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SIXTH WORLD POWER CONFERENCE

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DIVISION III SUB-DIVISION III.1_1

GENERAL REPORT

TRANSFORMATION OF PRIMARY TO SECONDARY ENERGY, AND TRANSPORTATION OF ENERGY
WATER POWER — LOW LOAD FACTOR DEVELOPMENTS, ETC.

General Reporter

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The wide range of subjects covered by the nine papers allocated to Sub-Division III.1_1 has made it necessary to group the papers as follows:

(A) Accounts of Developmental Trends in the Use of Low Load Factor Hydro Power Including Pumped Storage Schemes — five papers from Great Britain, United States of America, Spain, Italy and Australia.

(B) Benefit of Long Term Regulation — one paper from Sweden.

(C) Advances in Pump Turbines — two papers from Switzerland.

(D) Evaporation Control Experiments — one paper from United States of America.

(A) Accounts of Developmental Trends in the Use of Low Load Factor Hydro Power Including Pumped Storage Schemes

Paper No. 16 by Fulton, Mountain, Haldane and Jones (Great Britain) refers to the considerable development in the field of low load factor hydro plant that has taken place in Great Britain since the last war. Descriptions of two pumped storage plants, Ffestiniog and Cruachan, are included in the paper as a special type of such hydro development.

The advantages of hydro plant over thermal plant for low load factor duty are described and details are given of the factors which have to be recognised in an economic study comparing the two alternatives. The fact that the head-works of a hydro installation do not change with plant capacity means that the incremental cost per kilowatt is very much less than the average cost per kilowatt for such plants. The economic study should pay due regard to the costs associated with keeping thermal plant available for peak load operation and also to what might be termed the "negative value" of the hydro plant in its early years of operation. This so-called "negative value" arises from the fact that, if thermal plant were considered as the alternative to peak load hydro, it would be of high efficiency and often of large capacity, and thus would displace less efficient older plant in loading priority. In other words, the introduction of low load factor hydro plant results in a greater amount of energy being produced by the less efficient thermal units than would be the case if new base load plant were introduced and this has to be taken into account in the study. This "negative value" becomes insignificant after a reasonably short period of time — 10 years in the case of Great Britain.

The effects of inflation, rates of interest and security are outlined, and also the decreases which have occurred in recent years in the capital cost of thermal plant with increases in size of units, and, to a lesser extent, in the construction costs of hydro works, particularly following improvement in tunnel driving and lining techniques and in dam designs.

The paper goes on to point out that, although the reduction in the capital cost of thermal plant and the current high rates of interest are both unfavourable to pumped storage plants, this is offset by such plants enabling thermal units to run at more efficient higher load factors and by the influence of nuclear plants where their capacity exceeds that needed for base load.

Reference is made to the various low load factor hydro developments in Scotland, England and Wales, and also to the principles of operation adopted for the Scottish hydro stations to ensure that the peak load stations with small storages giving low degrees of water regulation always have sufficient water available to make their capacity effective, whilst at the same time maximum use is made of the stations to give minimum loss of water consistent with overall economy of operation.

The paper then describes in some detail the pumped storage schemes of Ffestiniog and Cruachan. Although commencement of the two projects was separated by only about three years, significant advances in plant development occurred in that period. Whereas in Ffestiniog separate turbines and two-stage pumps were used, reversible machines with single stage pumping have been adopted for Cruachan with considerable savings in cost.

Paper No. 77 by Vencill (United States of America) also refers to the economic study necessary to decide what type of peak load plant should be installed in any system, pointing out that such a study requires forecasts of future trends in load factor, shape of the load curve and in costs of such items as fuel, materials and labour.

Reference is made to the various means which may be chosen for supplying peak load requirements, listing pumped storage plant, low load factor hydro plant, specially designed steam turbine units, overload steam capacity in conventional stations, gas turbine driven units and diesel electric units.

Several examples are quoted of what are termed combination projects, where pumping augments the output that would otherwise be available, and

is also used to meet special operating conditions such as at Niagara Falls. It may also be of benefit to pump water to a higher level to permit shorter and more economical diversions from one catchment to another. The possibility of using flood storage reservoirs as a part of a pumped storage scheme is also discussed, although the incompatability of the two purposes is a disadvantage.

Pure pumped storage schemes generally give scope for both variety and originality of arrangements, as is illustrated by the Taum Sauk Project, Missouri, which, with a firm capacity of 350 MW (two units) is due to commence operation in May, 1963. A full description is given of the economic studies which led to adoption of the project, including evaluation of an "energy penalty" (referred to previously as "negative value"), the significance of which in this case also decreases with time.

The operating advantages of pumped storage units, both in regard to use as spinning reserve and, similar in effect, interruptibility when pumping, are mentioned and reference is also made to ability to follow rapid load changes and the overall high degree of availability as applied to all hydro plant. These advantages have to be compared with the more complicated operation which has to have regard constantly to the limited amount of peak energy available in storage and the amount of energy available for pumping in following off-peak periods.

The effect of likely future trends in generating plant and in the shape of system load curves on the application of pumped storage schemes is considered and reference is also made to the possibility of redevelopment of existing hydro schemes as pumped storage projects.

Following brief reference to the organization of the electric industry in their country, Vincens, Castillo, and Urbistondo (Spain), Paper No. 101, outline hydrologic and meteorologic conditions which vary considerably over the country and fluctuate widely from time to time. Despite this, the very high cost of mining solid fuels in the country has resulted in development to date being concentrated on hydro power. Due to the exhaustion of hydro-electric resources in some areas thermal energy, which constituted less than 10% of the total energy production in 1943, has now grown to some 30%. The thermal stations operate on low load factor and thermal energy output varies inversely with rainfall.

If the annual load demand continues to double every 8 years, as at present, hydro-electric power resources will be exhausted by 1976; hence substantial increases in thermal power are required with hydro-electric energy being utilized more for the provision of peak loads. Peak load power has been provided by increasing the capacity of existing hydro-electric stations, providing new hydro-electric stations with large installed capacities, operating at correspondingly reduced capacity factors, and by the construction of additional storages to combine the requirements of peak energy demands with those of irrigation. As a result of these developments, the supply of peak load energy is not a serious problem in Spain at the present time. However, attention is being paid to the future provision of peak power, particularly by means of pumped storage schemes located close to load centres.

The paper goes on to describe the first phase of the development of the Tage Basin. This project will develop some 400 feet of head in two stages —

Valdecamas and Torrejon — and will incorporate a regulating storage to control the very irregular river flow. An account is given of the generation, transmission and distribution facilities of the company supplying power to this east-central area, and the integration of these facilities with the national power grid. A detailed description is given of technical aspects of the scheme, especially the use of typical load curves to determine the relation between energy and power demand for the supply of peak loads.

An earlier proposal using Francis turbines for generation only is compared with the adopted scheme which incorporates closed cycle pumped storage at Valdecamas and also between the Tiebar River and the Torrejon Reservoir. The particular value of the adopted scheme lies in the increased availability of installed capacity (the guaranteed minimum capacity is increased by 73%) which will enable this development to supply the peak loads of an expanding market in this area for the next 30 years. It will also result in an appreciable reduction in the variability of annual energy production from 1 : 4 without pumping, to 1 : 2.5. This reduction is equivalent to the provision of large additional storage.

Paper No. 105 by Padoan (Italy) outlines the problems facing Italy at this stage in planning to meet the various sections of the future load demand from the most appropriate sources. Having regard to the increasing proportion of thermal production, the allocation of load from base towards peak goes to run-of-river hydro, geothermal, thermo-nuclear, thermal and hydro with storage in that order. To a certain extent, the problem varies with the network but in long range planning ever-increasing networks must be assumed as interconnections are made throughout the country and even between countries.

Reference is made to the need for a careful investigation of the optimum use to which a country's hydro resources can be put. For Italy, the factors investigated include utilization of the existing storage stations and the possibility of increasing their capacity, modification of existing limited storage stations to include pumped storage, and the addition of even relatively small storage to existing run-of-river stations. An overall assessment is required of the ultimate full development of hydro resources and the extent to which pumped storage can be utilized.

In assessing likely load growth in Italy both in total and in composition, load curves for the past 9 years have been examined, both for the country overall and for two component parts of the system. Dimensionless curves are used to highlight any changes in the composition of the load, but the conclusion is reached that the shape of the curve averaged for the years studied gives a reasonable basis for forecasting the future load composition.

The paper then goes on to consider the use of hydro plants to meet peak load demands. It is estimated that some 64% of the economic hydro potential of the country had been developed by the end of 1960. Assuming full development of remaining economic potential both for storage and run-of-river plants in the next ten years, the position is studied for present conditions, for the likely situation in 10 years' time (with demand double that existing now) and for the case where storage hydro meets the full peak load (assumed in the study to be that which has a duration of less than 5000 hours per annum). The study does not take into account possible large pumped storage installations.

To further illustrate the types of problem likely to be met the study is extended to the particular cases of the days of

(*a*) maximum demand,
(*b*) winter minimum flow,
(*c*) summer minimum flow, where irrigation requirements are also involved,

for the three periods assumed previously, i.e., present, 10 years hence and when hydro is fully utilized to meet peak loads. It is shown that in such conditions it is possible for summer loads to govern the thermal installation required to fully utilize available hydro resources.

The paper concludes that optimum utilization of hydro resources in Italy under favourable circumstances will be sufficient to cover peak load demands until the present total load is quadrupled.

Paper No. 130 by Andrews and Warrell (Australia) gives details of progress in both planning and construction of the Snowy Mountains Scheme in south-eastern Australia.

Since the 1956 World Power Conference, when a paper on the Scheme was presented (259H/43 — Progress on the Snowy Mountains Scheme), a major change has been made to general plans for the southern section of the Scheme. This change provides for a direct connection of the southern section, the Snowy-Murray Development, to the main regulating storage, Lake Eucumbene, and also utilizes pumping to achieve full development of the Snowy River water.

Reference is made to the potential of the area being developed by the Scheme and to the very high degree of regulation which it has been possible to achieve due to the availability of favourable storage sites, and to the extensive use of inter-catchment diversion involving the construction of considerable lengths of tunnels.

The advances made in underground construction techniques are therefore of great importance to the Scheme. The paper attributes the high rate of tunnel excavation achieved largely to thorough works planning, including the use of new plant and equipment specially selected or even designed for the job. Due to this, the cost of tunnel excavation has remained virtually constant over the last 10 years despite the fact that various cost indices have shown an overall increase of some 50% in that time.

A better understanding of rock mechanics has resulted in a great expansion in the use of grouted rock-bolts. This factor and other advances in this general field have led to reductions in the amount of concrete lining of tunnels and also in the nominal thickness of lining used.

All of these factors have assisted in reducing costs. Rock-bolting techniques have been found particularly useful in the construction of the large underground machine and transformer halls.

Use of pneumatic concrete placing equipment for tunnel lining has also resulted in considerable savings. Care taken with operating techniques ensures that the overall standard of work is in no way reduced.

The advances have been reflected in the low bids received for the works now in progress, which include 50 kilometres (31 miles) of 6.4 metres (21 feet) diameter tunnels. Contractors have indicated that new developments are envisaged in tunnelling techniques which are expected to result in further improvement in tunnelling rates of progress.

(B) Benefits of Long Term Regulation

Paper No. 87 by Larsson, Nordstrom and Edblad (Sweden) discusses the desirable degree of regulation for hydro power in Sweden. The conclusion is reached that, in general, the desirable degree of regulation (defined as the ratio of storage capacity and mean annual inflow) in that country lies between 25% and 45%. Regulation up to 25% is nearly always justified, while benefits to be obtained seldom warrant works giving a degree of regulation greater than 45%.

In view of the present stage of development of the electricity industry in Sweden where an increasing use of thermal power is envisaged during the 1960's, becoming even more pronounced during the 1970's, the study was carried out both for present conditions, in which 95% of the electricity consumption is provided by hydro power, and on the basis of future conditions for a system employing a large share of thermal power. The general conclusion remains unaltered, however.

It must be stressed that the conclusion reached is for a country where the ratio of maximum to minimum annual flows is approximately 2. The cases studied refer only to single purpose projects.

Other papers in this section have referred to ratios of 4 (Spain) and 5 (Australia), and in both of these countries developments now under construction or planned, are aimed at making maximum use of available hydro resources in meeting peak loads and involve some consideration of irrigation.

(C) Advances in Pump Turbines

Paper No. 116 by Strub (Switzerland) points out the benefits to be gained by the utilization of hydraulic storage plant as a complement to large thermal plant. The attractiveness of such plants, however, depends on high efficiency being achieved at relatively low capital costs. Recent rapid developments in equipment have resulted in overall efficiencies of 75 to 78% and have also resulted in a considerable reduction in costs.

The types of plant considered by the paper are radial and semi-axial, and characteristics for both types, for both single and double stage units, are given. The problems involved in starting the large pump units are also discussed.

The trend of development is towards greater power for a given sized machine. This is achieved by increasing the running speed, the specific flow, and the stage pressure separately or together. Limiting factors to be considered in any such development include the strength of the motor generator to withstand centrifugal forces, the cavitation limit for given suction pressure, resistance to erosion, and the fatigue strength of blades under fluctuating pressure. The first of these limitations is no more severe than for conventional turbines of the same capacity. With regard to cavitation, underground stations sited at considerable depth can be readily adapted to give greater suction pressure and this will permit a reduction in the dimensions of the plant in such cases.

Provided suction pressure is available, the head per stage of a pump turbine depends essentially on its mechanical strength. The order of magnitude of stage pressures envisaged at the present time are:

	Pressure per stage — metres
(*a*) Radial machines, fixed guide vanes, *Ns* equals approximately 170	500
(*b*) Radial machines, movable guide vanes, *Ns* equals approximately 170	400
(*c*) Semi-axial machines, *Ns* equals approximately 250	200

The paper concludes by giving brief details of the plant now being installed or planned for the Taum Sauk Project in the United States, the Cruachan Scheme in Scotland, and the Stafel Scheme, Switzerland.

Paper No. 203 by Wenger (Switzerland) also refers to the benefits to be gained in modern systems by the utilization of hydraulic storage plants.

The paper then goes on to give details of a pump turbine in which a double-wheel carries turbine blading on one side and pump blading on the other. A system of regulators and guide vanes ensures that either side may be disconnected from the water conduit so that minimum resistance to running is obtained.

The paper also refers to the advantages of such an arrangement in flexibility, in particular in the easy and rapid transition from generating to pumping and vice versa without reversing the direction of running and without stopping or starting.

(D) Evaporation Control Experiments

The final paper considered in this report, Paper No. 30 by Dominy (United States of America) gives details of evaporation control investigations carried out by the Bureau of Reclamation. During these investigations, which commenced in 1952, over 200 monolayer forming compounds or combinations of such compounds have been studied, with widely varying results.

The investigations have included field tests on Lake Heffner (surface area approximately 1000 hectares) near Oklahoma City, Oklahoma, and on Sahuaro Lake (surface area approximately 500 hectares) near Phoenix, Arizona.

On the basis of results obtained to date, it is expected that, under future operational conditions for sites suited to such work, the techniques and materials for reducing evaporation will be perfected to the point where the most probable evaporation reduction will be about 40%, with a range from about 5% to about 60%.

The paper goes on to discuss the effects of seasonal factors on evaporation and hence on the consideration of evaporation reduction for reservoirs under various climatic conditions. It is suggested that an evaporation reduction season could comprise a period during which one-half to three-quarters of the annual evaporation at the site occurs, depending on climatic conditions at the site.

Turning to economic considerations, reference is made to the cost of materials, the quantity of materials applied, and the cost of application. On the basis of present knowledge, techniques and cost, the savings outlined in the paper do not appear to be justified when related solely to additional

electrical energy production. However, because of the possible variations in all the factors involved, the need for further research work is emphasized, particularly in regard to the materials utilized and methods of application.

The likely order of cost is compared with the energy value of water saved and as an example calculations are carried out for a portion of the Colorado River system. It is pointed out that the calculations take account only of energy value and the water saved still remains for other uses, such as irrigation or town water supply. The value of water for such purposes can be based only on the cost of obtaining a similar supply from other sources, and this will tend to increase as resources are progressively developed.

Points Suggested for Discussion

Although all major electricity producing countries are not represented by the nine papers in this Sub-Division, it is apparent that increased interest is being taken in the use of existing and new hydro developments, including those involving pumped storage, to meet the peak demands. The number of papers is such that the material presented could not deal with the full scope of the subject. The following subjects proposed for discussion therefore cover a somewhat wider field than that covered in the papers.

(1) What limitations are considered desirable on the amount of pumped storage plant in a system? It is apparent that an increasing percentage of pumped storage plant will result in some loss in flexibility and that some limitation may have to be imposed, such as, for instance, that pumped storage plant should not exceed the reserve capacity available. Somewhat similar considerations exist in relation to run-of-river hydro plants used for peak loads.

(2) What studies have been made and what experience has been gained on the optimum allocation of load fluctuations between thermal and hydro plant? Although storage hydro and pumped storage units can readily take large and rapid fluctuations, thermal units can handle small fast fluctuations and also the larger less rapid fluctuations without undue loss of efficiency. Modern systems of unit and network regulation would permit any predetermined division of fluctuations to be achieved.

(3) What are the main factors in the choice between separate and reversible pump turbine machines? It is apparent that there are a number of factors to be taken into account apart from the practical design of a satisfactory machine.

(4) What criteria should be adopted in assuming lives for economic studies in the comparison of hydro plant (including pumped storage) and thermal plant, having regard to the major influence of this factor?

(5) What is foreseen as the role of control of evaporation and planned management of catchment vegetation in obtaining a greater useful yield from the overall precipitation? It is apparent that by far the greater part of precipitation never reaches the streams and is thus ineffective for power purposes.

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DIVISION **III** SUB-DIVISION **III.1$_1$**

RAPPORT GENERAL

TRANSFORMATION DE L'ENERGIE PRIMAIRE EN ENERGIE SECONDAIRE ET TRANSPORT D'ENERGIE

ENERGIE HYDROELECTRIQUE — DEVELOPPEMENTS A FACTEURS D'UTILISATION BAS, ETC.

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L'étendue des sujets des neuf rapports réunis dans la Sous-section III.1$_1$ a conduit à leur classement suivant:—

A. Comptes rendus des tendances du développement de centrales hydroélectriques à facteur d'utilisation bas, y compris des aménagements d'accumulation par pompage — cinq rapports en provenance de la Grande-Bretagne, des Etats-Unis d'Amérique, de l'Espagne, de l'Italie et de l'Australie.

B. Avantage du réglage à long terme — un rapport de la Suède.

C. Progrès des pompe-turbines — deux rapports de la Suisse.

D. Expérimentation du contrôle de l'évaporation — un rapport des Etats-Unis d'Amérique.