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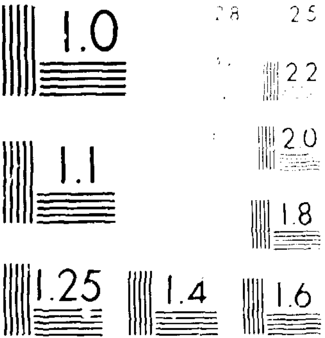
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Distr.
LIMITED

ID/WG.329/36
10 September 1981
ENGLISH

United Nations Industrial Development Organization

Second Seminar-Workshop/Study Tour in the Development and Application of Technology for Mini-Hydro Power Generation (MHG)

Hangzhou, China, 17 October - 2 November 1980

Manila, Philippines, 3 - 8 November 1980

SMALL SCALE HYDROELECTRIC POWER TECHNOLOGY*

by

Norwegian Water Resources
and Electricity Board**

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** Oslo 1, Norway, February 1980.

V. 81-29620

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SMALL SCALE HYDROELECTRIC POWER TECHNOLOGY

(Norwegian report to the UNIPEDE expert group on small hydro power)

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1. INTRODUCTION

The history of Norwegian hydro-power in the meaning of electricity generation began one hundred years ago. The first very small units were established for supplying electric light, and were built and utilized by private enterprises.

Although there were few power-plants constructed up to the turn of the century, this period has a particular place in the Norwegian electrification history. The construction of hydro-power plants during this period was mainly undertaken by mining- and papermill companies, and formed an important origin for the further development of industry in the country. Beside supplying electricity to the factories, the surrounding communities were provided with electric light.

During the period from 1900 up to 1940, a large number of power-plants were constructed. All of these were basically operating on limited local grids.

Out of a total number of 2,009 powerstations (2,300 MW) in 1944, altogether 1,463 stations, or 73 % of the total number, had a generating capacity of less than 100 kW. However, the total output from these 1,463 stations was only 1.6 % of the total generating capacity.

After 1945 a boom regarding development of large plants started. A countrywide development of a high voltage transmission line system began, and successively the small local powerstations became too expensive and unreliable to keep in operation compared to the safe and abundant supply from the new system. Most of the small powerstations were therefore closed, or they were included in the development of bigger schemes.

In 1979 a total number of about 680 water-power stations, with a total capacity of 17,540 MW, were in operation. These stations provide more than 99 % of the country's electricity production today. Out of 1,818 stations with a capacity less than 1 MW in 1944, only 250 still were in operation in 1979.

Up to 1976 little attention has been paid to the small units of hydro-power potensials, mainly because of an abundant supply of cheap electricty. However, as development of new large schemes are facing a growing resistance from groups of people and various organizations, it has become more and more difficult to find new schemes for providing sufficent electricity. Therefore the small potentials again are in focus, and at present a countrywide investigation is going on for registration of the small hydro-power potensials. During 1979 a registration of about 500 power-plants, ranging between 300 kW and 10,000 kW was carried out. The total energy output from these plants amounts to approximately 5 TWh mean annual production, which is 7 % of the hydro-electric potential already developed in the country. The cost limit for economic feasible power-plants is assessed to an investment of 0,40 US $ per kWh annual production (cost level 1979).

The articles in this paper intend to give an outline of modern Norwegian technology regarding design, development and operation of small scale hydroelectric power-plants.

2. CIVIL AND STRUCTURAL PART

2.1 Nature of design problems

The civil and structural engineering problems to be dealt with include:

- Rehabilitation of old power stations, dams, intakes and waterways, where condition permits
- Rebuilding of old plants beyond repair, where new or replacement structures are required
- Construction of new small hydro projects.

2.2 Dams

A large number of small dams have been built in Norway over the years, both for the purpose of log driving and for the operation of small hydropower plants. Constructed usually from masonry, timber or concrete on a foundation of bedrock, design and construction was based on long experience. Many dams exist even today and may with some expense be made serviceable and used for new small hydro installations.

Embankments have become the most common type of small dams in recent years. Construction of embankments requires new design concepts in comparison to those used previously, with emphasis placed on the risks for erosion resulting from seepage through the dam, or through its foundation in case the dam is placed on soil.

Government regulations giving detailed specifications for the design of dams causing more than 4 m depth of inundation and storage exceeding 500 000 m^3, are presently being issued. Guidelines for the design, construction and maintenance of smaller dams are also being prepared.

2.3 Power conduit

The separate falls of any major watercourse, if situated reasonably near each other, are normally developed jointly in one power station. It is on the other hand considered good economy to develop the falls of a small river separately, thereby saving long, costly waterways such as tunnels. Penstocks of short or moderate lengths are often the best solution for small hydro plants.

2.3.1 Types of penstocks

The materials available are steel, wood and fiberglass-reinforced polyester. Bored-and-reamed conduits in rock are another alternative.

For heads greater than 50-75 m the only possibility until recently, was steel penstocks, "tailor-made" from welded steel plates. This is an expensive solution.

Mass produced steel pipe of standard diameters may be considered as an alternative. These pipes are available also for high heads, and cost less than half of the conventional steel penstock. Mass produced standard bifurcations and transitions are also available, and may be factory-delivered with corrosion protection.

The wood penstock is an old and well-known type of conduit with numerous good points. It requires a minimum of levelling and foundation work, and may undulate through rugged terrain with a curve radius of as little as 60 times the pipe diameter. The smooth pipe invert ensures low friction losses. If manufactured from quality materials and assembled professionally, these penstocks will normally have a long life. However, since the water pressure is carried by the steel hoops alone, the pipes are economical in comparison with conventional steel penstocks in the range of lower heads only.

Penstocks for heads up to 160 m and dia. 2000 mm can also be made from fiberglass-reinforced polyester pipe (GUP), produced in Norway. This exceeds by far the range of head covered by their closest competitor, the wood pipe. Experience from practical use of GUP-pipe for penstocks is so far very limited. Polyester pipes are probably very durable. They are light and therefore easy to transport. The penstock may be placed in a ditch and covered, or erected on supports above ground. In the latter case the vulnerability to impact gives reason for some concern. Apparently, polyester type penstocks have many advantages, and it may be assumed that any drawbacks appearing will be corrected as experience is gained.

In recent years certain special conduits, generally for the diversion of a creek down to a tunnel below, have been built as bored-and-reamed holes. Such conduits are rather costly, even under the best of rock conditions. Nevertheless, the solution is interesting and should be looked into as an alternative to the more conventional type of penstock.

2.4 Power house

Arrangement and design of a power house is largely governed by the type and the position of the turbine, together with the chosen standard of building and equipment. A few examples will be given, out of the great variety of existing solutions.

2.4.1 Mago C and Mago D

Figs. 2.1 and 2.2 show these two small hydro stations, recently rebuilt, and both situated on the river Andelven near the south shore of Lake Mjøsa.

In Mago C a horizontal propeller turbine was installed in 1978. Here the conventional power house crane was left out, and the heavy lifts were taken by a mobile crane placed adjacent to the building. With a view to future maintenance work, the roofing is made from elements of light aggregate concrete, easily detachable. This principle of leaving out the crane is widely acknowledged for small hydro stations.

Mago D, built in 1979, has a vertical Francis runner and a fixed power house roof. The power house is designed so that a truck can be backed a few meters inside the doorway and positioned under a crane girder equipped with a mobile electric hoist. This is an inexpensive arrangement, and for operational purposes preferable to the system described above.

The costs of the civil and structural works at Mago C and D contributed 30 % and 35 % respectively to the total investment. The superstructures alone accounted for no more than 6 % of the total investment.

These new small hydro plants represent two types of low-head installations that may become quite common in the future:

- The one with a horizontal propeller in a steel encased waterway equipped with a butterfly valve
- The other with a vertical propeller or Francis runner placed in an open tank with a gate as closure device.

Draft tubes of conventional type have been provided for both alternatives. Where Francis runners are to be used, it may be possible to replace this somewhat complicated draft tube configuration with a straight funnel without seriously affecting the turbine efficiency. An example of a simplified draft tube is shown in Fig. 2.3, a scheme on the river Rakkestadelven, where a 200 m long penstock will be included, and where the civil and structural cost in calculated to be 40 % of the total investment.

2.4.2 The Flatenfoss Extension Scheme

Situated on the river Nidelven near the city of Arendal, the work with a new power station is now in progress. Competetive offers for the new installation, a 5,5 MW unit at 10 m head and 60 m^3/sec, resulted in a horizontal tubular turbine, a solution approximately 20 % lower in total cost than one with a vertical Kaplan unit, see Fig. 2.4.

2.4.3 Exploitation of power potencials at regulating dams and in diversion tunnels

Many existing regulating dams have unexploited heads that could be utilized through small hydro installations. Particularily where new dams are planned it is useful to bear this idea in mind.

Also, where excess head is available in a diversion tunnel or a transfer tunnel, a small hydro plant may be the answer. The annual power production from a scheme of this type which was looked into was estimated at 9 GWh, and the total investment at 20 mill. kr. This gives a relatively high power price.

2.4.4 Standardization

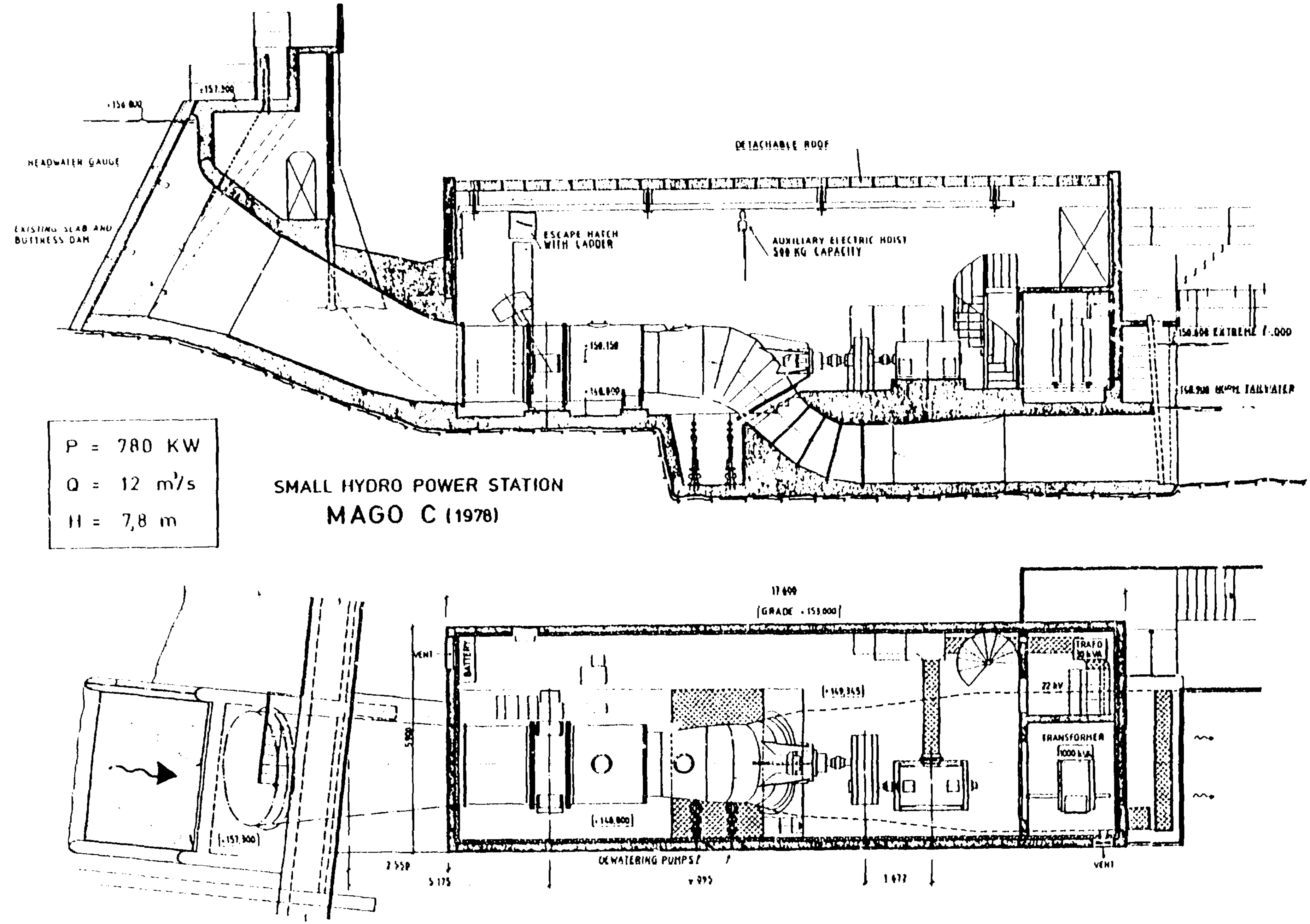
Provided that the range of turbine solutions could be limited, it should be possible to present main layouts and designs for the power houses corresponding to these solutions. This could lead to a less time-consuming civil engineering contribution, i.e. saving of man-hours in the design stage.

For certain, limited parts of th power station, such as the superstructure, standardized features may be introduced in the future. In all other respects, however, the design will have to adapt to the local conditions, such as topography, head- and tailwater levels, design floods etc.

2.5 Hydrology. Operation method.

Small hydropower developments often refer to small watersheds where no direct gauge reading of the flow exist. The runoff, therefore, will have to be estimated on the basis of readings from adjacent, larger watersheds. Attention should here be given to the fact that the runoff from small watersheds is subject to more rapid and larger fluctations from the mean flow. Unless the runoff data are adjusted accordingly, the estimated production will be too high and in some cases misleading.

Intermittent service, i.e. the station starts and stops operating according to the availability of water, may be desirable where turbine efficiency varies widely with the load. However, this strategy may be unacceptable where the tailrace is a creek with a fish population, or where ice formation may result.



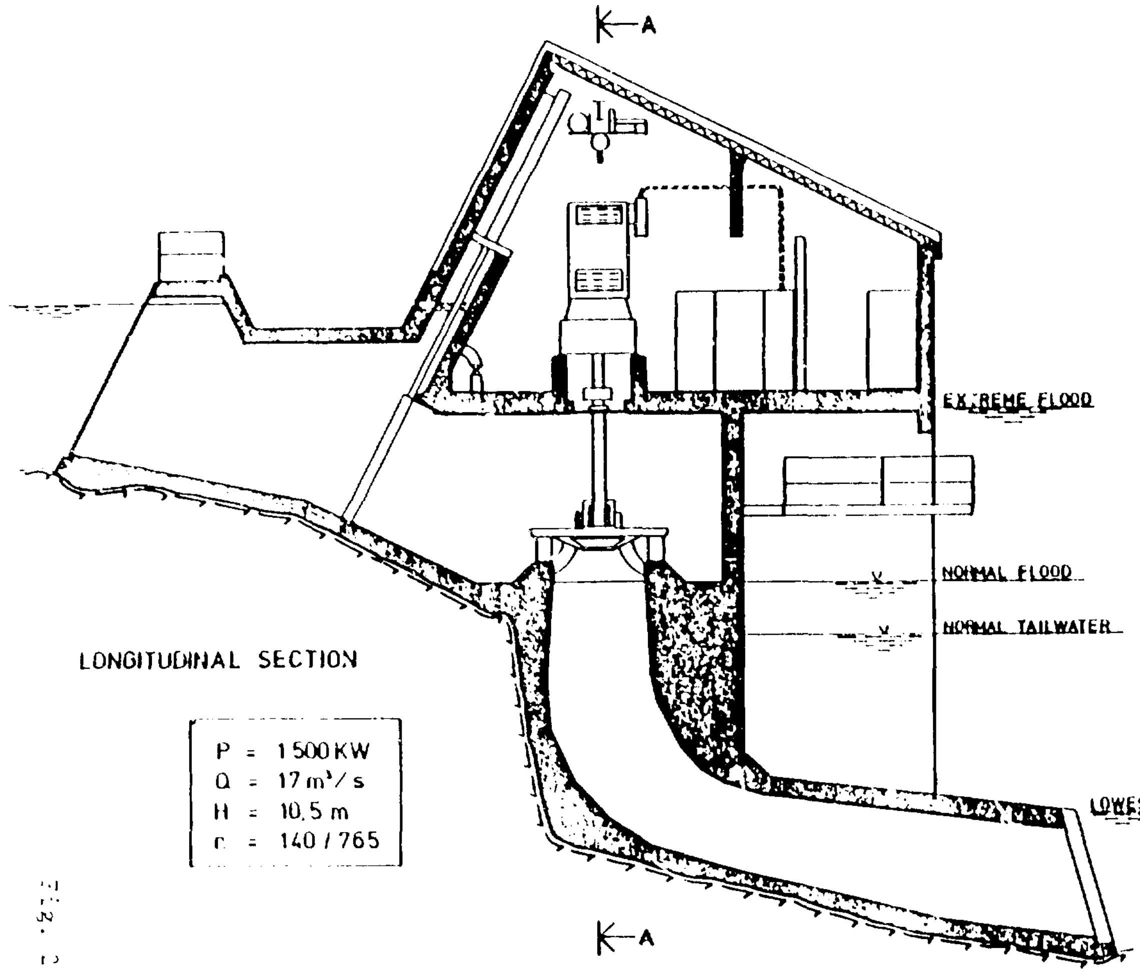
P = 780 KW

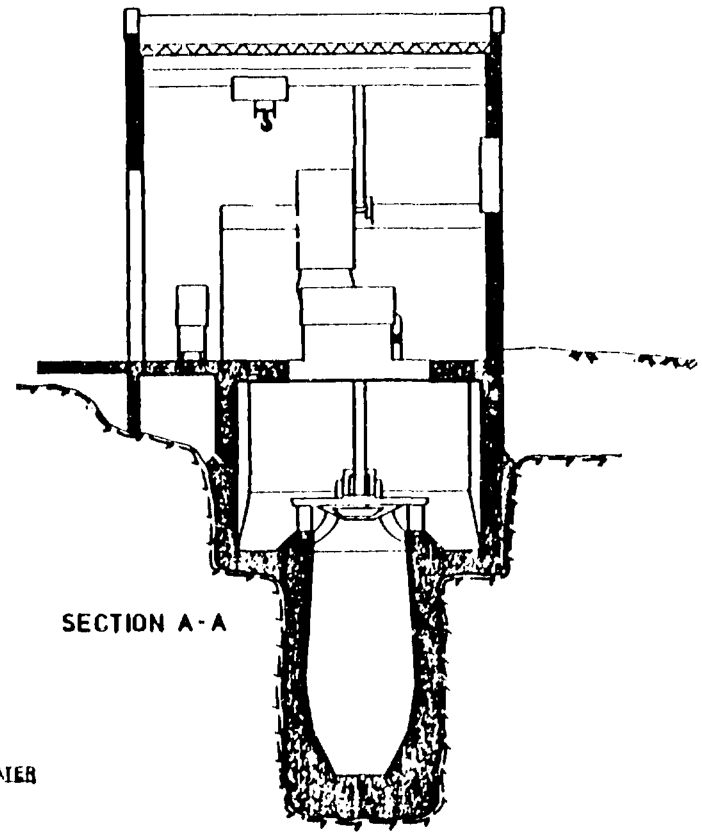
Q = 12 m^3/s

H = 7,8 m

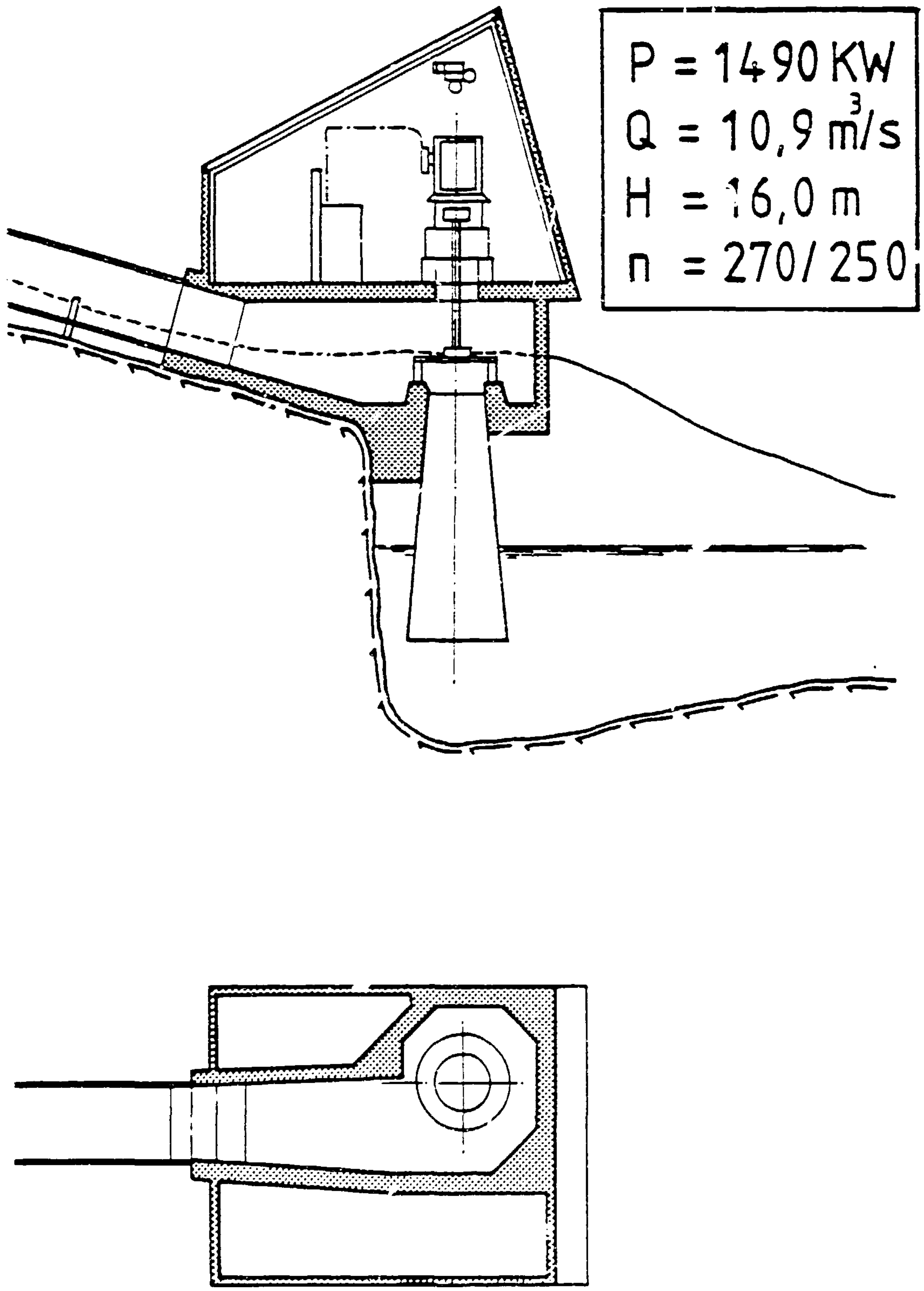
SMALL HYDRO POWER STATION

MAGO C (1978)





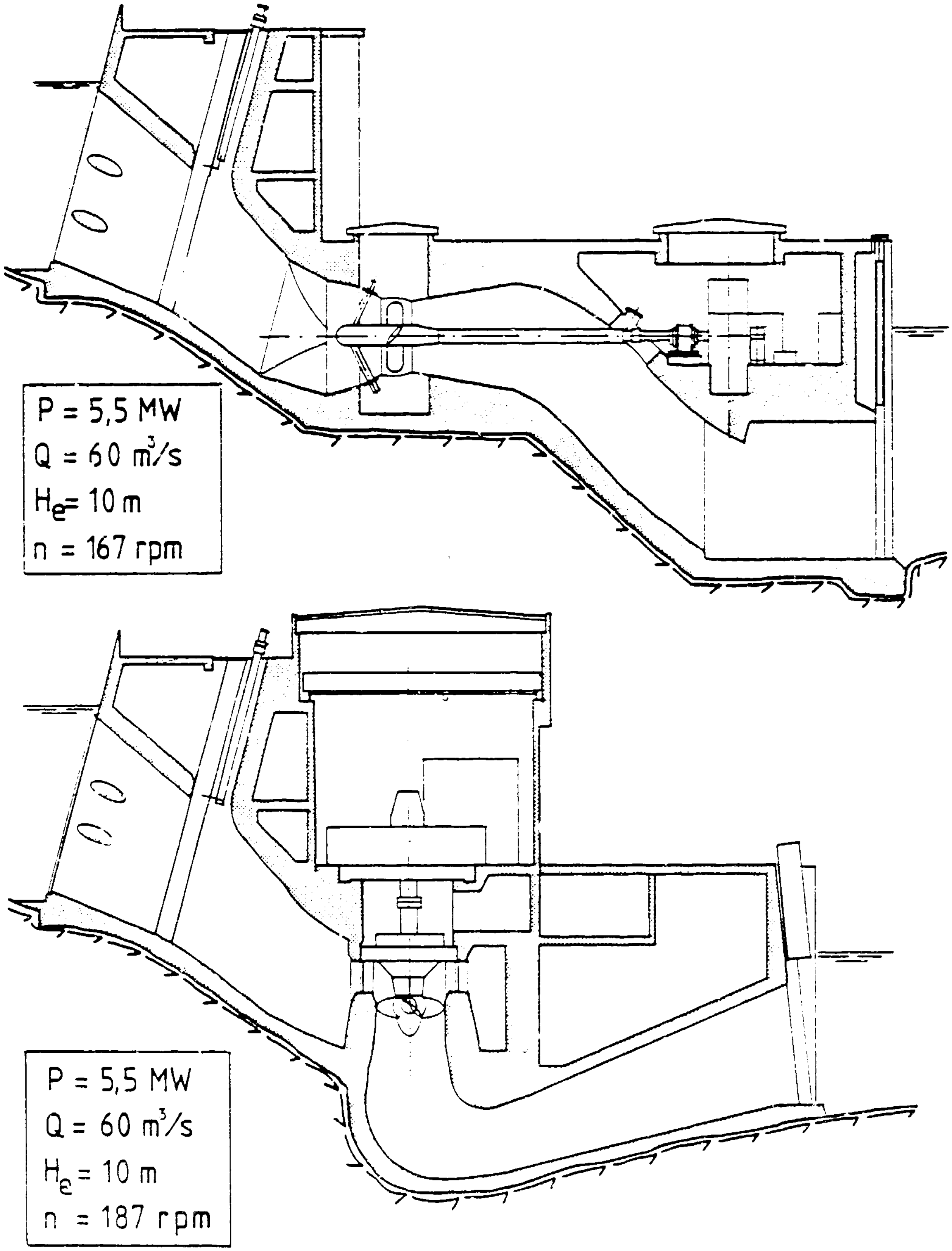
SMALL HYDRO POWER STATION
MAGO D (1979)



SMALL HYDRO POWER STATION

BREKKE (RAKKESTADELVEN SCHEME)

Fig. 2.3



SMALL HYDRO POWER STATION
FLATENFOSS (1981)

Fig. 2.4

3. HYDRO POWER TURBINES - TECHNICAL EVOLUTION AND STANDARDIZING

Most suppliers of hydro turbines were in fact established last century. To begin with, they produced small-sized turbines, which gradually developed into the large units produced today for outputs up to several hundred MW per unit. This increase of size was primarily a result of a growing demand for low cost electricity to consumers. This is made possible through the large water power plants. Therefore, the demand for small sized units has been minimal during the last 20 years, and consequently, the technical evolution in this field stagnated.

However, shortage of energy has now made the small-sized units an interesting alternative, provided that they are able to compete successfully with other forms of energy, such as oil, coal, nuclear power etc. Redevelopment has, however, been necessary. It is neither sufficient nor possible just to down-scale the dimensions of a large turbine. This would result in high priced and inappropriate solutions. By analysing the cost-affecting factors, it has been found necessary to:

- Reconsider mode of operation
- Simplify and standardize the design
- Use stanardized components.

The most common types of turbines are the Francis, Pelton, Kaplan and tubular turbines. The Kaplan turbine and the tubular turbine are suitable for low heads and heavy discharge, while the Pelton turbine is used for high heads and relatively modest discharge. The area inbetween is covered by the Francis alternatives. The abovementioned types are all well suited for simplified mode of operation as described below:

3.1 Constant water flow/output through turbine

In cases of parallell operation of power stations where other units keep a constant frequency, the turbine can be designed with fixed guiding apparatus, and also fixed runner vanes on the Kaplan and tubular version. The unit is regulated only by the main valve in front of the turbine. This is also used for parallelling to the grid. After parallelling, the valve will be in open position. It is impossible to operate on partial load. However, it is to some extent possible to regulate a variable waterflow if the power plant is provided with an intake reservoir of adequate capacity and the pond level is allowed to vary between certain limits. The turbine is operated for a certain period of time on full-load, while the water level falls until it reaches a determined level, at which time the machine will stop. When the maximum level is resumed, the machine will start. This cyclus can be automized. Thus you will save the costs for adjustable guide apparatus, frequency governor and supplementary flywheel effect. Compared to a conventional turbine, the savings will represent approximately 25-30 %, depending on the type of turbine involved.

3.2 Variable water flow/output through turbine

If it is required to adjust the water flow through the turbine, it must be equipped with adjustable guiding apparatus, which is controlled by a simple oil-hydraulic unit. This is suitable for control of intake reservoir and remote load control. It will reduce the costs for frequency governor as well as supplementary flywheel effect. In some cases it will also eliminate the costs of safety valve and surge chamber.

This presupposes employment within a large grid system. Further, it must be ascertained that there will not be an unacceptable pressure rise as a result of the fact that this simplification (low flywheel effect) in most cases will entail runaway speed of the turbine at load rejection. When this alternative is suitable, it will represent a cost reduction of 10-20 % compared to a conventional turbine.

3.3 Variable power take-off from generator

When operating either periodically or continually on a separate network, the stability of the system must be considered. As a minimum the turbine will have to be equipped with a frequency governor of electro-hydraulic or mechanical-hydraulic construction. Considering the amount of maintenance involved, the mechanical-hydraulic type will often be preferred, but this is also very much dependent upon the competence level of the staff responsible for operation and maintenance of the equipment.

Usually, it is necessary to have more supplementary flywheel effect than what is built in by natural means in generator and turbine runner. Pelton turbines will normally require water jet deflector. Francis turbines will sometimes require pressure relief valve, Kaplan/tubular turbines will require adjustable runner blades and guide vanes in order to obtain maximum efficiency for a large load range and capability to perform with stability on a separate net.

The above three alternatives have in common the requirement for minimum inspection and maintenance. Consequently, the turbines are equipped with control and safety devices resulting in automatic stop in the event of the more ordinary failures. However, the equipment is not as comprehensive as it will have to be for a large unit where failure consequences will be much more calamitous. Such units are therefore equipped with a much larger number of control devices. Further, the units are normally equipped only for manual start, because the necessary ancillary equipment for the automatic start procedure will represent a considerable increase in price.

3.4 Simplifying and standardizing of design/construction

In order to minimize costs it has been necessary to simplify the design as much as technically possible without reducing the demands for safety of operation and maximum output. It was particularily necessary to use welded details instead of cast details. Today's welding technology and range of material types have strongly contributed to reducing the production costs. It is essential that choice of material quality is made from a maintenance point of view. On a long term basis, it may prove extremely profitable to use stainless steel in some of the vulnerable elements of the construction, even if this will increase the initial costs. Most of the small-sized turbines are designed with horizontal shaft. Today, we do not have turbine shaft or bearing for these turbines, see figure 3.1.

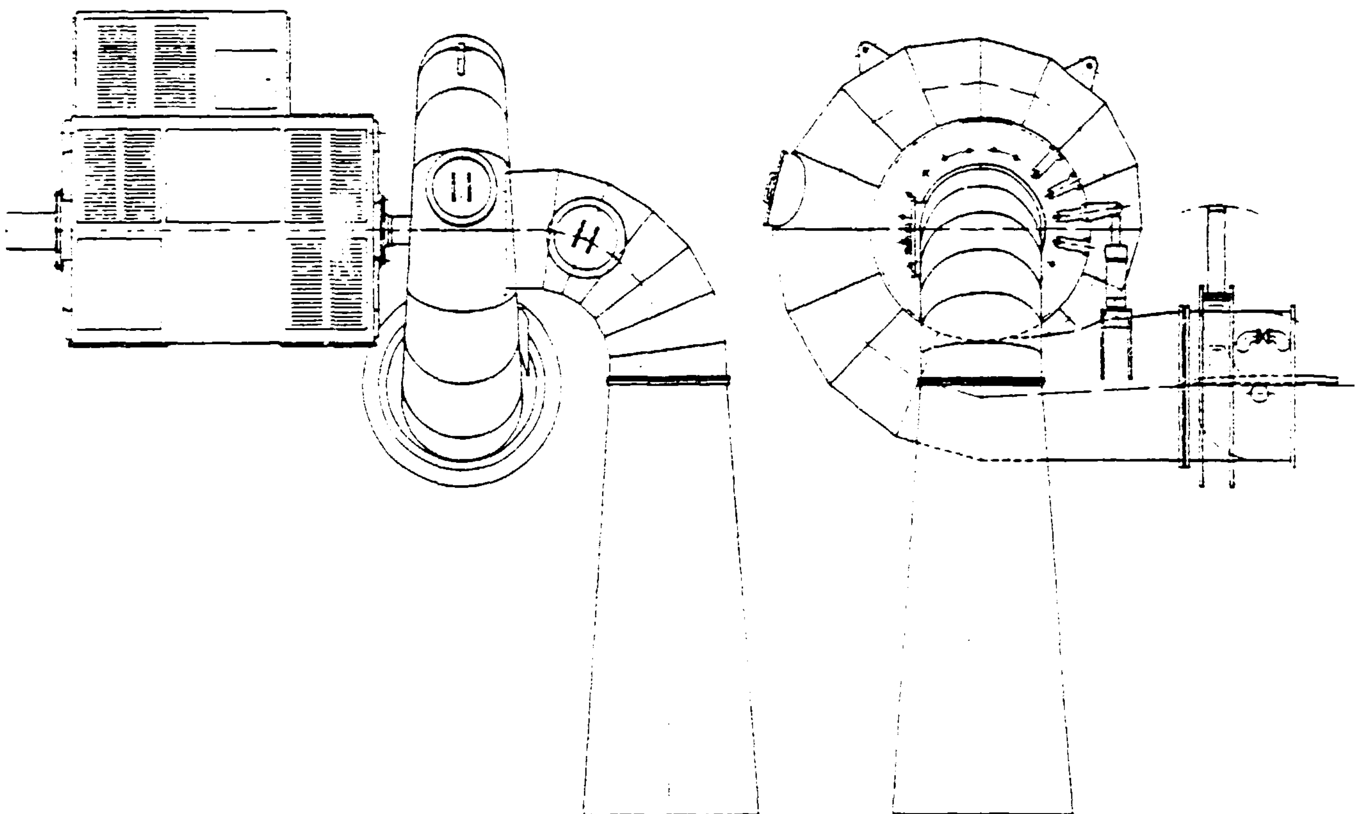


Fig. 3.1

The runner is mounted directly on to the generator shaft by means of a shrinkage joint by the oil pressure method. This simplifies the dismantling and erection, shaft keyways are avoided, thereby reducing the danger of fatigue fractures in the shaft. However, the axial forces of the turbine will have to be absorbed by one of the generator bearings. On the other hand, the unit will have only two bearings. Further, the shaft sealing box is designed so that it does not touch the shaft. Previous grease-lubricated bearings and bushings are today replaced by self-lubricated bushing. If additional flywheel effect is required, a flywheel is mounted on the generator shaft on the opposite side of the generator.

It is further necessary to standardize as much as possible in order to minimize the costs. There are, however, so many factors to be considered when designing hydro turbines that only a certain extent of standardization can be obtained. Apart from head and discharge, revolutions per minute and suction head (for Francis and Kaplan/-tubular turbines) will be essential for the applicability of a given turbine design for various combinations of head and discharges. The efficiency will be considerably reduced if a turbine designed for a specific combination of flow and head is operated under combinations which differ much from the design data.

Units for employment in the 0.1 - 1.0 MW output range, and where the Francis turbine is suitable alternative the turbines are produced in 8 fully standardized sizes. The design of these turbines are shown in fig. 3.2.

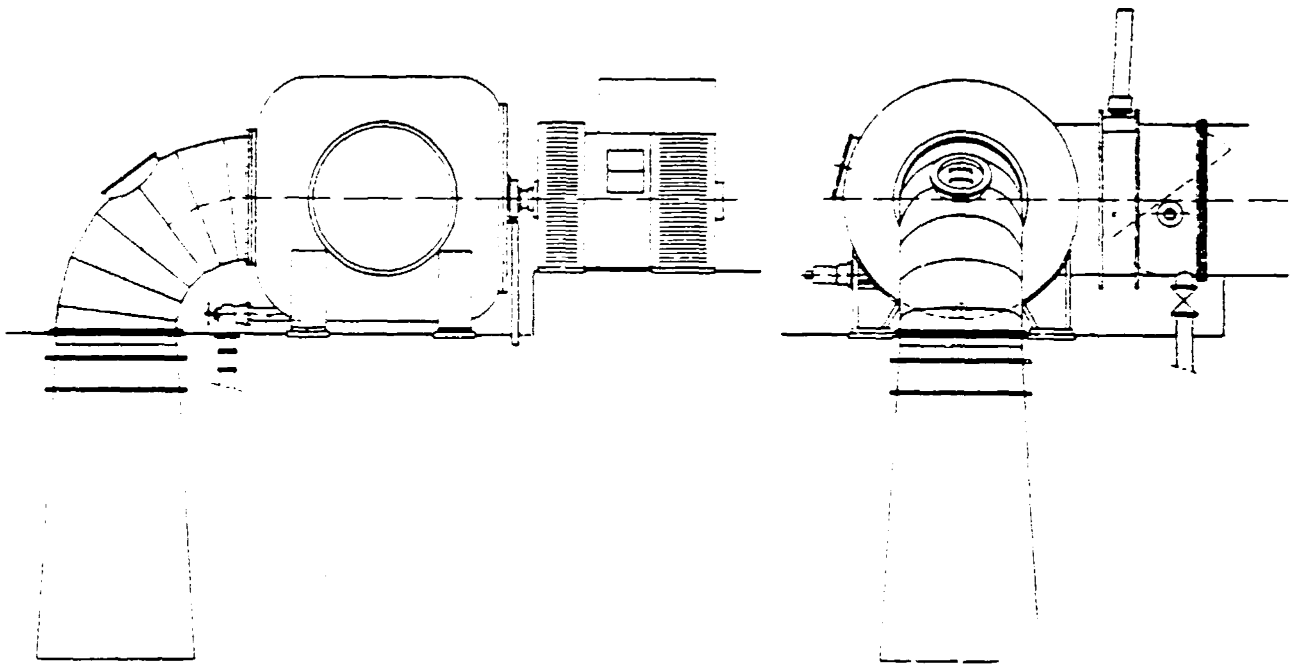


Fig. 3.2

The turbine is installed with the shaft horizontally positioned and the runner is mounted directly on the free end of the generator shaft. Turbines which operate with a low speed allow the employment of a speedreducer between the turbine and generator, thus the price of the generator will be substantially reduced. However, it has to be considered the friction losses effected by the speed reducer.

Our production programme for small scale Francis turbines in the range of 0.5 - 10 MW incorporate 12 different hydraulic configurations, each which represents a specific speed, back of these designs has been standardized, and their scale may be varied as required. Any specific speed inbetween 12 variants can be achieved by minor alternations to the runner, thereby enabling coverage of the whole specific range from 60 to about 350 (specific speed is calculated to turbine output in kW and head in m).

This combination of severe standardization and one-off design has enabled us to reduce costs by as much as 30 to 50 % and still deliver a turbine which is properly suited to the demands of flow, head and speed. A diagram showing the utilization range has been worked out for each of the 12 variants. This is supplemented by such information as output, outlet diameter of runner, speed as well as demands for setting of the turbine for cavitation free performance as a function of flow and net head. The overall dimensions of the turbine can then be expressed as ratios of the runner diameter. Fig. 3.3 shows one of 12 diagrams representing a certain specific speed range.

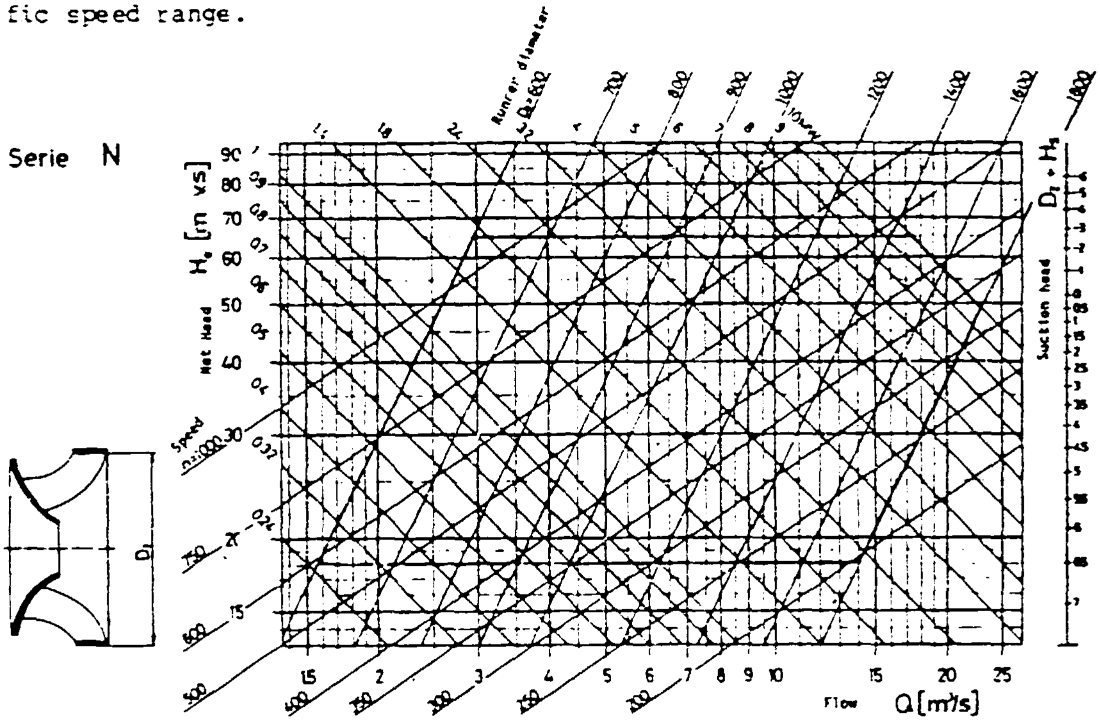


Fig. 3.3

Extensive use of mass produced components is also a cost reducing factor. This will primarily apply to the control system elements. The use of such elements, however, requires previous evaluation and testing. It is of vital importance to ascertain that the often prevailing disadvantageous surroundings (humidity, vibrations, pressure oscillations etc.) will not destroy the functional characteristics of such elements.

Finally, I would like to stress the importance of standardizing the purchase specifications for small-sized hydro units. Large units will normally require detailed specifications. Detailed specifications for small-sized plants will often make it impossible for the suppliers to offer their standard versions. Studying of such specifications and trying to adapt the standard versions that are developed will also be time-consuming and expensive, resulting in an unintentionally high priced solution.

4. ELECTRICAL EQUIPMENT

When designing a small scale hydro-electric power-plant, the economical aspect of the matter must be kept in sight. One design goal is therefore cost reduction in order to make such a power plant economically feasible.

The establishing of the task of a small scale hydro-electric power plant must therefore be part of the design process, and in short this task can be expressed as:

- To produce KWh, under due consideration of minimized maintenance, and the use of operational staff.

This leads to the design philosophy itself, which will be:

- Simplicity
- Standardizacion
- Automation to a certain extent - e.i. unmanned operation but manual starting up
- Remote control should be avoided but is, of course, possible.

4.1 The generators

Since the task of such a power plant is to produce kWh,

- an induction generator with squirrel cage rotor is thus suitable for such a power plant providing that a grid - fed by synchronous generators - is at hand. This is due to the fact that it must draw its magnetizing current from the grid. Voltage regulation is not possible.

The induction generator thus acts as a reactive load on the grid and part of the magnetizing current of the generator may be compensated by means of a condensor battery.

Complete magnetization of an induction generator with a condensor battery is conceivable. Single operation - in any case, with constant output - is thus possible.
However, this is a theoretical aspect.

Careful consideration must be given to the output of the battery, as it may cause undesirable overvoltages during a runaway condition.

However, there will also be occasions where it is desirable to maintain operation of such a plant in the absence of the grid - e.g. for supply to a small local community or industrial plant, necessitating a more costly solution by applying a synchronous generator and speed regulation of the turbine.

Furthermore, the synchronous generator is capable of producing reactive power, and if the grid demands a contribution of reactive power from the small scale hydro-electric power plant, a synchronous generator is the only solution.

A summary of possibilities for the use of synchronous or induction generators is given below.

Type of generator	Suitability	Parallel operation				Single operation			
		a	b	c	d	a	b	c	d
Induction generator	Most suitable	X							
	Very suitable		X						
	Not very suitable					X			
	Unsuitable			X	X		X	X	X
Synch. gen.	Suitable	X	X	X	X	X	X	X	X

a: Operation with constant output
b: Operation with varying output
c: Operation with varying load and constant voltage
d: Operation with varying load and production of reactive power

The summary states that a synchronous generator is suitable for all types of operation, whilst the use of the induction generator is for practical purposes, limited to parallel operation. The induction generator has furthermore no influence on the grid with respect to frequency or voltage.

Due to costs and delivery time, the generators must be taken from standardized machine series. This implies that, in the case of the induction generator, it would be taken from the industrial motor series and, in that of the synchronous generator, from the generator series for combustion motors.

Demands on a generator in a hydro power plant differ from those in a diesel plant or on a motor in an industrial plant. Modifications are, therefore, necessary. This applies, in the first instance, to strain on bearings, strain in connection with runaway speed as well as control of critical speed.

Synchronous generators are delivered as brushless generators. They are fitted with AC magnetizing machine and rotating diodes. The voltage regulator is situated on top of the generator. The latter is also equipped with the necessary measuring transformers for the regulator. The generator with magnetizing and regulating system is thus a package delivery.

4.2 Protection system

The object of the protection system may be described as threefold inasmuch as:

- Its nature must be preventive - i.e. an abnormal condition must be detected at the earliest possible moment
- It must instantly leave the faulty point currentless in cases where the fault develops rapidly
- It must be able to guard against faults in the grid to which the generator is connected.

This may lead to a relatively comprehensive system and, for small power stations, a compromise is necessary.

The majority of faults result in inadmissible rises in temperature. The obvious solution is to install temperature sensors in all bearings and in the windings of the generator.

By installing overcurrent time relays with instantaneous short circuit release, reliable protection is attained against:

- Overload
- Prolonged overcurrents
- Short circuits

In the event of short circuit in the winding between two phases in the generator, the point of short circuit will be fed from the grid.

To which extent the overcurrent time relay will afford any particular protection (release the breaker) depends upon the location of the short circuit in the winding - in other words, the magnitude of the current from the grid.

However, dependent upon conditions as well as the size and voltage of the generator, the use of differential relay as a safeguard against internal short circuit should be considered.

Frequently, a winding short circuit will originate as a stator earth fault.

A winding short circuit between two phases always entails considerable damage to the generator and costly repair. The main objective must therefore be to prevent a stator earth fault from developing into a winding short circuit. Thus it may be quite as important to use a stator earth fault relay rather than a differential relay.

Overvoltage may occur both as a result of defects in the voltage regulator - magnetizing system - and of runaway. Overvoltage protection is therefore included as standard equipment. Overspeed protection is also included - as in all other power plants.

4.3 Automation and controls

4.3.1 Bringing to a standstill

As a main rule and due to the fact that the plants are normally unmanned, any fault will result in automatic disconnection of the generating unit from the grid and, furthermore, the unit will be brought to a standstill.

However, depending upon the location of the plant and the nature of the fault, it may be reasonable to keep the plant running but disconnected from the grid. This is especially important in areas where temperatures below 0° C (or 32° F) are to be expected. Otherwise, the penstock may freeze. If necessary, arrangement for by-pass of the water may be made.

The unit is disconnected from the grid and brought to a standstill by the built-in automatic control, the general procedure being:

- The turbine is de-loaded
- The valve in front of the turbine will close
- The circuit breaker trips time delayed. The delay is adjustable
- In the case of a synchronous generator, it is demagnetized.

4.3.2 Start procedure

In order to start, certain conditions must be fulfilled. Furthermore, the presence of the operating crew is required in order to initiate the starting and to control it.

Once initiated, the starting procedure runs automatically.

- Manual starting of the oil pump to build up the oil pressure of the hydraulic system to the required level.
- Manual setting of the automatic to operating position. If any faults exists within the system, an alarm will now be given and the fault may be identified on the alarm panel. The starting procedure is automatically discontinued until the faulty component has been repaired.
- Following the setting of the automatic, the various elements of the turbine are brought to start position and, upon opening of the valve, the turbine starts and accelerates to nominal speed.

4.4 Excitation system and voltage regulation

Slip-rings and brushes always require a certain amount of maintenance. They may further be one of the weakest points with regard to reliability.

The modern synchronous generator for the small scale hydro power station is therefore of the brushless type. The rotating diodes as well as the AC exciter are mounted on the generator shaft inside the stator frame.

The voltage regulator is of the solid state type and mounted on the top of the generator, as are also the current transformers for feeding of the regulator.

The generator, excitation and voltage regulating equipment thus form a complete unit.

4.5 Water level regulator

As small pow^r plants are designed for unmanned operation, automization of the rbine admission is therefore necessary.

The following modes of operation warrant automation:

a. Water supply to the reservoir varies throughout the day or the week. The variation may be within the output range of the turbine but outside the capacity of the reservoir. This is especially true for power plants with small intake ponds or run-of-river power plants.

b. The inlet to the penstock at the intake pond may be blocked by foreign bodies.

c. Power plants where regulation of the water level of the intake pond is desirable.

d. To ensure the utmost exploitation of varying water supply by maintaining constant level in the reservoir.

En electronic water level regulator has therefore been devised in order to safeguard the automatic operation.

4.6 Connection to the grid

Apart from the equipment directly related to the generators (synchronizing, voltage regulation etc.), the main power circuits for an induction generator are similar to those for a synchronous generator. However, the power circuits for high and low voltage generators are somewhat different.

The generators in question may be designed for operational voltages up to 13.2 kV. However, since the grids to which the small scale power plants are to be connected normally have higher voltages, step-up transformers are necessary.

Furthermore, in the event of a short circuit - for instance on the generator terminals - the short circuit current from the grid can reach a considerable magnitude. The impedance of the transformer will limit this to a more suitable magnitude, reducing the strains to which the equipment otherwise could be exposed.

The magnetizing current of the induction generator is supplied from the grid. The generator is thus unable to regulate its terminal voltage - i.e. the terminal voltage is completely governed by the grid. The grid voltage may fluctuate over the day/night and, since the output of an induction generator - keeping the current constant - is proportional to the voltage, it is important to know the magnitude of these fluctuations.

Otherwise the output will be reduced when it is most needed - i.e. wh n the load demand i. high and the grid voltage at its lowest value. Careful consideration must therefore be given to the ratio of transformation and the transformer must be equipped with the correct tappings.

The attached single line diagram, fig. 4.1, shows the standard versions of the electrical part of a small scale hydro-electric power plant, and employing synchronous generators. On this diagram the standard voltages, for which the equipment is designed, are stated.

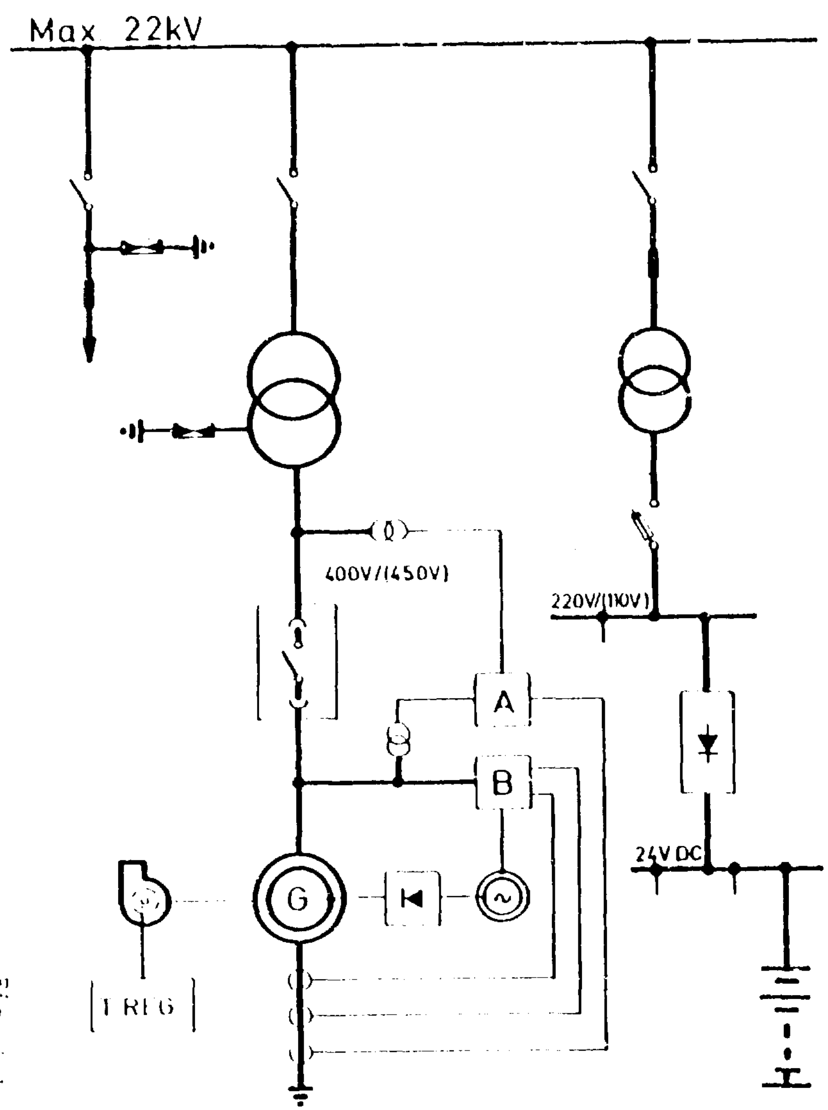


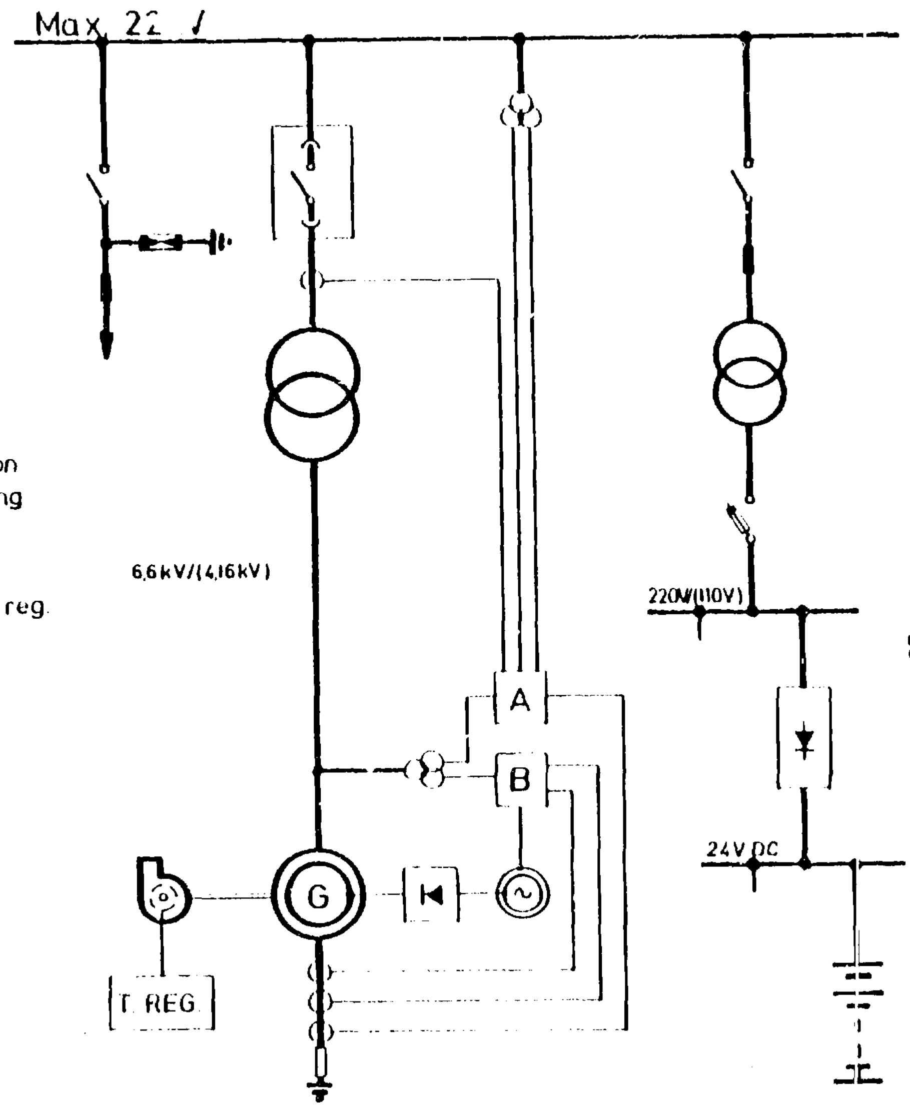
Fig. 4.1

Typical single line diagram for a small scale power station with a low voltage generator.

A) Protection Measuring Synchr.

B) Voltage reg.

Figures in brackets refer to 60 Hz systems



Typical single line diagram for a small scale power station with a high voltage generator.

5. OPERATING CONDITIONS

This chapter is based on experience gained by two Norwegian power utilities, both with long operating experience of small hydro power stations. A/S Istad Kraftselskap (IK) and Sør-Troms Elforsyning A/S (STE) are today the owners of 14 small power stations with installed machine capacity ranging from 70 to 5800 kW.

Average yearly production at STE is 55 GWh which amounts to 15 % of the gross consumption in 1978. The equivalent figures for IK are 22 GWh and 5 %.

5.1 Prerequisites

The objective of a power utility is to meet the demands for electric power within own territory of supply at the lowest possible cost and with acceptable quality.

The individuel small size power station will in general contribute moderately to the total turnover and does not influence the reliability of supply significantly.

Within given limits the objective of operating these stations will then be to have them yield the maximum power output.

The age of the small power stations in question differ considerably and many of them are producing beyond a normal techincal and economic lifetime.

It is therefore very difficult to make a general and total economic evaluation with capital costs included, and we have therefore chosen to look at the yearly operating expenses only.

Further, we have found it suitable to consider the specific figures øre/kWh for the purpose of comparison.

5.2 Operating costs

It is practical to divide the operating costs into costs of maintenance and costs for supervision of the station.

5.2.1 Maintenance

The maintenance costs are to a great extent determined by the "interior" condition of the power station and thus the age of the station and its equipment are most decisive. These costs are subdivided into four items:

- material/equipment
- wages
- hired services
- hired labour.

Such a subdivision of costs can also be informative about the pattern of the utility organisation.

5.2.2 Supervision

The costs for supervising a station will to a large extent depend on "exterior" conditions such as, alert stage, the station's importance to the overall system, supervising arrangements according to laws and regulations, etc.

We can divide the costs for supervising into the following items:

- inspection
- supervisor available at home
- taking time off as compensation for unpaid work.

Inspection costs include expenses incurred from supervising during ordinary working hours. Costs for "stay-at-home supervising" are directly connected to the supervising scheme and to stated agreements concerning allowances and compensations.

Some cost figures are shown below:

	STE	IK
Average yearly production (GWh)	55	22
Number of power stations	10	3
Number of supervising teams	3	1
Maintenance costs (øre/kWh)+	2.4	1.5
Supervising costs (øre/kWh)	1.2	0.9
Total operating costs (øre/kWh) (General costs not included)	3.6	2.4

+) 1 øre/kWh = 0.002 US$/kWh

5.3 Operating functions

The operation of small power stations is divided into the following three functions:

- Control
- Inspection
- Maintenance.

5.3.1 Control

Control of the installations comprises functions which will lead to the quickest possible operational correction when unacceptable conditions occur, or when a change in the running schedule is desired due to other reasons.

Control of small power stations is particularly related to:

- water utilization
- plant components

and is performed by manual observations or by detectors mounted in the plants.

The water utilization is for some stations encumbered with restrictions related to:

- fishing interests
- water flow in duct and channel systems
- max. production at high outside temperature
- max. interuption time for stations (winter)
- reservoir level

Control of the following two parameters is of special concern:

- the water storage reserve
- the turbine admission.

Control of components is done both manually and automatically.

The manual control include:

- visibility,	leakage oil/water, corrosion brush dust/-wear and tear
- smell,	fire electric flash-over
- hearing,	vibration (loose parts)
-feeling,	temperature, vibration (not audible).

The automatic control include:

- temperature bearing/transformer/generator
- water circulation turbine bearing (pressure gauge)
- abnormal position inlet valve
- ground contact generator
- runnaway speed
- flash-over voltage generator
- excess current
- under-tension voltage gridside transformer
- gassing of transformer
- Spiral case pressure
- oil pressure turbine governor.

The power utilities have two remote controlled stations for which the need for transmission of information is judged somewhat differently. In one case all the control data are transmitted. In the second case only a minimum of information is transmitted, percentage admission and the circuit-breaker position. A check of the admission (or the position of the inlet valve) is regarded as satisfactory in connection with an automatic shut down of the station.

5.3.2 Inspection

Inspection comprises supervision and checking of components and equipment in order to judge their technical and functional condition. Included are also smaller tasks like cleaning, lubrication, function tests on valves etc.

In general the following conditions are inspected:

- wear and tear
- oxidation
- pollution
- serviceability.

Inspection on outdoor structures concerns:

- dam leakage
- dam erosion
- penstock pipe leakage (icing problems)
- roads.

The frequency of these inspections can vary from once a month to once a year.

The oxidation problems are most severe in the hydraulic system where iron and steel appear, and especially on those parts which are in contact with water continuously. Components exposed to oxidation are:

- discharge gates with conducts
- screw spindle
- valves
- trash racks
- penstock
- turbine.

The inspection of the penstock also includes:

- gaskets for stuffing box
- drainage surface water
- hoops (wood pipes)
- spring-fly caterpillars (interior iron pipes).

Sediment discharge can cause pollution and clogging of:

- trash racks
- obstructions for fish
- water cooling of bearing
- turbine runner
- overflow weir (icing)
- channels (icing).

Some components and equipment are checked frequently to assure proper performance. Examples are:

- governors
- protectional devices
- firefighting equipment.

5.3.3 Maintenance

According to how the maintenance is arranged, the following distinction can be made:

- diagnostic maintenance
- periodic "
- corrective ".

Most of the work to be done is registered by the routine inspection and handled in accordance to general practice, i.e. - planning, decision on priority and execution.

Even with a comprehensive inspection programme some failures will only be recognized after a break down.

The corrective maintenance work is characterized by the fact that it often has to be performed during critical periods and thus has an acute character.

Organization, crew and own know-how will determine to what degree maintenance work shall be performed by own crew or by hired services.

The cost set-up shows that maintenance represents a predominant portion of the operating costs. These maintenance costs are, however, in turn closely related to the condition (age) of the plants and some replacement costs may be included which should not be charged to the operating account directly.

On the other hand, high expenses for supervising a station will inspire to change to automatic operation, eliminating the permanent supervising system. In that case, an adequately developed grid system will permit shut down of a plant that shows signs of of certain irregularities and await a convenient time for necessary repairs.

6. DIFFERENT ASPECTS REGARDING SMALL SCALE WATER-POWER

6.1 Organizing the development

In 1973, the Norwegian electricity supply system was organized in 535 separate units. Of these units 337 were responsible for distribution of electric power to domestic consumers. Most of them were owned by the municipalities or by the counties. Among these units most of the small scale hydro-power development is expected to take place.

Almost 30 % of the power production comes from stations owned by the State Power System, which is a directorate under the Norwegian Water Resources and Electricity Board (NVE). This directorate is planning, designing, constructing and operating its own system, and possesses all necessary functions for these purposes. The State Power System is normally engaged with the largest power-plants and transmission lines, and is therefore to a little degree concerned with small power-plants.

The official policy in Norwegian electricity supply is, that the excisting electricity institutions shall operate their own excisting power system as they do it now, either directly or in joint co-operation with other electricity companies. Furthermore, they should have responsibility for the development of the smaller water-power sources which are spread around the country. However, to promote a more efficient electricity supply, the policy is to work for a concentration of the smallest units in companies comprising a county, or if certain circumstances make this difficult, 2-4 units in a county.

For organizing the development of smaller water-power schemes, two models seem interesting:

- The county (or another larger unit) is responsible for planning, financing and construction, and is also the owner of the plant. The local municipality is given the responsibility for the operation and maintenance of the technical equipment.

- The local municipality is the owner, and has the responsibility for operating the plant, but has to join the larger system through a power production co-operation.

Both models aim, as far as possible, to maintain a decentralized electricity organization system with units big enough to promote a strong economy and an efficient utilization of the energy resources.

6.2 Financing the development

As the small water-power plants are regarded as an integrated part of the total system, any special financial arrangement has not been proposed. The possibility of giving some economic support for promoting planning, excepted.

This will of course impede the small municipality units in developing their own plants, because they usually have the possibility of buying much cheaper electricity from the gross suppliers, for example the county. (The electricity price in Norway has been kept considerably lower than the cost of developing new power, caused by the great number of old depreciated water-power plants). The financial policy makes it necessary with units big enough to manage this financial problem. The financing of hydro-power developments is normally arranged by loan.

6.3 Time schedule for the development

The small sources of hydro-power should be considered as any other source of available energy. At which time the various small sources are to be developed, will depend on the development costs compared to the costs of other available energy sources.

The development costs for small hydro-power plants in Norway prove to range from about 0,20 US $ per kWh, up to the limit of economic feasible power, and even higher. This indicates that the development of the cheapest sources ought to be started as soon as possible, while the more expensive ones probably should be developed within 20 years or so.

However, one factor should be taken into account in this regard, the small plants are often located nearer the consumers than the big plants are, and should therefore be given some economic credits because of reduced transmission costs and losses.

6.4 Integrated power production

From the outline above, it should be quite clear that the electricity from small power-plants ordinarily will be intermixed with the . wer floating in the main grid. Only in particular cases, as for example in especially remote areas of the country, the power will be produced for a limited grid. It also seems to be of limited importance to keep the small power-plants as a reserve in case some parts of the main system should have a breakdown. This will require more expensive equipment, and is consequently a question of economy.

6.5 Planning procedure

Because of the large number of schemes, a pre-feasibility study, comprising plants up to 10,000 kW, will be carrid out for the whole country. This study is undertaken by the Norwegian Water Resources and Electricity Board (NVE) which is the official body for water resources and electricity matters in Norway.
The study starts with a topographical og hydrological investigation based on available hydrological data and maps in scale 1:50,000. The office work is combined with a field visit and discussions with the local staffs, in order to get a more realistic impression of the prosjects than map studies can give. The pre-feasibility study gives a brief assessment for each project regarding hydrological data, reservoir data, waterways (pipes, shafts, tunnels etc.), head, installed capacity, energy output and cost estimate.

This registration makes it possible for each county to establish their own schedule for wanted development of hydro-power.

With basis in such a schedule, the local electricity bodies may apply to the NVE for official financial support for further planning. Such support may be given on special conditions.

Whether financial planning support is given or not, the next step is to develop a more comprehensive feasibility study. This study has to include a far more comprehensive technical investigation, beside reports considering juridical matters (water rights), ecological and environmental consequences etc.

6.6 The formal official treatment

The feasibility study is the basis for an application to the NVE, and further to the Ministry of Oil and Energy, to get approval for implementation of the planned scheme.

In most cases, except pure reconstruction of old plants in their old shape, applications according to the water-right laws have to be produced Similar applications according to the electricity law are required if the voltage is higher than 1,000 V.

Approvals regarding the water-rights are finally given by the Ministry of Oil and Energy, or by the Parliament (larger plants), while the electricity approval is given by the NVE.

The detailed studies and design, together with preparation of the financial arrangements, normally proceed parallel with the formal application treatment.

No construction should start until the formal approvals are given.

6.7 Consultants, contractors and mechanical/electrical industries

The feasibility study, as well as the detailed studies and the design, are carried out by Norwegian consultants, or in some cases by the electricity bodies themselves. (Some of the bigger organisations have established their own design and construction offices.)

A number of Norwegian contractors have an outstanding experience regarding water-power constuction, and most of the work is undertaken by these contractors.

The manufacturing of hydraulic-mechanical and electrical equipment is also dominated by Norwegian companies, although the international competition is far harder here than for the civil works.

Both for the civil works (contractors) and for the mechanical/electrical equipment, a tender procedure is usual.