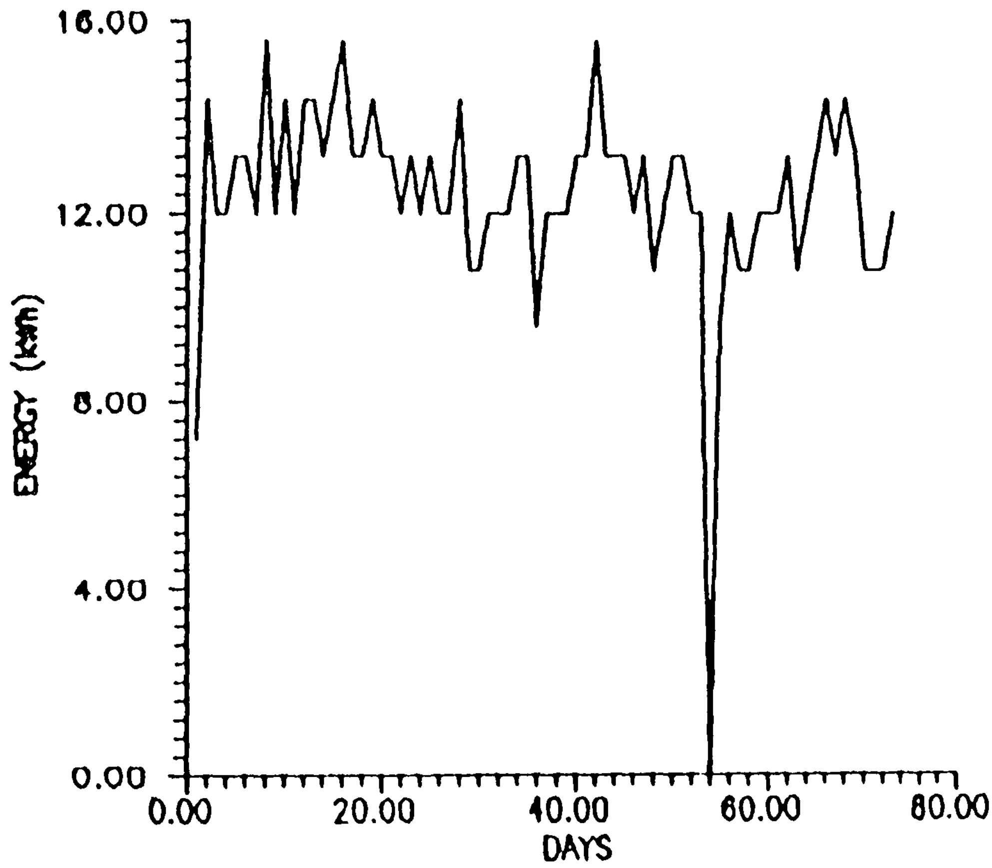

Fig. 2. Daily consumption evolution

7. CONCLUSIONS

Since the first time, the PV system operates correctly which shows the current maturity of the PV technology to solve electrification situations on such isolated locations.

The experience gained in this project suggests to :

- give a special care to the transport of the electronic equipments to avoid any damage
- reduce the on-site intervention
- make the users participate before, during and after phase installation to the management of the plant. The social organization existing in the village can play an important role to guarantee the success of the PV rural electrification

The PV system was well accepted by the users and shows that PV solar energy could represents a very elegant solution for a lot of isolated villages in the south of Algeria.