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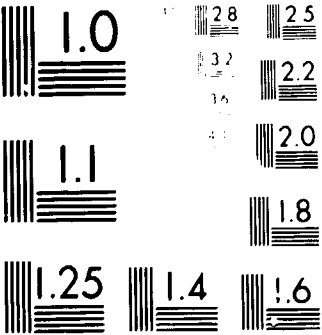
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Seminar-Workshop on the Exchange of
Experiences and Technology Transfer
on Mini Hydro Electric Generation Units

Kathmandu, Nepal, 10-14 September 1979

MINI HYDRO ELECTRIC POWER GENERATION IN FINLAND*

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by J G Wallén
Helsinki FINLAND

1 Introduction

Finland is one of the northernmost countries in the world. Its total area is 337 000 km^2. Of this 31 670 km^2 is covered by 60 000 shallow lakes. The volume of water in these amounts to some 210 km^3. This means that, on the average, the depth of lakes is only 6.6 m. The average yearly precipitation in South Finland is 600 mm and in North Finland 475 mm which translated into volume, adds up to some 200 km^3. This would seem to be a reasonably ample source of energy for a population of only 4.6 million, but unfortunately it is not so. The country is low and in the main level offering few opportunities for power generation on a large scale.

Before the industrialization the hydro power resources were quite sufficient and at that time even experts were inclined to believe that the water resources would be ample for a long time to come.

The story of Finnish hydro-electric power began in 1882 when the first dynamos were installed in Tampere. The development was still slow and by 1917, when Finland became independent, the total installed hydro power capacity in the country was only 37 MW.

2 Government action

After 1918 a campaign to build a large central power plant began. The plant was to be located at Imatra. Plans for this plant were discussed already 1905 in connection with the proposed electrification of the Finnish State Railways. The conditions in the country and the World War I brought a halt to the plans which were not to be realized for a long time to come. Finally towards the end of the 1920's Imatra Power Station was constructed by a state owned company. Its first unit was brought on stream in 1929 and the fourth one in 1930. The last unit was commissioned in 1951. Imatra is the largest hydro power station in Finland and will remain so.

The three largest Finnish power companies are in the main owned by the State. Legally these companies are private joint stock companies and do not enjoy any special privileges compared with other companies. During the years 1946-1970 the government companies constructed a great number of hydro-electric power plants concentrating their efforts on those rivers in which the largest and cheapest plants could be constructed.

The private companies and consumers developed smaller plants satisfying their own as well as the surrounding rural area's needs. Normally these plants were connected to a larger grid to ensure some degree of reliability. In addition some thermal power plants were constructed by the industry for the supply of electricity as well as process heat. By the end of the 1960's most of the "utilizable" hydro-potential had been made use of and the total installed capacity was 2679 MW.

Generally speaking the hydro-electric power stations are rather small as the following table shows:

Capacity (MW)	Number of stations	%	Production % of total
100 -	5	2.3	24.3
50 - 100	13	5.9	33.6
15 - 50	26	11.8	27.8
5 - 15	26	11.8	7.7
- 4	150	68.2	6.6
All	220	100.0	100.0

The total capacity of above plants is 2 672 MW and their max. yearly production about 14 TWh. The max. yearly production of plants smaller than 15 MW i.e. mini plants is about 1.9 TWh or on the average 11 GWh per plant.

By the end of the 1960's it was considered that developing the remaining hydro power was not economically feasible because of the low fossil fuel costs and because the most advantageous hydro power sites were already developed. In addition there was a growing resistance towards the hydro power because, it was claimed, it spoiled the sceneries and destroyed the ecological balance of the rivers. The country, with the government in the forefront, abandoned further hydro developments and embarked on an extensive construction programme of thermal power plants, both conventional and nuclear.

After the 1973 oil crisis there has been a general awakening and it has widely been realized that development of the hydro power potential is, after all, desirable. Hydro power is clean, pollutionfree, and a renewable domestic resource. It has also been realized that the hydro power despite its higher initial costs is always cheaper than any other form of power presently known. Due to this an extensive inventory of potential hydro power sites has been made. The results are not quite ready, but some of them are already now available:

In the whole country 2932 sites for hydro plants were investigated by the State Water Board and the non-profit organization SITRA. These sites had a potential of 505 MW. On the sites there were 371 power plants, 1132 dams, mills, saw mills etc. The rest of the sites 1429 (317 mW) have never been used. In addition it was estimated that sites having a potential of 506 MW was not included in the inventory. The oil which could be saved each year by constructing the "forgotten" mini plant sites is 1.8 million tons or at current prices US dollars 250 million. In a few years the saving would be much greater due to the sharply rising oil prices. In view of this the government has started to reconsider its position and assists already now in many ways mini hydro developers. But the procedures are complicated and there still is no economical assistance for the hydro developers.

3 Mini Hydro in the Finnish Power System

Hydro power has been used in Finland for industrial purposes long before the advent of the electric generator. In the early days the units were normally connected to the mechanical drive shafts of the factories and, in those days this system worked reasonably well. As a matter of fact some expert remarked that the large-scale industry was in no need of electric power because the factories were located on the shores of rapids and turbines could drive all the necessary machinery directly. This attitude changed radically after the country became independent 1917 and the completion of the first stage of Imatra Power Plant in 1928. A further impetus towards electrification was given by the 110 kV power line which connected the major cities, Helsinki, Turku, Lappeenranta, and Viipuri in South Finland with the important Imatra Power Plant. When the grid gradually expanded most of the old power plants of the industry and municipalities were tied to it. Presently, for all practical purposes, the whole production capacity of the country is tied to the so called super-grid which consists of 400, 220, 110, 45 and 20 kV lines. The smaller, under 10 MW, plants are usually connected to the 45 or 20 kV circuits. The production of the small plants is absorbed by the National grid when in excess of the local demand and complemented by it when the discharge through the turbines is too low to satisfy local requirements.

Frequently, however, the small plants built during the 1950's were constructed as peaking plants in order to improve the economy of power consumed from the National Grid. This was achieved by the use reservoirs to ensure daily, weekly or yearly control. The large plants were base-load plants.

Later when most of the readily available hydro power was developed and the world oil markets made thermal power much more advantageous than hydro large thermal plants were built. Also, a considerable amount of the wood and pulp industry constructed their own thermal back pressure power plants to fill their requirements for process heat and electric power. Accordingly thermal power became dominant in the system. The large hydro power plants which had adequate reservoirs began to be operated as peaking plants. The thermal stations and the mini hydros became base-load plants.

Now that the oil prices are rising at an ever increasing rate the construction of the remaining hydro resources has rapidly become more attractive despite of the high initial investments. This is mainly due to the long life of the equipment and their negligible operating costs. The most re nt mini hydro developments have faced severe criticism due to ecological reasons. It has, however, been possible proceed with these developments in connection with general schemes to improve the use of the watercourses by implementing multipurpose projects for flood protection and recreational use in co-operation with the National Board of Water. Unfortunately lack of capital prevents rapid expansion of the country's hydro potential which in any case would not be sufficient to meet the ever increasing demand for power. Full utilization of the remaining hydro resources can only ameliorate the need for thermal power, but it can never obviate the need for imported fuel or other energy. In 1977 58% of the energy was of foreign origin, 28% hydro, 6% mini hydro, and 8% from other domestic sources. Today the situation is much the same.

3.1 Mini Hydro Development

Due to the high initial capital required for developing storages for mini hydro plants in a rather low and level terrain it has been found expedient to construct predominantly run-of-river plants. Frequently the plants are nevertheless operated as peaking plants by utilizing available pondage. The head of the plant becomes rather small and ways have to be found to utilize the available heads as economically as possible. One solution has been to construct the turbines with horizontal shaft connected to a synchronous or asynchronous generator as the case may be. In addition the operation of the plants has been completely automatized in order to reduce the daily running costs. These plants are mostly of the so called tubular design.

Usually the turbine shaft is connected to a gearbox in order to keep the generator reasonably small and enable the turbine to be run at its most economical speed. Presently the limit for gearboxes is about 3 MW due to economical reasons. The turbine casings are normally built of fabricated fine grain plate steel. The wicket gate trunnions and shaft sleeves are normally made of stainless steel. The runner blades are always of stainless steel and sometimes the runner chamber is also made of stainless steel.

The turbine regulators, when used, are of the mechanical type. Only in cases when special attention has to be paid to the speed regulation electro-mechanical regulators are used.

The generator speeds chosen are usually 600, 750, 1 500 depending on the turbine output and its runaway speed. According to the local requirements either induction generators or synchronous generators are used. The induction generators are in general much cheaper than the synchronous ones and have in addition some advantages such as simple connection to the grid and little sensitivity to runaway speeds. One major disadvantage is the capacitors which are required for the compensation of the magnetizing current. Also, it is not advisable, though possible, to use an induction generator separately specifically due to the accurate speed regulation required. If, however, the load is changing only slowly as in the case of heating or similar applications there should be no special problems in this respect, but despite of this induction generators are not normally used in isolated networks.

3.2 Selection of Machinery

3.2.1 Turbine

When the available head of a power plant site is less than 20 m a Kaplan tubular turbine is usually selected. If the flow is in the main steady a so-called half Kaplan turbine is used. In this turbine the guide vanes are not adjustable. This type of machine is used only where intermittent or continuous full-load operation is possible. When flow variations are large a Kaplan turbine with fully adjustable wicket gates and runner is used. This type has a very flat efficiency curve for any flow between 15-110% of the design flow.

If the head is more than 20 m it is advisable to use Francis turbines in small plants. The Francis turbine is always equipped with a shut-off valve located before the turbine. If the penstocks are long, it is important to ensure sufficient governing characteristics to avoid water hammer problems. It is also frequently necessary to use a surge tank or to include a flywheel with the rotating parts. Usually the Francis turbines behave well in runaway situations and due to this they are often chosen for plants having a low head but long penstocks.

3.2.2 Generator

In mini power plants two kinds of generators are frequently used:

1 Induction generators

2 Synchronous generators

The induction generator is often simply a standard squirrel-cage asynchronous machine which is operated at a negative slip. In this mode of operation the machine delivers power under certain conditions i.e. the machine must be magnetized from some source. Normally the source is a synchronous generator. It is, however, possible to dispense with the external power source if a bank of capacitors are connected to the machine. In this case the initial voltage is generated by remanent magnetism.

Due to difficulties in regulating the voltage as well as frequency if the induction generator is operated autonomously the economic gains of the initially cheap standard induction machine are lost. Because of this autonomous operation of inducti n generators should be discouraged in favour of the more efficient synchronous generators.

In small plants the brushless synchronousgenerator is normally used to avoid maintenance problems arising from the rapid wear of the coal brushes. In small generators the voltage usually varies between 400-660 V. In large ones from 3 to 10.5 kV. The excitation power is taken from an a/c exciter generator installed on the generator shaft through a rotating rectifier bridge. The generator frame is normally fabricated and dimensioned to meet the prevailing runaway conditions.

4 KAARNI Power Station - a case study

Kaarni Power Station is 1.2 MW asynchronous mini hydro plant in which a number of simple, inexpensive and yet reliable solutions have been employed. It was completed in 1977. The station consists of an unregulated Francis turbine equipped with a simple clappet valve, an induction generator, frequency relay for synchronization, overspeed protection and a clock activated starting and stopping device.

4.1 Water conduits

The water from the upstream side is conveyed approximately through a 1 km long open channel to the penstock which is 130 m long and 2 m in diameter. The penstock is fabricated from 6 mm steel plates and installed in 9 m long sections which connected by rubber sealed flanges. Corrosion protection consists of 400-600 μm thick epoxy paint. The penstock is buried in the ground without any supports. It is installed as a syphon which affords additional runaway protection should the clappet valve fail.

The penstock is primed by pumps and deprimed by a remote controlled air valve.

4.2 Machine Station

The machine station is built on a concrete foundation block on which the machinery is installed. The station consists of a steel fram. .ilding which can be dis antled if any parts of the machinery must be removed for repairs.

4.3 Turbine

The turbine is a horizontal Francis without adjustable guide vanes. The spiral casing of the turbine is made of rolled steel sections of equal cross-section throughout its length. This was a simple solution and yet efficien~. The flow through the turbine is controlled by means of the clapper valve only and due to this the turbine cannot be operated at partial load.

4.4 Generator

The generator is a standard squirrel-cage motor which operates at 3 kV and 1000 rpm. It is designed to withstand the runaway speed of the turbine. The design power of the generator is 1250 kW. Because the excitation cannot be adjusted as in a synchronous generator the shaft power of the turbine must not exceed the nominal power of the generator by more than the generator losses i.e., in this case, 45 kW or about 3% of the guaranteed turbine power. The generator is connected to the turbine by means of a gearbox having a ratio of 382/1006 rpm. The generator is connected to a 3/20 kV 1500 kVA transformer.

4.5 Operation and protection

The plant is remote controlled and completely unmanned. The main protective devices are the following:

"Non-fuse" compact circuit breakers
Main switch
Starting and stopping relays
Overspeed relay
Oil pressure relay
Back-power relay
Earth leakage relay

4.6 Starting

When the plant receives a start impulse from the control centre the clapper valve is opened and as the generator gains speed it is connected to the network at 97.9% of the synchronous speed because it was found that a slight positive slip was more advantageous and resulted in a smoother increase in the power delivered to the network.

Once the generator has been synchronised with the network no problems in the operation arise except due to mechanical or electrical failures. It should also be noted that the excitation current drawn by the generator is not compensated by capacitors. This reduces effect of the generator on the network voltage considerably and eliminates the possibility of overvoltages when the station is disconnected from the network.

5 Cost & Labour. In 1978 STYV (Sähköntuottajien Yhteistyövaliokunta) conducted a country wide enquiry entitled "Vesivoima ja sen rakennusmahdollisuudet Suomessa" (Hydro Power and its construction possibilities. The following table is calculated based on this investigation:

Construction & Capital Costs (USD, 50 years depreciation, 8% interest)

Plant size	No.	Power MW	Annual Production GWh	Average Cost USD/kW	Min. cost/ USD/kW	Max. cost/ USD/kW	Av. cost/ kWh	Min. cost/ kWh	Max. cost/ kWh
5 MW	31	77	303	1225	710	2060	2.8	1.4	4.9
5-10 MW	8	58	154	875	520	1423	2.4	1.7	3.9

It is of course difficult to assess the exact requirements of labour for the development of mini hydro since the variations are huge depending on whether the project requires large storages, dams, or complicated and expensive waterways. On the average the projects investigated had an annual production of 3270 GWh/a and required 31900 man-years labour or by production unit about 10 man-years/GWh. Normally the actually required labour force was about 10% larger than originally estimated during the design.

6 Organizations actively developing mini hydro

1 Sähköntuottajien Yhteistyövaltuuskunta (STYV) Fredrikinkatu 48, SF-00100 Helsinki 10

2 Finnish Association of Electricity Supply Undertakings
P.O.Box 100, SF-00101 Helsinki 10

3 IVO Consulting Engineers
P.O.Box 138, SF-00101 Helsinki 10

4 Oy Tampella Ab, Engineering Division
SF-33100 Tampere 10

Bibliography

1 STYV Raportti 2/79
Vesivoima ja sen rakennusmahdollisuudet Suomessa
(in finnish), Helsinki

2 Kilpeläinen J E
Hydro power development in Finland, Rakennustekniikka
8/78, Helsinki

3 Ahovuori Kauko, Leino Kalevi
Kaarnin voimalaitos
Sähkö 51 (1978) 3, Helsinki

4 Creager William, Justin Joel
Hydro-electric Handbook, John Wiley & Sons, Inc.
London, 1951