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DEVELOPMENT AND APPLICATION
OF
SMALL HYDRO-ELECTRIC POWER PLANTS*

by

Satish Dewan**

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SMALL HYDRO-ELECTRIC POWER PLANTS

Table of Contents

APPENDICES:

Appendix No. 1 - Layout showing major equipment for a Hydro-electric power plant

Appendix No. 2 - General view of a Hydro Power Station

Appendix No. 3 - View of a small Hydro-electric Power Plan

Appendix No. 4 - Measurement of gross head in Reaction and Impulse turbine Installations

Appendix No. 5 - Single-line diagram for electrification of equipment

Appendix No. 6 - Exploded view of a generator

Appendix No. 7 - Synchronous generator-view of a rotor withdrawn form stator

Appendix No. 8 - Synchronous generator-brushless with unilateral ventilation

Appendix No. 9 - Synchronous generator - brushless with bilateral ventilation

1. Introduction

For any economic development of the country the offering of low-priced electric energy is a basic requirement.

Optimal planning and exploitation of hydro-electric power potential is a complex and enormous task, particularly when one considers the numerous possibilities of transferring water to neighbouring catchment areas; problem to decide how the various river systems could be appropriately used or most advantageously combined; selection of project location, water supply installations, civil, mechanical and electrical engineering; feeding electricity to priority areas, etc.

Not the construction of larger power stations alone will in future determine the picture of energy generation but more than previously the erection of small plants utilizing the possibilities of a region.

Large power stations with the associated infrastructure for the distribution of the energy can only be considered for limited, already developed areas. They cannot supply remote areas of the flat land. The construction and maintenance of the required transmission networks would be too uneconomic.

The subject of this report deals with the necessity and advantageous of installing small hydel projects, methods of planning and technical design with a layout showing the set-up of a power station, application of major equipment involved in hydro power plants like turbines, generators, control panels, transformers, etc., a check-list for elaborating tenders and important basic technical datas such as height of fall (head), layout - flow water quantity, power speed, weir, transformer capacity etc., which must be collected at the planning stage.

2. General Overview of Hydro-electric Power Plants in Various Countries.

Small hydro-electric generating units have vindicated their utility, so much that small hydel power generation is not considered an established practice in many countries, including the most advanced and highly developed ones. Economically viable, the hydel units have been found in practice ample rewarding. Indeed, in secluded, hilly and inaccessible areas, the only promise of an electrification programme comes from the use of small hydel units.

On the basis of statistical data and informations available upto mid seventies, hydro power plants upto 1500 KW capacity installed and under construction, in various countries are as under :

Country	Approximate No: of units in operation	
1. Austria	over 950	many are being considered
2. Burundi (Southern part of central Africa) **Important Rivers are:** Rusizi Tributaries to the Rusizi Rivers falling into Lake Tanganjika Malagarazi with tributaries Akanyaru with tributaries Ruvubu Tributaries to the Ruvubu	over 15	Burundi has a noteworthy water power potential. The potential worth developing, i.e. the sum of water power which could be utilized with the present state of the art at favourable cost compared with other energy sources, amount to more than 400 MW.

Country	Approximate No. of Units in operation	
3. China	over 2500	
4. Colombia (Northwest corner of South America) Important Rivers are: Bogela Patia Magdalena Cauca Sinu Putumayo Meta	over 38	A few are under planning stage. Since 1975, as part of the programme of technical co-operation between Colombia and Germany, a joint German - Colombian study group has been drawing up a systematic inventory of the hydroelectric power potential throughout the entire country.
5. Czechoslovakia	over 4800	
6. France	over 800	A number of low head and medium head installations are being progressed.
7. India	over 2000	
8. Italy	over 1200	
9. Japan	over 170	
10. Norway	over 500	
11. Sweden	over 1000	
12. Switzerland	over 350	
13. USSR	over 2250	
14. W. Germany	over 800	

3. Need for Small Hydro-electric Power Plants upto 1000 KW Capacity

The increasing demand for electric power makes it necessary to utilise even small streams. The economic operation of small installations presupposes low initial costs, the highest degree of perfection of the machine and equipment installation and the best possible utilization of the water power. These requirements have led to the developments of a type of water turbine which utilises efficiently for electricity generation the power contents of small streams.

Exploitation of hydro-electric power is usually combined with enormous dams, pipelines and power plants. Small plants represent an alternative and additional solution to the increasing demand for energy. The following are the necessary points for installation of small hydel projects in the developing countries.

3.1. It would increase rural electrification from village to village and produce wealth and prosperity for the countryside by lifting water to farm and field and by turning the wheels of rural industry.

3.2. Areas would get priority if they had ground water and, therefore, agricultural potential; raw material and skills and, therefore, industrial potential.

3.3. The project could be considered in it's two-fold aspect - (1) producer and (2) consumer. To the village as producer, electricity would come as a basic input. To the village as consumer it would come as a basic amenity. Village electrification would then become something much beyond domestic and street lighting. It would be rural electrification in the fullest sense of the phase.

3.4. The utilization of rivers, streams and canal drops for power generation has special importance for an agricultural country.

3.5. Small hydel projects can be easily manufactured by various developing countries without importing much of equipment. This would then supplement power generated by large power station, as electricity would be available in short span of time.

3.6. The availability of local power can be of great assistance in fast construction of bigger dams and reserviors required for large hydro-electric power stations.

3.7. Obtaining electricity from far distances, for a few scattered wells and neighbouring areas, gives losses in transmission and distribution networks. Local power generation through small hydro projects can help in reducing these losses.

3.8. Hydel resources in the form of small streams and rivers are available in abundance in hilly and mountainous regions, which can be tapped through small hydro-electric power plants and help the valley inhabitants.

3.9. In many developing countries, forest wood is being used for burning fuel. The availability of electricity would save the forests.

3.10. Lastly, small hydro-electric power plants can be used in large hydro power projects as anixiliary power source during emergencies.

4. Advantages From Small Hydro-electric Power Plants

Electrical energy generated by power stations throughout the country has to be distributed to many millions of outlets in factories and houses, transport systems and offices, shops and hospitals. More power stations are under construction and distribution network is constantly being expanded to supply electricity to large industrial complexis, to metropolitan, transportation systems, and communication system but less thought is being given to rural areas.

4.1. As more than 80% of the world's poorest people live in rural areas, rural development should be a priority means of eradicating poverty in the developing world. By suppling electricity to the villagers, they could benefit and initiate cottage industries and small enterprises. The small enterprise sector is important in several ways. It is a rich potential source of new employment opportunities, and a rapid means of utilizing local resources and saving foreign exchange. An efficient small enterprise sector goes hand in hand with the progress of large industries - especially in rural areas and the service sectors. Yet small enterprises in rural areas tend to be neglected.

<u>Beside increasing the employment facilities</u> here below are some more advantageous from small hydel projects.

4.2. Hydro-electric power plants are clean and pollution free.

4.3. Hydro power is a renewable resource and manages it's own transport.

4.4. A small hydel project requires a moderate investment, depending on capacity of the plant. Furthermore, it has low running costs.

4.5. The load demand of the rural sector from the bigger power stations will be reduced, which would assist in reducing power shortage in factories and major operating industries. Furthermore, production of individual plants would also increase.

4.6. Energy is converted close to the consumers, hence short distribution networks and saving of transmission overhead lines.

4.7. Hydro power plants can be manufactured indigenously which would result in saving of foreign exchange and avoid depending on import deliveries.

4.8. The small units would speed up rural electrification programmes.

4.9. Significant socio-economic environmental changes would take place which will increase the standard of the local people for a better living.

4.10. Lastly, small hydro-electric power plants are idealy advantageous for rural development, planning and small cottage industries.

5. Planning and Layout of Hydro Power Stations

There has been a slow down in the building of oil-fired power stations and a step-up in the number of hydro-electric stations to meet the growing need for power.

The planning, design and layout of hydro-power projects cover a wide field which embraces all branches of conventional engineering. Civil, mechanical and electrical engineers must co-operate closely in order to obtain the best solution for the project. The field of work embraces: Preliminary studies; design planning; detail planning; overall consulting and co-ordination of engineering work; preparing of invitations to tender and construction supervision; constructional measures with full responsibility in the erection of turnkey installations; foundations; hydraulic problems; hydraulic structures; civil and mechanical engineering calculations and design for building and industrial constructions; progress and time schedule supervision using network planning techniques.

The activity of the hydro-power engineer starts at a very early stage. It is often he who instigates the systematic development of an entire river or makes proposals for the electrification of extensive regions on the basis of the existing water resources. Hydro-power has often been the point of crystallization of new industries or has introduced industrialization.

In conjuction with irrigation requirements and discharge regulation, or the diversion of water to the catchment areas of other rivers, it forms part of large-scale water resource planning, increasing in importance with the increasing density of population occuring everywhere.

The layout of a hydel project is much simpler and can be constructed with a moderate investment.

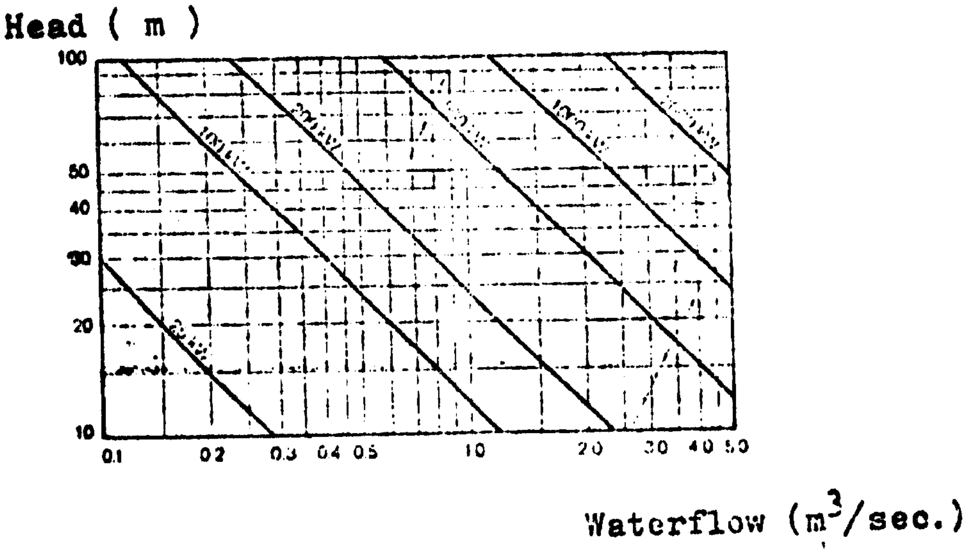
Appendix No. 1 shows the layout of a small hydro-electric power plant, comprising of a turbine, a electric generator, control panel, cables and a transformer. Application and functions of the above equipment are explained in the following point No. 6.

Appendix No. 2 shows a general outlook of a hydro-power station. Appendix No. 3 shows the view of a small hydro-electric power station. A single-line diagram in Appendix No. 5 shows the electrification of the equipment.

The above appendices with sketches and diagrams have been prepared for the developing countries in order to make the subject of hydro-electric power station look simpler and understandable.

The diagram below gives a visual impression of the more common output combinations for the Francis turbines. Using the diagram, one can easily make a first rough estimate of the available power in the water stream.

As an example we see that a water flow of 2 m^3/sec at a head of 30 metres will give 500 KW.



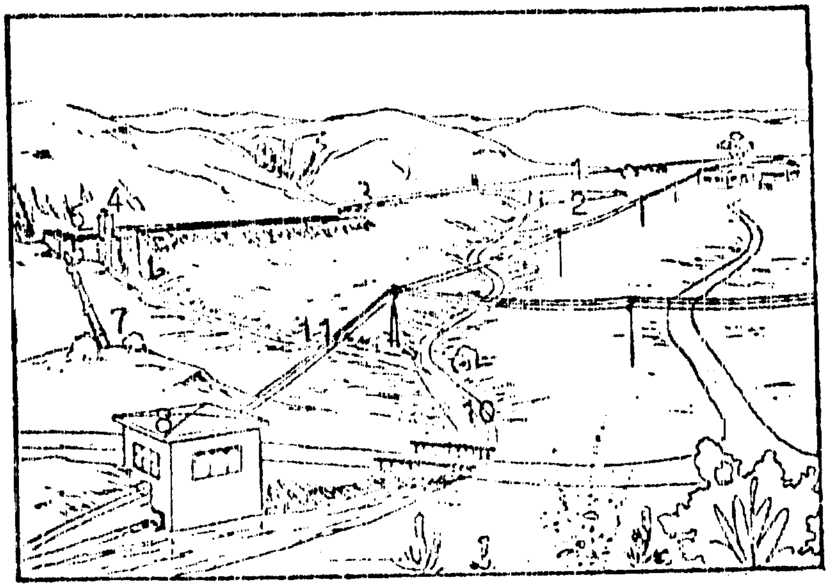
5.1. Technical Design of the Small Hydro-electric Power Station

Prior to mentioning the technical factors of small hydro-electric power stations some of their favourable ecological points should be indicated which have gained in importance not only in our countries but to an increasing extent also in developing countries.

Hydro-electric power plants conserve the environment and do not cause water pollution. On the contrary, in its passage through the turbine water is aerated and enriched in oxygen causing a better self-cleaning effect supporting the biological life and abundance of fish. The necessary damming of the water together with a controlled outflow have a favourable effect in the catchment area both on a normal, relatively constant ground water level and the storage for ensuring the water supply.

There are in addition, the provision of evaporation areas and the consequent improvement of the micro-climate. It can easily be seen from these reasons that severl reservoirs along a river favourable influence the water economy situation and that they have, in planning rural development, a task not to be underestimated.

View of a small hydro-electric power plant



1. Reservoir
2. Dam
3. Inlet channel
4. Control gate
5. Surge chamber
6. Retaining grate
7. Pressure pipeline
8. Power station
9. Turbine outlet
10. Bed of stream
11. Electrical transmission line

The above figure shows the principle of a hydro-electric power station.

Plants of this kind are generally constructed by the operators themselves, communities, small industries etc. with the aid of local workers and without much of foreign assistance.

The river water as shown in the figure is dammed by a dam and passed through an inlet channel to the surge chamber with control gate and retaining grate without significant head loss. The subsequent pressure pipeline drops to the turbine plant converting the water energy into useful mechanical energy to drive machines, e.g. generators.

Dams are constructed using local material and are called gravity dams which can take up the horizontally acting water pressure in the reservoir by their own weight. The surge chamber has to pass the water to the pressure pipeline after a simple grate has retained disturbing suspended foreign matter. The turbine plant can be stopped by operating the control gate. The water energy is converted in the pressure line into velocity energy. Suitable pipe cross-sections are recommended by the turbine manufacturer. To take up the shear forces it is simplest to bury the pipelines.

The flow turbine has been recognized worldwide as the machine suitable for small hydro-electric power stations. It was invented by the Australian engineer A.G.M. Michell in 1903 and was further developed in the meantime to the present maturity by the Ossberg Turbine Works in Weissenburg, Bavaria, Federal Republic of Germany. Its working principle consists in the water flow being passed through an adjustable control apparatus and penetrating through the blade rim into the interior of the cylindrical turbine rotor, passing through it and leaving it again. The remaining head difference to the tail water can be utilized by the subsequent suction pipe, a friction-less ventilating valve controlling the head of the suction water column.

The special feature of this design is that the cylindrical rotor can be designed for strong seasonal fluctuations of the diving water volume which is almost always the case in tropical regions, as cells for dealing with small, medium and large water volumes at favourable efficiency.

This produces an excellent partial load behaviour for the optimum utilization of the energy offered; an efficiency of about 80% can be reached from 1/6 of the rated water volume upwards. This high adaptability is the special feature of this type of turbine for small hydro-electric power stations in developing countries.

For power generation in island operation a three-phase synchronous generator is used, smaller aggregates being assembled in the works for installation mounted together with speed controller and gears on a base plate.

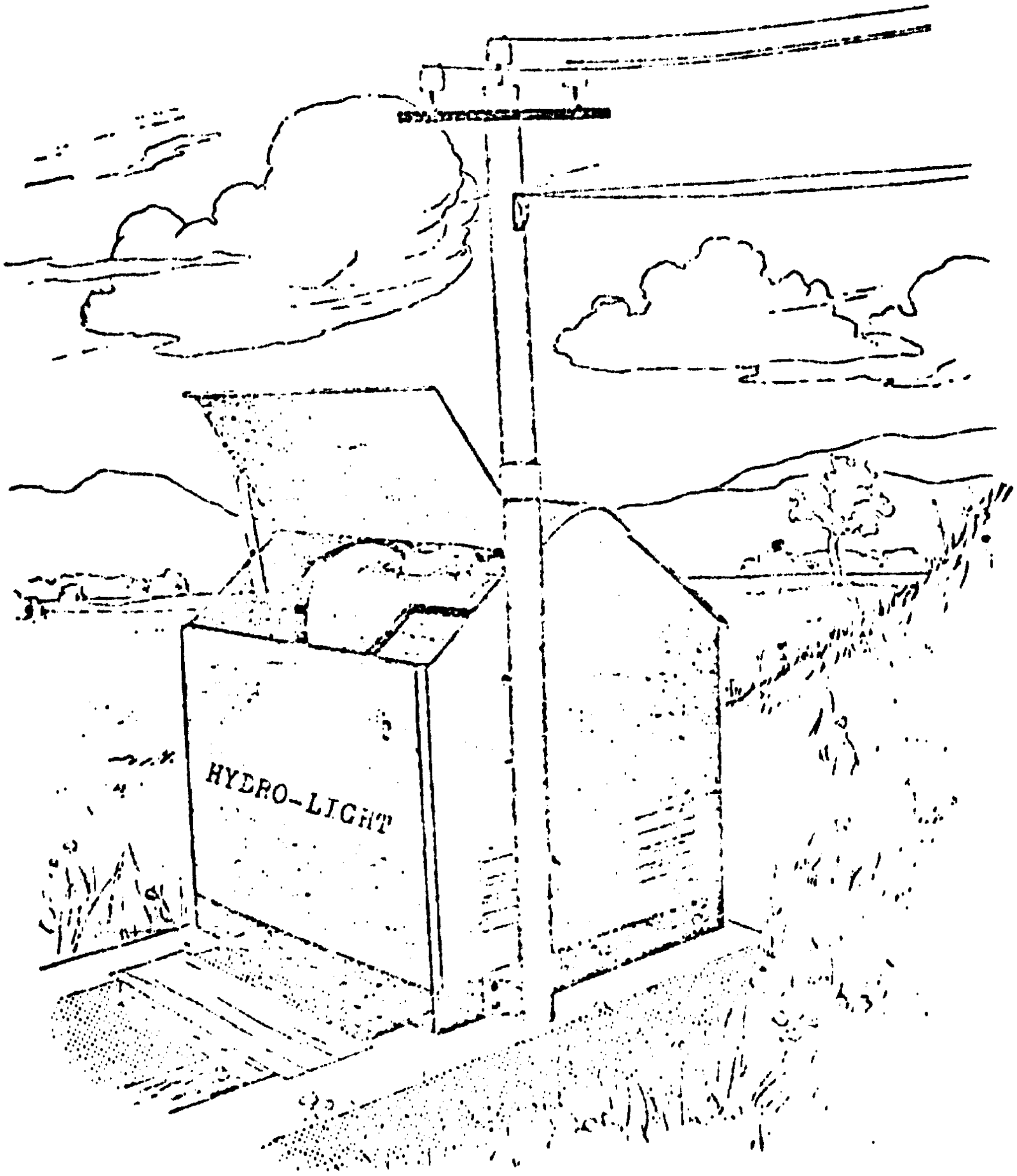
Because of the favourable speed range of the flow turbine the mechanical output supplied can of course also be used for directly driving pumping plant, mills, sawmills and agricultural machines.

The turbine is designed as suction pipe turbine with two cells. Two control rods connect the control apparatus of the turbine with the lateral speed controller. The gear with the flywheel is an extension of the turbine shaft. The shafts lead from the gear through coupling to the generator and pump which can selectively be connected and disconnected.

This type of turbine meets the requirements of small power stations. It can be installed by local workers and maintain for decades in the continuous operation with the simplest means because of it's robust construction. Freedom from maintenance with only a yearly lubricant change is an added advantage.

Here below is another example of a manually controlled small hydraulic power generating unit supplying current to farms, detached dwellings, mountain hotels, weekend chalets, etc.

The sketch hereafter is a miniature power plant accommodated in a neatly designed housing of about 1.5 cubic metre volume for supplying energy for smaller premises where water is available in quantities of about 30 to 85 litres per second. This is an economic substitute for diesel units and other power generators which are costly to run continuously. Unit construction requires a minimum of foundations. It only needs connecting to the pressure and draft tubes and electrical gear for starting.


HYDRO-LIGHT

6. Application, Description and Functions of Major Equipment

Application

Experience in many countries of the world has proved that the electric power generated by harnessing even small water drops is an attractive, economical preposition. This hydel power can be derived from water drops is an attractive, economical preposition. This hydel power can be derived from water drops available in various forms:

a. Small rivulets, streams and falls.

b. Irrigation releases and distribution canal drops.

c. Effluent releases of chemical plants.

d. Cooling water releases from thermal power plants, or at sites where head is available.

The power generated by harnessing the potential energy stored in these resources can be usefully employed for electrifying small villages, isolated industries, defense camps, valleys or contractors' camps. It can also be utilised for battery charging equipment and telecommunication equipment.

Many countries are now developing very small hydro-electric generating units, called micro-hydel units in 3 KW, 5 KW, 10 KW and 25 KW.

These micro-hydel units are usually designed for heads of 3 metres, 7 metres, 10 metres, 15 metres, 60 metres, 100 metres, etc.

The outstanding feature of these units is that except for a few components like runner, casing and guide vanes, all components are common, irrespective of the ratings of the units and also the heads against which they are designed to operate.

Description and Functions

The hydro-electric power plant consists of the following major equipment -

6.1 - A Turbine
    6.1.1 - Butterfly Valve
    6.1.2 - Governor

6.2 - A Generator
6.3 - A Control Panel
6.4 - A Transformer
6.5 - Cables

6.1- A Turbine

The water turbines are broadly categorised into two types, namely -

- a. Impulse Turbines
  - i. Pelton wheels
  - ii. Turgo impulse wheels

- b. Reaction Turbines

  They are available in enclosed and open type -
  - i. Francis turbines
  - ii. Propeller turbines
  - iii. Kaplan turbines

The above two types of turbines are shown in Appendix No.4 indicating the measurement of gross head in reaction and impulse turbine installations.

The most commonly used turbines in the small hydro-electric power plants are the Francis turbines. The selection of the type is always governed by the parameters head, speed and output of the unit. The parameters generally decide what type of turbine should be installed for particular site conditions.

However, as a general rule, it is noted that for higher heads impulse turbines are used, where as for lower heads reaction turbines are used.

Basically, for small units, a turbine is of the vertical type and has a spiral casing. The flow of water is controlled by the governor which operates the guide vanes. The turbine runs in various selected r.p.m. and is directly coupled to the generator.

The spiral casings are of cast iron construction (for smaller units) and for larger units they are of the welded steel construction. The turbine runners and guide vanes are also made of cast iron or bronze depending on the duty conditions.

6.1.1 - Butterfly Valve

The housing and disc are made of welded sheet steel. The housing of the valve is connected to the inlet section of the turbine by a flange joint. The connection with the penstock is usually welded.

6.1.2 - Governor

Hydraulic turbines which are coupled to A.C. generators require close speed governing in order to keep generated voltage and frequency constant.
The governor consists of a centrifugal pendulum. The centrifugal force set by the weights is opposed by a spring. The moving sleeve of the pendulum slides on the shaft and is connected through links and levers to a deflector which diverts the jet from the turbine runner when the speed tends to rise.

In hydraulic turbines the governor also has to control the speed by regulating the flow of water which is in massive quantity and obviously calls for large force. The water turbine is usually designed to control these water forces in a way that keeps the speed variation at the minimum and the pressure rise in the pipelines within permissible limits.

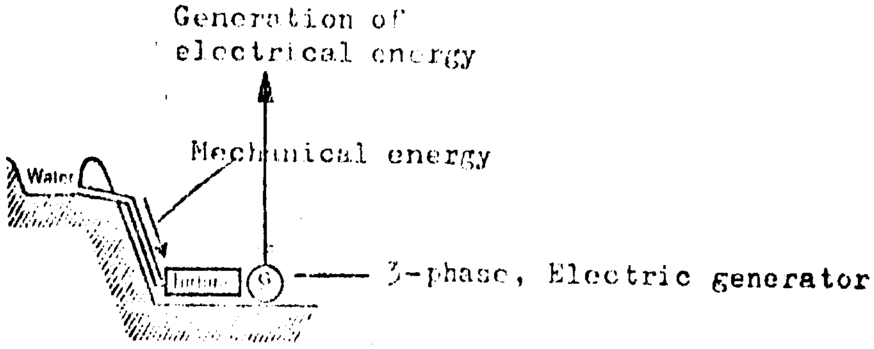
6.2 - A Generator

The electric generator and the electric motor-generator and motor for short - are electric machines used for energy conversion.

The word "Generator" is derived from Latin and means "Producer". The electric generator, earlier known also as dynamo, converts mechanical energy into electrical energy.

The electric generator, an electromotive force (voltage) is induced by changing the magnetic flux in the winding turns either by moving the turns into magnetic field or the magnetic field with respect to the turns.

The voltage produced drives a current through a load.
The principle of energy conversion with generators is shown below with a sketch:



One could write a lot on the subject of 'electric generator' but to be more precise and to have a general idea the author has restricted himself not to make it a lengthy chapter by showing in -

Appendix No. 6 - Exploded view of a generator
Appendix No. 7 - View of a synchronous generator - rotor withdrawn from stator
Appendix No. 8 - Synchronous generator-brushless with unilateral ventilation
Appendix No. 9 - Synchronous generator-brushless with bilateral ventilation

Generally synchronous generators are used in majority of hydro-electric power installations. However, in certain instances where units have to operate continuously in parallel with local supply network, a much simpler arrangement employing induction generators may be adopted.

Generators are available in two types of construction - vertical and horizontal with stationary or rotating poles.
In case of all small machines, static self-regulating and self-exciting system provides D.C. excitation in controlled form to

the generator field. This eliminates conventional rotating exciter and voltage regulator. The static excitation system consists of following components:

i. Series current - transformer
ii. No load adjustable air gap choke
iii. 3-phase bridge connected rectifiers
iv. A set of delta-connected condensers

For rural areas in the developing countries, this has the most outstanding salient feature, that the static exciting and regulating system is the fast and accurate response which keeps the voltage fluctuation within close limits.

In the planning of an optimal power supply system many criteria must be taken into consideration. Different excitation methods are employed including D.C. main and auxiliary exciters, brushless excitation with rotating rectifiers and also static excitation.

Herebelow are the important constructional features of a synchronous generator, which have not been forgotten but can be explained and designed according to the requirement of the project:

Construction of the stator
- Laminated core
- Stator winding
- Rotor
- Rotor winding
- Impellers
- Excitation current circuit and sliprings
- Bearings
- Bearing shells
- Oil system
- Insulation
- Cooling-air circuit
- Enclosures
- Brush and brushgear
- Anchoring

For further technical data see point 8 - check-list of this report.

6.3 - A Control Panel

All the measuring instruments, indicators and control devices, necessary for the control of the generating set, are mounted on a panel in the control room of the power plant. This panel is designed as a switch board with fixed frontpanels and doors on the backside. It should be possible without problems, to extend this switchboard for adaptation of a new generator/ expansion programme.

For smaller units, as a general practice, the following equipment and instruments are provided as part of the generator control board:

- Air-break automatic circuit breaker of suitable rating
- Ammeters with selector switches
- Voltmeter with selector switch
- KW meter
- Power factor meter
- Synchronising bracket for other units
- Synchronising selector switch

The control room should also be equipped with alarm system and protection devices.

6.4 - A Transformer

The transformer can be a standard three-phase oil immersed or dry type transformer, suitable for operation under the climatic conditions prevailing in the country.

See Appendix No. 5 showing single-line diagram for the set up of the electrification of the plant. The ratings are not given as they would vary from the power supply received.

On the high voltage side of the transformer normally an isolation switch is mounted. This is either installed in the station or in the first mast.

Similarly as stated in point 6.2 under the heading 'Generator' herebelow are the important constructional features of a transformer which could be emphasized and discussed at the designing stage of a power plant :

- Main data
  - rating
  - frequency
  - type of connection, etc.
  - cooling method
  - losses
  - insulation
  - design and constructional features
  - core
  - windings
  - tank
  - bushings
  - off-load tap changer
  - wheels
  - conservator and breather
  - valves
  - terminal cabinet
  - neutral ground and lightning arrester
  - transformer oil
  - buchholz relay
  - dial type indicating thermometer

6.5 - Cables

The cables should be installed in accordance with the rules and regulations of the country's standards.

Preferably PVC and paper insulated cables with copper conductors should be used in all types of hydro-electric power plants.

Type of cables to be used:
For the connection from alternator (generator) to transformer (in case of generator being of the high voltage type) and high tension switchgear, paper insulated single core cables should be used.

The conductors, preferably should be of copper conductor.
Cable shielding should be grounded on one end.

Low voltage power cables,
Multicore cables,
Cable fittings,
Cable racks.

7. Systematic Approach and Problems of Optimal Power Plant Control

The steady increase in the consumption of electricity, the substitution of other kinds of energy by electricity and the growing consciousness of the need to protect the environment not only make the construction of new power plants compulsory, they also force operators to optimize the operation of existing plants, i.e.-

- optimal utilization of hydro-electric plants (meaning, that the available should be optimally utilized, with a minimum of spillage)
- Optimal hydro-thermal operation (meaning minimal fuel costs for the thermal and nuclea plants, economic l utilization of equipment, safe and dependable power supply).

These optimizing tasks may be so complex that man cannot cope with them unaided when -

- the number of variables affecting decisions is large
- there are numerous subsidiary conditions
- control conditions are difficult.

Modern methods of data acquisition, transmission and processing, efficient computers and above all, the principles and methods and system eneginecring enable these problems to be solved now a days, provided they are properly, systematically and in particular, purposefully employed.

7.1 Problems of Optimal Plant Control

In order to optimize a system, the following aids must be available:

- a model of system;
- the parameters of the model must have been identified or it must be possible to forecast them;
- characteristic variables of state and for decisions must have been defined;
- a target function must have been stipulated;
- the constants must be known;
- practicable methods of optimization must be available.

Accordingly, the general problem of optimal plant control - in the case of hydro-power plants has to be divided as follows:-

For the model of the system the structures, parameters, variables and relationship have to be defined. Fig.1 and Fig.2 illustrate schematically storage and run-of-the-river hydro plants and their characteristics.

The most important characteristics, for example, are the relationship between the volume V of the reservoir and it's level, V = f (h), the relationship between the efficiency of the turbines n and the power output P and the level h of the reservoir n = f (P,h), as well as the limits of the parameters such as the maximum and minimum output of the turbine Pmax, Pmin, and the maximum and minimum of rates of flow Q in a duct. Optimization and control, however, have to rely dynamic models.
For these the running time of the water in a duct, for instance, the response of the spill-gate controls, of the turbine control system or of the surge chamber, must be known in advance, if control is to be optimized.

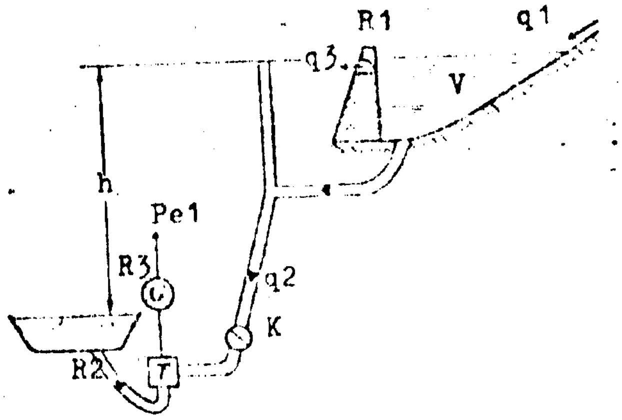


Fig.1 - Schematic representation of a high-head hydro plant

q1 = water inflow
q2 = water outflow
q3 = water overflowing and lost
V = volume of reservoir
Pel = electric power output
h = overall head
Rl = overflow control
R2 = turbine control
R3 = generator control
K = butterfly valve

The rate of flow Q of a river, for example, can only be calculated when it's relationship to the water level h is known, see Fig. 1 and Fig. 2.
Generally data acquisition is carried out cyclically with respect to time. The results are stored.

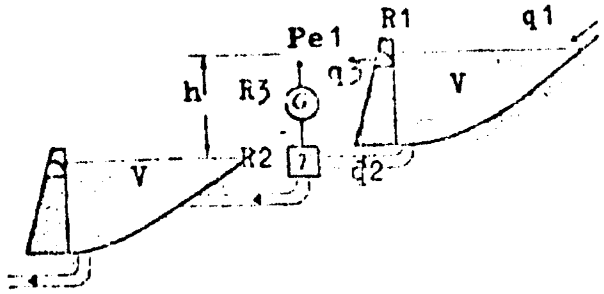


Fig.2 - Schematic representation of a low-head hydro plant
Notation as above for Fig.1

The tasks of data processing, statistics and forecasting depend to a large extent on the mode of operation. They include the calculation of characteristic values, such as the volume of reservoir, water consumption, overflow, water spillage, water inflow, etc.; also involved are recording (operational events, disturbances), the preparation of statistical reports, costing and identification or estimation of system parameters and states, especially forecasting the natural flow of water Q (short-, medium- and long-term).

The latter is a very difficult problem, especially when rainfall is irregular or stored in the form of ice and snow. Then it is necessary to work with statistical models for the relationship $Q = f(q,t,hs,qs)$, where -

q = amount of rainfall
t = average atmospheric temperature
hs = mean depth of snow
qs = mean amount of solar radiation

the parameters of which would have to be continuously improved.

The general task of optimization must cover a definite period of time in accordance with the cyclic availability of energy that can be supplied by hydraulic systems. The task can, however, be subdivided into long-term, medium-term, short-term and momentary optimization because the demand follows different cycles and storage permits decoupling.

7.2 Systematic Approach to Plant Control Concepts for Hydro Plants.

A feature of hydro plants is that their problems, characteristic and operating conditions are particularly varied.

If we compare the basic systems:

- Run-of-the-river plants, independent or coherent, with or without storage reservoirs,
- Storage plants with reservoirs, independent or coherent,
- Pumped storage plants, independent or coherent as well as
- All possible combinations of the foregoing.

We find that a generally valid plant control concept covering all kinds of hydro plants cannot be established. On the other hand -

- A generally valid modular hierarchically orgnaized structure of the plant control system,

- Modules for dealing with parts of the overall problem, such as data acquisition, stat estimation, linear optimization and
- A formel procedure for the development of a plant control system, known as systems engineering do exist. This systems engineering solves problems by the systematic application of -
- A formal solution procedure (methodology),
- Standardized technical aids and generally valid technical and scientific means (methods).

The objective is to find an optimal solution for the overall system, which satisfies overriding assessment criteria.

The formal procedure of systems engineering consists of the following steps:

1. Analysis of the problem;
2. Deciding on the rough structure of the system;
3. For every sub-system;
4. System analysis (examination of the concept).

8. Check-List to Elaborate Tenders for Hydel Power Plants

Here below are the important points for elaborating tenders for hydro-electric power plants -

1. General

Client, engineers
Kind and limit of tender

2. Project Information

General
Climatic conditions

3. Type, Purpose and Mode of Operation

Requirements of load
Design criteria
Hydraulic data
Electrical and mechanical data
Electrical data of grid

4. Water Supply

Cooling water
Fire fighting water
Drinking water
Waste water

5. Civil Engineering Part

Soil conditions
Site conditions
Regulations
Construction materials
Contractors
Additional buildings
Power house
Additional rooms

6. Local Conditions

   Personel
   Transport

7. Mechanical Part

   Hydraulic installations
   Electrical installations
   Pipings and armatures
   Pumps
   Water conditioning plant
   Cranes, grabs and freight elevators
   Fire fighting plant
   Air conditioning
   Workshops
   Test-Platform and laboratories
   Compressed air plant

8. Electrical Part

   General data
   Energy conductor
   Power supply for start-up
   Generator bus bars
   Station load equipment
   Transformer
   Control, supervision and protection
   Additional low voltage plants
   Site power supply

9. Supervision of the Building Work and Erection at Site, Commissioning

   Building and errection site supervision
   Commissioning

10. Economic Research

   Estimation of construction costs
   Estimation of annual costs
   Benefits
   Power costs
   Comparison of varieties
   Penality / Bonuses

11. Commercial Terms

   Pricing
   Terms of payment
   Passing of risks
   Consequences of failure to comply
   General material guarantee
   Customs, taxes and duties
   Law and jurisdiction

12. Agreements with other Suppliers

8.1 - Questionnaire - for Calculation of a Water Turbine Plant

Since water turbines are always dimensioned and constructed in accordance with the local conditions, therefore, for each case, a questionnaire, as stated below is necessary to be filled in, so that a well designed and suitable Hydel Power Plant can be undertaken. If possible, one must make sketches or drawings (plan of site and elevation) of the existing situation to enable the manufacturers to offer complete proposals of installations.

Questionnaire

Address and name of the ....
prospective customer ....
....

1) Gross head
(vertical distance between head water level in the intake channel or water chamber and tail water level) .... m

2) Which flow rates are available for driving the turbine and during which periods?
Maximum ......liters/sec.,
how many months a year? ....
Average.......liters/sec.,
how many months a year? ....
Minimum.......liters/sec.,
how many months a year? ....

3) a) Is a storage available? ....
b) Will turbine draw from storage dam or open stream? ....

4) What area? .... m^2

5) Allowable differential of water level in storage above and below average head water level. .... m

6) Distance from storage to turbine: .... m

7) In what way will water from storage to turbine be transported?

a) by means of open channel?
State length: .... m

b) by means of a penstock?
State length: .... m

c) what other way? ....

8) What type of machine will be driven? ....

9) Which is the smallest capacity to be expected? ....

10) Which is the largest capacity to be expected? ....

11) Is speed regulation of the turbine required by manual operation or by automatic oil pressure governor? ....

12) In case of driving an electric generator, specify:

nature of current energized: ....
number of phase: ....
number of cycles p/sec.: ....
tension: ....

13) Which is the distance between turbine room and location where main part of the output is taken off? .... m

In case of energy transmission state if ground cable or overhead line is preferred.

14) In case electric motors are connected, please specify the capacity of the largest motor ....

FOR MECHANICAL DRIVES ONLY:

15) Should the turbine be connected to a main transmission (e.g. via flat belt, V-belt? etc) ....

16) Position of main transmission to direction of water flow or position of up stream pipeline (parallel or perpendicular to?) ....

17) Position of main transmission above down stream level in metres: .... m

18) Number of revolution of main transmission to be driven: .... rpm

19) Sense of rotation of main transmission (if necessary, a drawing should be submitted) ....

Country concerned is requested to state which items are available indigenously and which are to be imported.

8.2 - Design Criteria with Important Technical Datas

8.2.1- Hydraulic data

- Upper reservoir	
storage capacity	m^3
maximum storage level	m above sea level
minimum storage level	m above sea level
- Catchment area of head water	km^2
- Lower reservoir	
storage capacity	m^3
maximum storage level	m above sea level
minimum storage level	m above sea level
- Average annual water quantity	m^3/s
average annual maximum water quantity	m^3/s
average annual minimum water quantity	m^3/s
- Water quantity of the heaviest flood of the last century	m^3/s
- Duty water	m^3/s
- Obliged minimum utilized water quantity	m^3/s
- Lay out water quantity	m^3/s
- Net gross-head	m... ÷ m...
- Net delivery-head	m... ÷ m
- Number of units	....

- Are there further power plants to be considered above or below?
- Are measures for navigation to be considered?

8.2.2- Electrical and mechanical data:

- Type of turbine respectively of pump	
- Horizontal / vertical assembly	
- Rated power at the shaft	MW
- Rated speed	U/min
- Rated frequency	Hz
- Rated power of motor / generator at load factor $\cos\varphi =$	MVA

- Moment of inertia
- Cooling: direct
  air/water
  water/water

8.2.3- Electrical data of grid:

- Tension of the high-voltage grid	kV
- Short circuit capacity of the hv-grid	MVA

- Number of power transport lines of the hv-grid
- Indoor or outdoor switchyard
- Number of buses
- Tension of the medium-voltage grid
- Short circuit capacity of the mv-grid
- Number of lines of the mv-grid
- Indoor /outdoor switchgear
- Number of buses
- Earthing system of the neutral point in the different grids
  - insulated
  - rigid earthing
  - low resistance earthing
  - inductive earthing

8.2.4- Water supply

Cooling water

- Where is the intake of the cooling water?

upper reservoir	m^3/h
lower reservoir	m^3/h
ground water	m^3/h
public water supply	m^3/h

- Is a reservoir for cooling water provided
  height above machine ground level capacity m^3
  in common with fire fighting water reservoir?
- Pollution of water due to floating goods
  grit or sand

- Chemical analysis available?
- Is a filtering installation required?
- Water temperature max. °C
  average seasonal deviation (curve)
- Need of water in closed circuit m^3
- Water conditioning device?
- Need of water in open circuit m^3/h
- Where are the pumps for the cooling water to be installed?
- Stand by pumps
- Regulation of cooling water
- Is a further profit of the cooling medium for heating purposes required or possible?
- Are prescriptions for heat exchangers to be respected?

Such as double-tube-coolers, specifications of materials

9. Small Hydro-electric Power Station or Diesel Engine Power Station

Locally existing rivers with greater or lesser head can be used with advantage for local power generation because this kind of generating is uncontestably the cheapest one for the private and the general economy. However, although utilizable water volumes are available at a suitable distance, little can generally be seen of this consequence in the planning of rural power supply in developing countries because mainly diesel generators are installed. The reasons appear to be exaggerated ideas of required planning expense. It is therefore particularly important to show clearly - experience over decades had proved it - that only modest planning work on the basis of their total conception is required for the special operating conditions of small hydro-electric power stations in developing countries and this work is generally supported by the manufacturers of the turbine plant.

In many cases it is more important to decide how decentralized rural regions can be supplied with energy - for instance small hydro-electric power stations and generator plants for the gasification of vegetable matter could be used. They operate in island - operation without connexion to the large network and utilize locally available energy carriers by an adapted technology : from water to rice husks.

A main problem of rural development today is the existing energy deficit of the developing countries combined with massed concentration of the existing energy at relatively few sites of industrial production and towns.
The preponderant part of all energy consuming heavy work is carried out in these rural areas by humans and animals.

Diesel generating plants certainly have advantages, such as independence of site, simple operating buildings, no time consuming preplanning, lower investment costs and relatively rapid startup so that diesel power stations have the attributes of quick and cheap erection. In comparative investment planning the economics alone should be used as criterion and then all arguments are in favour of using a small hydro-electric power station, particularly because the precarious diesel fuel supply situation and availability of foreign exchange in developing countries have already caused power switchoffs and production shutdowns of diesel power stations.

Further advantages are the trouble-free operation combined with simplest maintenance and lowest spare part requirements and the long life of 30 -- 40 years with fully automatic operation without permanent operating personnel.

The small hydro-electric power stations designed for the special operating conditions in rural development areas operate economically and are simple to maintain and supervise.

The superiority with regard to costs and operating economy over the diesel power station is, however, mainly due to the utilization without costs of water as energy carrier which is only utilized and not consumed. Quantification of this advantage results only from an economic comparison in the individual case. To the costs of the machines of the water power installation must be added those of the locally necessary hydraulic structures which greatly fluctuate according to the local situation so that experience has shown that total costs of a small hydro-electric power station may be between double to maximum four times the value of the machinery equipment. There are, on the other hand, the relatively high continuous operating costs of diesel aggregates which are also subject to the most different factors.

10. Conclusion

The report on small hydro-electric power plants concludes with the following remarks :

10.1 - The basic idea is to develop the backward regions by supplying electricity for agro/forest industries, plantations; isolated camps; generate higher income; bring prosperity; better living conditions; and create employment opportunities.

10.2 - In order to achieve the goals of point 1, above, one must supply energy by means of most economical methods.

This is possible by installation of small hydel sets which have been proved to be the most economical resources of energy in the long run.

10.3 - Unlike costly consumables like coal and oil, water is perpetually available, although it's full potential is untapped. Hydel sets achieve this by effective and efficient conversion of even limited hydraulic potential into electrical energy.

10.4 - Hydro-electric power plants offer several benefits in many ways. Efficiency is one factor. Running cost another. Although the initial investment may appear to be slightly high (only in comparative terms), the running cost of a small hydel set is almost negligible. Easy maintenance is the third factor and freedom from pollution yet another. No fire hazards. No dependence on fuel and it's depot.

10.5 - Diesel generating sets have a high initial capital cost and face the recurrent problems of transportation and storage of fuel.

10.6 - Substitution of imported electric current and of imported fuels by using the energy resources, will certainly strengthen the economic strength of the country.

10.7 - Diesel-electric plants are best utilized in areas where no other supply system is available - in remote harbours or islands, for example - or where there is a short-term demand for large quantities of energy.

11. Recommendation

Seeing the needs and advantages for installing small hydro-electric power plants, here below are the author's recommendations :

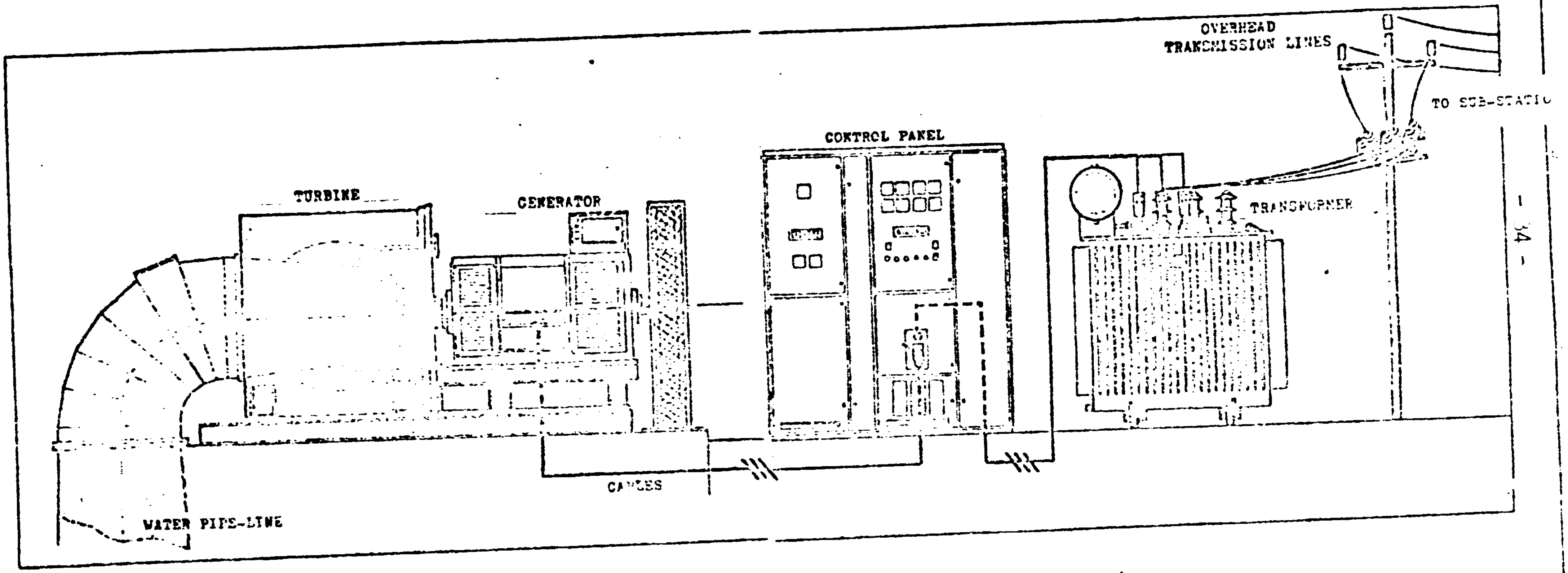
11.1 - Top priority should be given by the developing countries for installation of small hydro power plants (micro-hydel sets) ranging from 25 KW to 100 KW capacity - for the intial rural uplift programmes.

11.2 - Proper survey should be carried out on all available rivers, streams and canals for the possibilities of installing small hydro-electric power plants, ranging above 100 KW capacity.

11.3 - Standardization of a complete small hydro-electric power plant is extremely essential - (i) to reduce the cost of power generation and (ii) to make the planning, designing and implementation of the projects easier.
For instance 'falls' should be standardized on canals which would enable standardization of equipment and civil works. Irrigation canals, if provided with standard drops (to effect standardization in equipment for cost reduction), will prove a great boon to rural areas in many parts of the world.

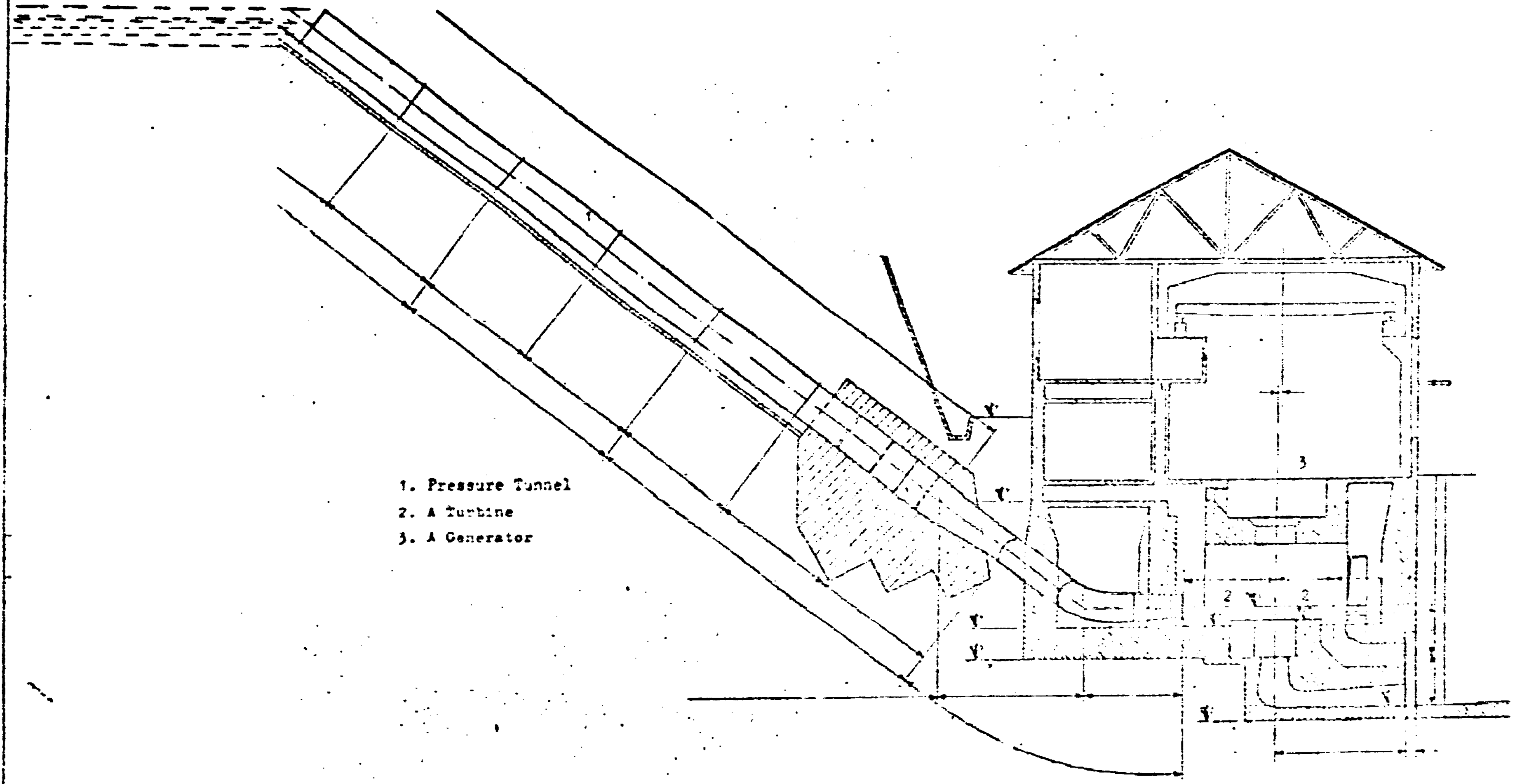
Appendix No.1

MAJOR EQUIPMENT
FOR A
HYDRO-ELECTRIC POWER PLANT



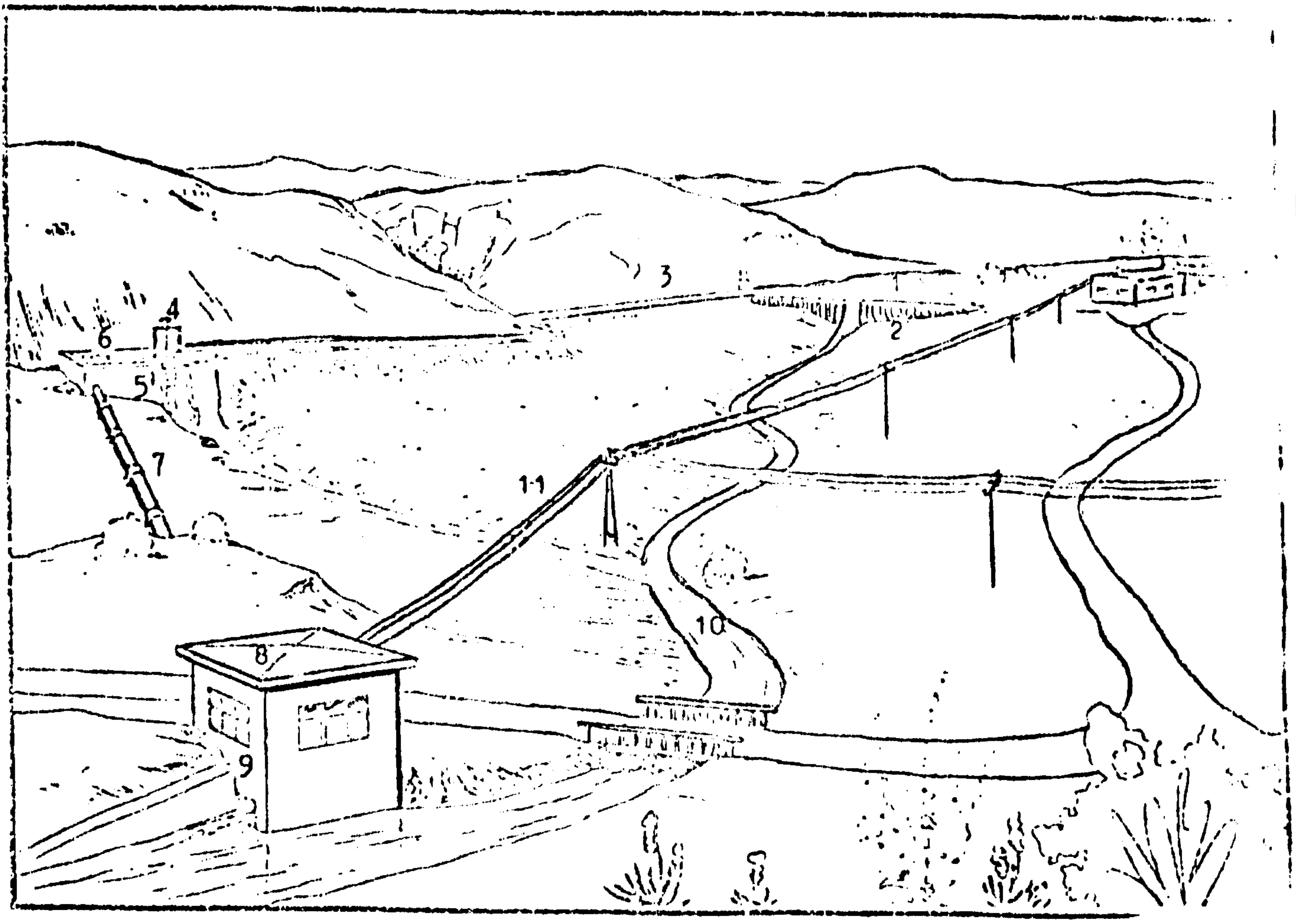
Appendix No.2

GENERAL VIEW OF A HYDRO-POWER STATION



Appendix No.3

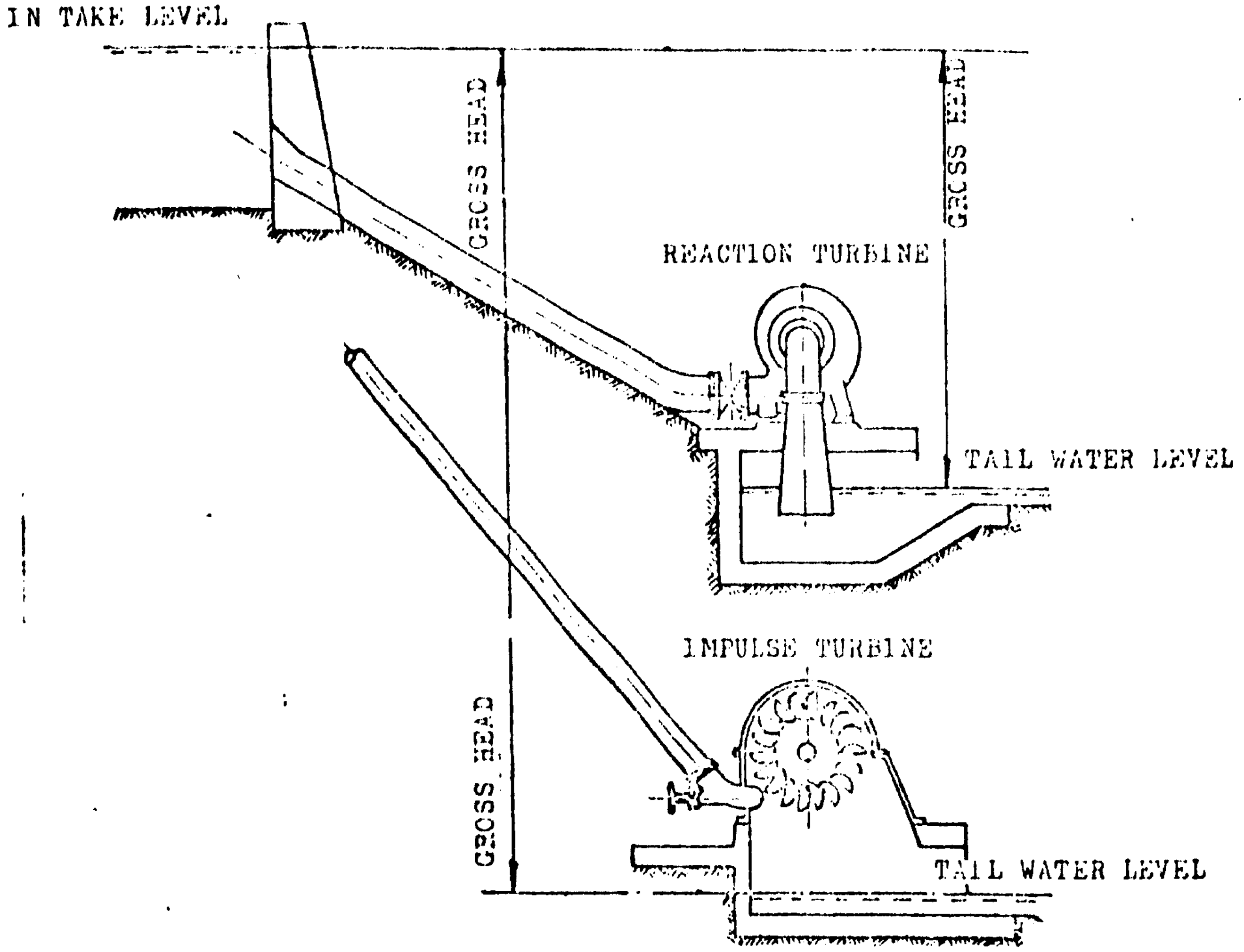
VIEW OF A SMALL HYDRO-ELECTRIC POWER PLANT



1 Reservoir
2 Dam
3 Inlet channel
4 Control gate
5 Surge chamber
6 Retaining grate
7 Pressure pipe-line
8 Power station
9 Turbine outlet
10 Bed of stream
11 Electrical transmission line

EV-Nr.:	Gezeichnet			View of a small Hydro- -electric Power Plant
Arb.-Nr.:	Geprüft			
Kunde:	Sachbearbeiter			
Anlage:	Gesehen			

Form 300



MEASUREMENT OF GROSS HEAD IN -

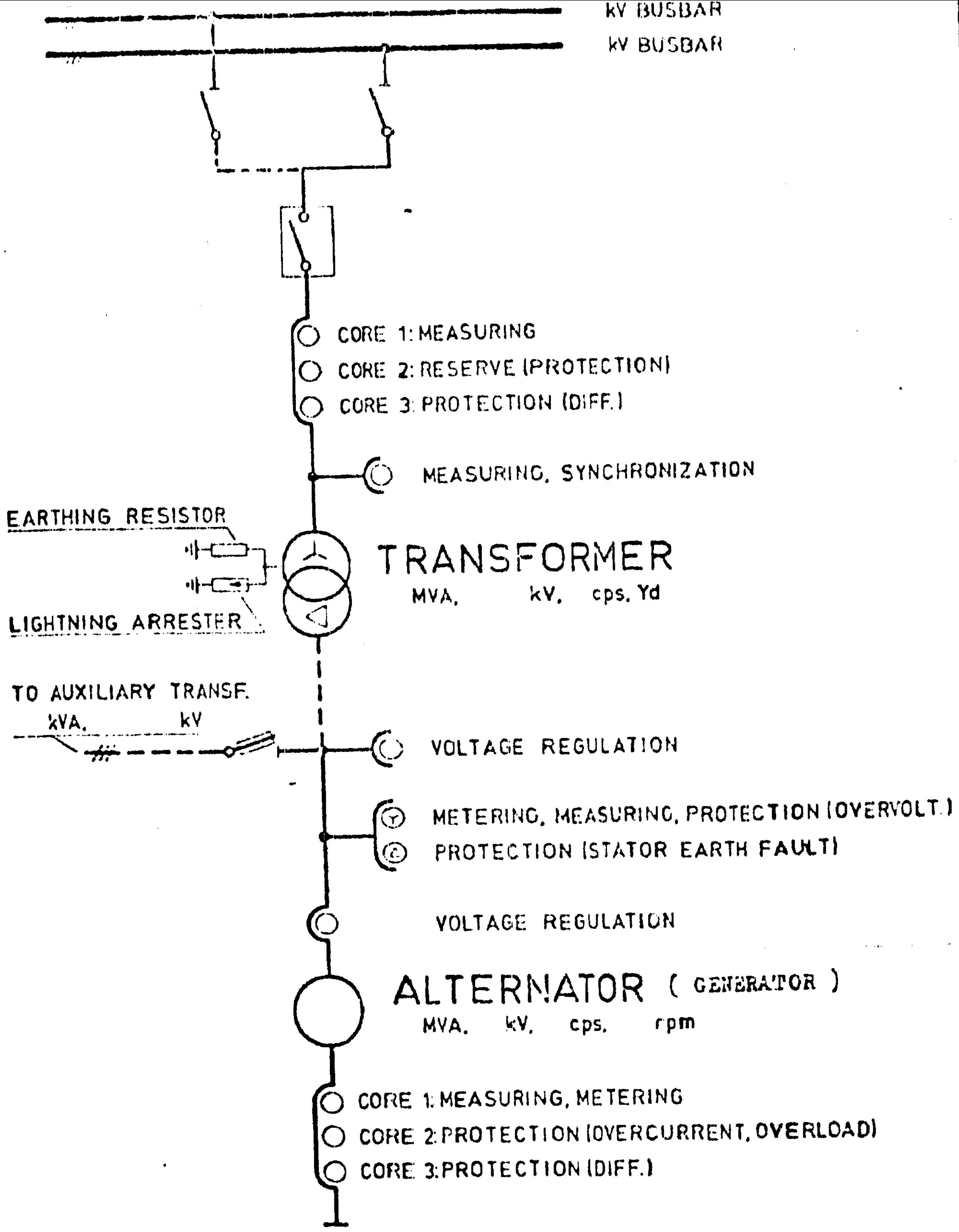
1 REACTION TURBINE

2 IMPULSE TURBINE

INSTALLATIONS

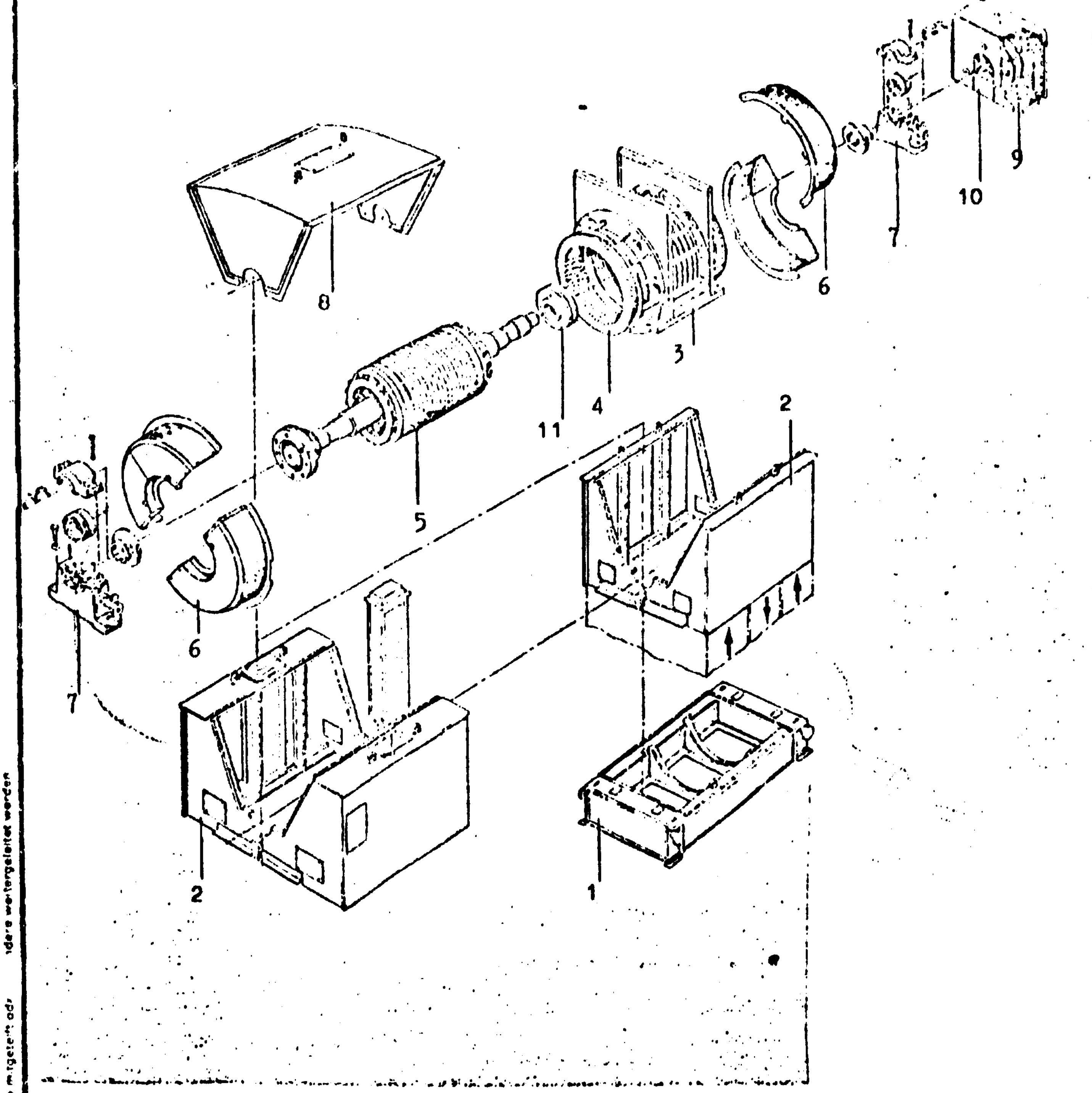
EV-Nr.:	Gezeichnet			MEASUREMENT OF GROSS HEAD IN REACTION AND IMPULSE TURBINE INSTALLATIONS
Arb.-Nr.:	Geprüft			
Kunde:	Sachbearbeiter			
Anlage:	Gesehen			

Form 500



SINGLE-LINE DIAGRAM

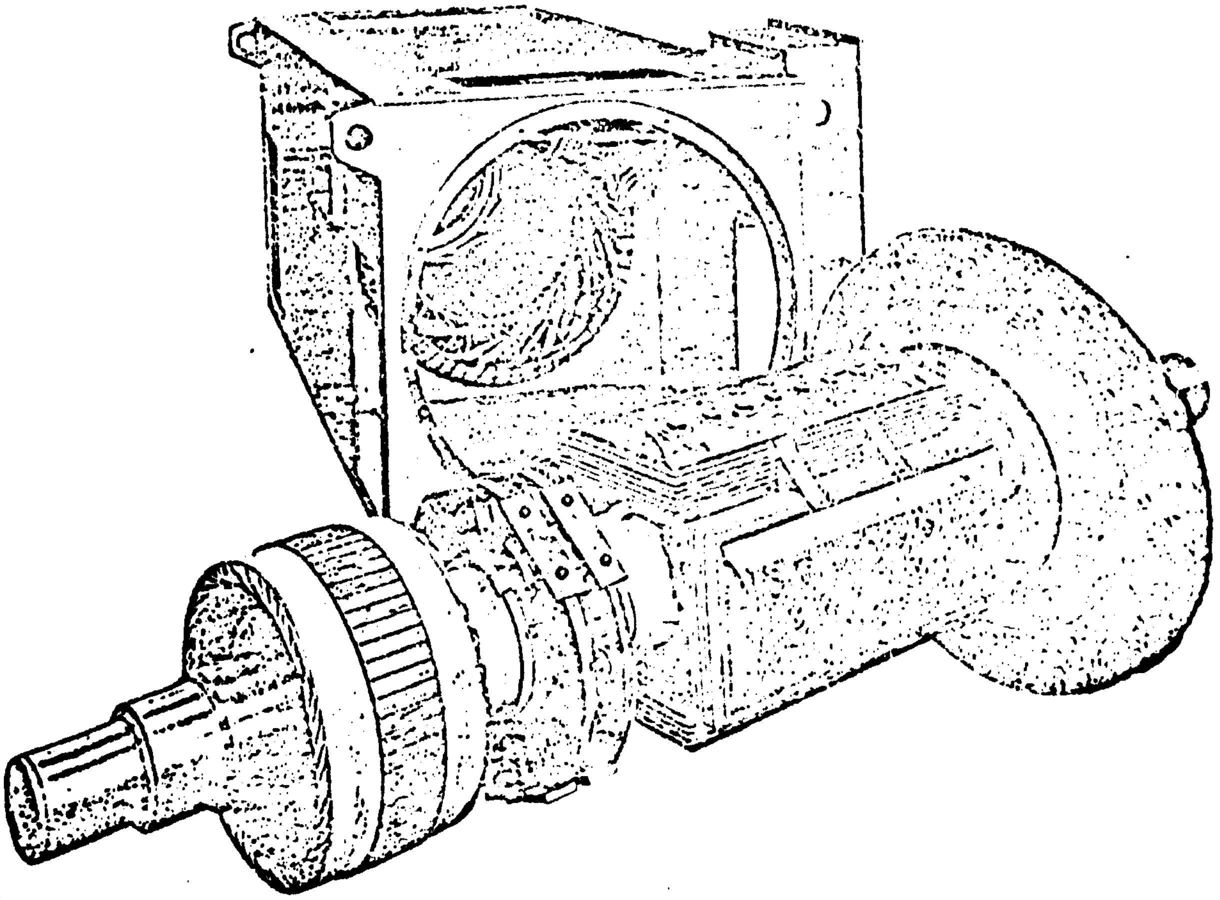
Appendix No.6



1	**Baseframe**
2	**Lateral walls of enclosure and cradle base**
3	**Stator**
4	Stator winding
5	Rotor
6	Winding shield
7	Pedestal-type sleeve bearing
8	Top cover
9	Brushgear
10	Slipring enclosure
11	Sliprings

EV-Nr.:	Gezeichnet			**EXPLODED VIEW OF A GENERATOR**
Arb.-Nr.:	Geprüft			
Kunde:	Sachbearbeiter			
Anlage:	Gesehen			

Form 308

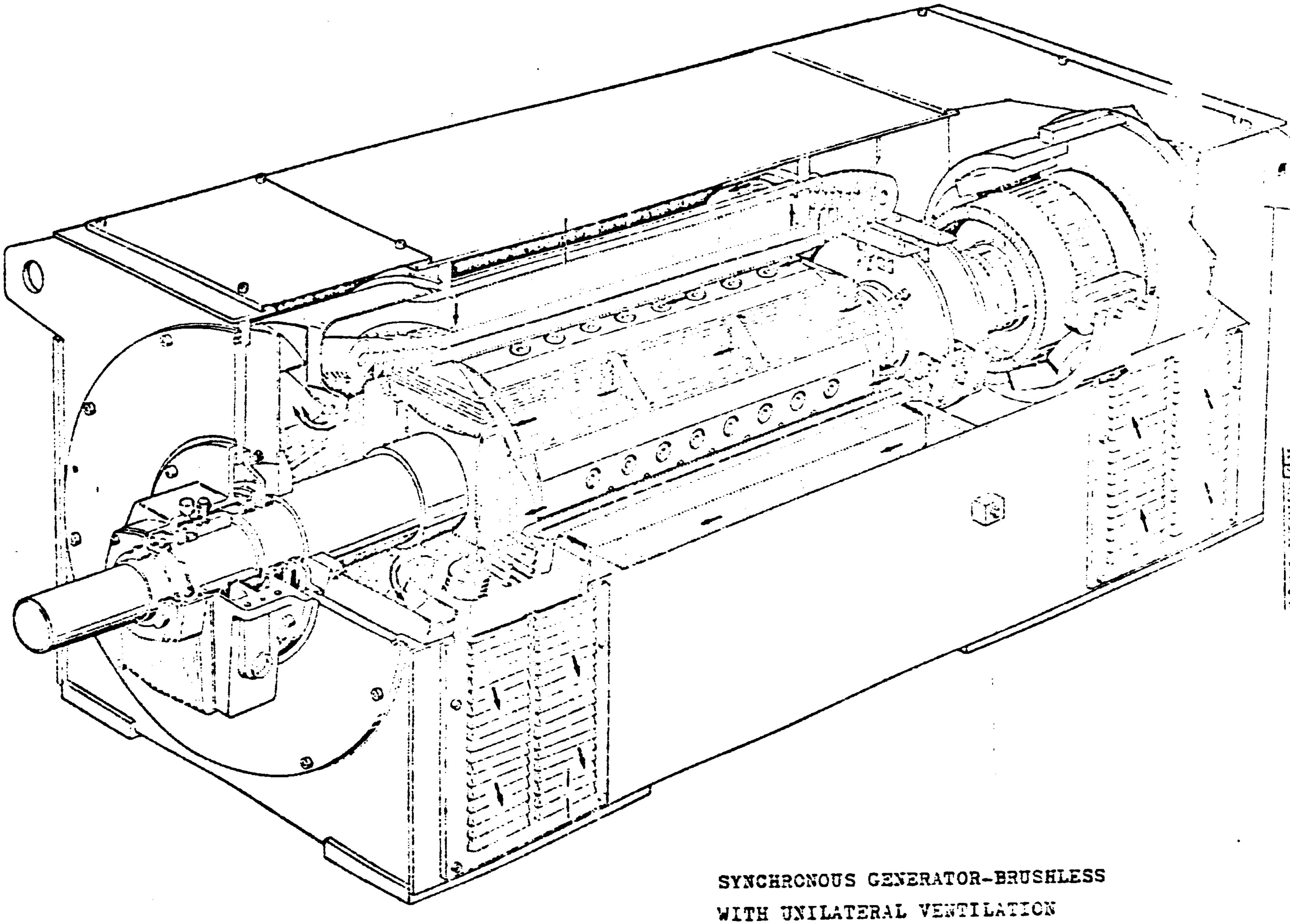


SYNCHRONOUS GENERATOR

VIEW OF ROTOR WITHDRAWN FROM STATOR

EV-Nr.:	Gezeichnet			
Arb.-Nr.:	Geprüft			
Kunde:	Sachbearbeiter			
Anlage:	Gesehen			

Form J08



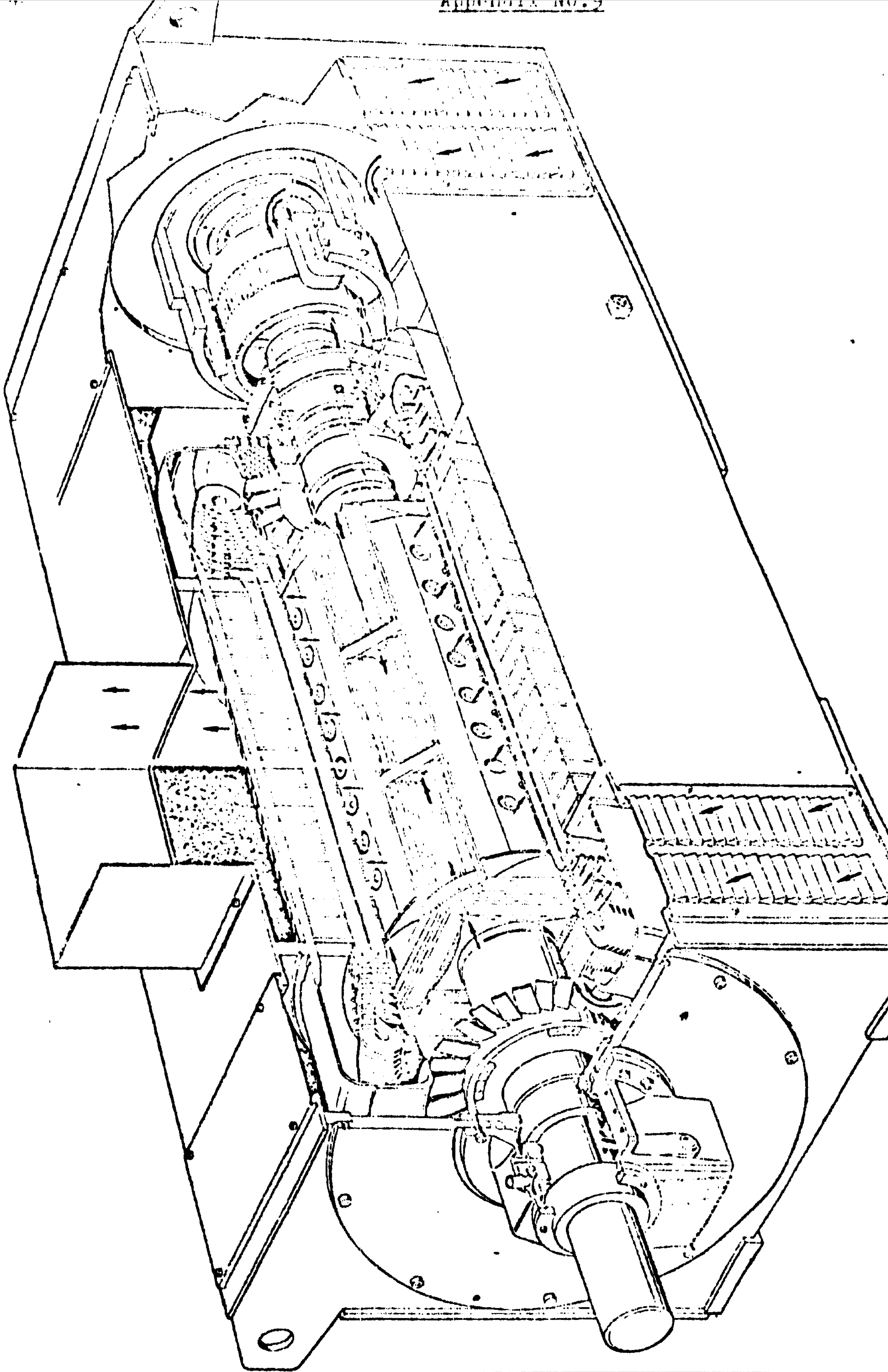
SYNCHRONOUS GENERATOR-BRUSHLESS
WITH UNILATERAL VENTILATION

Diese Zeichnung darf im Sinne der §§ 11 und 12 des Gesetzes über den unlauteren Wettbewerb (BG) weder unbefugt verwertet noch kopiert, anderen mitgeteilt od. dere weitergeleitet werden.

EV-Nr.: Arb.-Nr.: Kunde: Anlage:	Gezeichnet			
	Geprüft			
	Sachbearbeiter			
	Gesehen			

Form 308

Appendix No.5



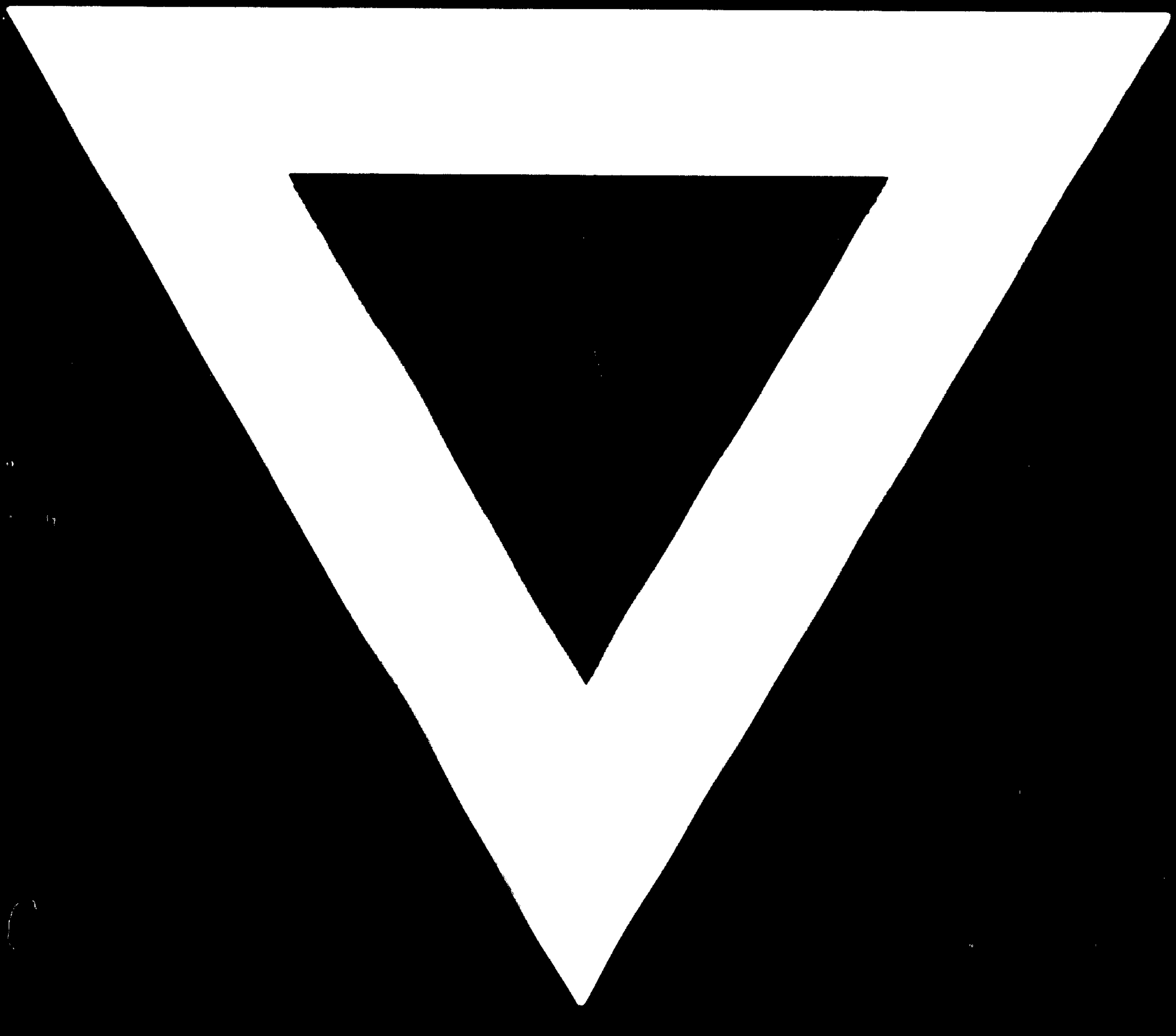
SYNCHRONOUS GENERATOR- BRUSHLESS

WITH BILATERAL VENTILATION

EV-Nr.: Arb.-Nr.: Kunde: Anlage:	Gezeichnet		
	Geprüft		
	Sachbearbeiter		
	Gesehen		

Form 308

I-624



81.10.20