UNITED NATIONS TECHNICAL PROGRAMME

Reference TE 323

FINAL REPORT

Subject of Study	General Power System Analysis and Planning
U.N. Fellow	Jakob Björnsson
Country	Iceland
Countries of Study	Sweden and Norway
Fellowship	Sept 12 to Nov 3 1966 (3 months)

Reykjavik, Iceland
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1. INTRODUCTION

The present report is a Final Report on studies undertaken by me under a U.N. Fellowship tour to Sweden and Norway in the period Sept 12 to Nov 3 1966.

The Report first sumarizes the impressions and learnings from the studies. Then some recommendations to the Icelandic Government, based on the findings of the study tour, are set forth. Then follows a detailed account of the studies undertaken at each of the institutions visited, followed by a chronological list of these institutions. Finally, acknowledgements to the many persons and institutions that have contributed to the fellowship are presented.

2. REASONS FOR MY NOMINATION FOR THE FELLOWSHIP

The Fellow is the head of a department within the State Electricity Authority [1] that is particularily concerned with exploration of the country's hydro-electric resources; with assessment of the future load growth and with drawing up long-term plans for extension of the country's power system, aimed at meeting the demand by utilizing the large untapped resources of the Hvítá-Thjorsá river systems and other rivers in the country.

With growing interconnection between power plants and their integration into unified networks, the problems of designing generating stations, transmission lines and other power system components change profoundly in that it is no longer sufficient to treat these components as independent entities. Instead, the system approach must be employed

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1) By an Act of Parliament, the State Electricity Authority has been reorganized and is from July 1 1967 to be known as the National Energy Authority.

and these elements must be treated as what they really are - component parts of a system. Various methods and procedures have been devised in recent years and are in course of development in Europe and North America to cope with the increasing complexities in power system planning brought about by this evolution. In Iceland, power systems are as yet in the early stages of interconnection and integration, but with the foreseeable rapidly increasing development of the large untapped reserves of the Thjorsá-Hvítá basins where all power plants will be integrated into a single network, planning problems of the type indicated above with present themselves with ever-increasing urgency. It was felt therefore that now was the time to prepare oneself to meet that situation. In particular, by taking up the matter at this moment, one would get the possibility of making full use of recent improved planning procedures almost right from the start of interconnection of Icelandic power systems, with corresponding benefits compared with less adequate methods. Any gains from the fellowship would therefore be of an immediate use to me in my present job.

3. SUMMARY OF IMPRESSIONS AND LEARNINGS FROM THE FELLOWSHIP

The fellowship studies were carried out at various institutions and companies in the electric power field in Sweden from Sept 12 to Oct 7 1966 and in Norway from Oct 10 to Nov 3 1966.

The most outstanding impression from the studies is the great amount of work that has been and is being laid down in Sweden and Norway in the development of new and improved techniques for the planning and operation of electric power systems, especially hydro or predominantly hydro systems. This endeavour is being pursued simultaneously by several bodies, and various modes of approach have been and are being tried out. At present therefore this field is in a way dominated by a multitude of approaches, which to some extent may be confusing. There are, however, indications that the various methods are being or will be modified in direction towards one another so that a few more or less uniform, to some extent even standardized, methods and procedures will emerge before long.

Some of the methods are partically or wholly in practical use.

Most of these new approaches towards power system planning rely heavily on modern mathematical methods like operations research, and would be virtually impossible without the electronic computer.

In addition to the acquaintance with these new planning methods, which I consider the most important single benefit of my fellowship, the latter also gave me a good general picture of and insight into the Swedish and Norwegian power industries; their structure and organization; the role played by Government in the power field; co-operation between power undertakings; research activities and many other aspects. This knowledge too, I feel, can be of great value to me in performing my duties.

4. APPLICABILITY OF THE RESULTS OF THE STUDY UNDER ICELANDIC CONDITIONS

The power systems of Sweden and Norway are both predominantly hydro, the bulk of the energy being generated by hydro-electric plants. This applies in particular to Norway where thermal power is virtually non-existent. In this respect Iceland lies between the two but closer to Norway, since in Iceland 97-98% of the energy is hydrogenerated. Further, the annual flow pattern of Icelandic rivers is by and large similar to that of Scandinavian rivers. Planning methods used by the Scandinavian power industry should therefore be quite applicable in Iceland although some modification may occasionally be necessary to suit special local conditions.

5. RECOMMENDATIONS TO THE ICELANDIC GOVERNMENT

Since, as is generally known, the power industries of Sweden and Norway are very advanced it would be fairly easy to draw up a list of items where we in Iceland could learn from the Swedes and Norwegians. I feel, however, that my recommendations may be of more value if I restrict myself to a few important items in such a list, treating the remainder in a more general way. My recommendations to the Icelandic Government, therefore, I formulate in the following way :

5.1 It is recommended that planning procedures for electric power systems presently under development in Sweden and Norway and partly in operational use be adopted for the planning of power systems in Iceland in the future. In some instances this may require some modifications of the Scandinavian procedures to adopt them to Icelandic conditions. In my view now is the right time to take up this matter, since we are here in Iceland at the beginning of comprehensive interconnections and integration of power systems. We are therefore now in a position to benefit from advanced planning methods almost right from the start with corresponding savings compared with less adequate methods. Although difficult to express explicitly in monetary terms, such savings can be very considerable. Just this "right from the start" opportunity will not exist a few years hence.

5.2 It is felt that planning of power systems clearly falls within the work sphere of the State Electricity Authority and its successor, the National Energy Authority. However, in order to promote the practical application of advanced methods in planning and operation of power systems in Iceland it is desirable that people outside the SEA/NEA participate in this work. It is therefore recommended that the SEA/NEA be instructed to set up a permanent Working Group on Power System Planning and Operation composed of members of their staff and under their leadership but if possible also with participants from the principal power producers in Iceland. The duties of this Working Group should be (1) to promote the application of advanced planning methods in the field of electric power in Iceland; (2) to keep informed on the developmental work in this field in other countries, the Scandinavian countries in particular, and (3) to the extent feasible to take part in such developmental work.

5.3 Finally, it is recommended that a close liasion be maintained by the SEA/NEA with leading Scandinavian institutions in the field of electric power, to keep informed on all aspects of the development of the power industry in the Scandinavian countries.

6. DETAILED ACCOUNT OF THE FELLOWSHIP STUDIES

1.

I arrived in Stockholm on Saturday Sept 10 1966 and started my studies the following Monday, Sept 12. After having met the officials of SIDA, the Swedish agency that arranged my study program in Sweden, and had my program, I went to the Skandinaviske Elverk power company (SEV) in Stockholm for a two-days visit.

2.

At SEV I acquainted myself especially with methods and procedures for optimization of hydro-plant operation. Engineers of the SEV have been among the leading ones in Sweden in the development of computer programs for these purposes. There appears to be two schools of thought in Sweden as regards treatment of possible power shortage in system optimization studies. One of them, proposed by the Sydkraft group and later on further developed by the SEV engineers, specifies a certain (low) probability level of power shortage as acceptable. This probability level may with the aid of the flow statistics be interpreted in terms of a minimum reservoir level in the water reservoirs of the hydro-plants in the system under study. This "minimum level" is different for different parts of the year. A graph of it versus time of year normally rises in summer ~~winter~~; reaches a maximum in early winter, ~~spring~~, falling off to a minimum at the beginning of the snow-melt season when it rises again. ~~at the beginning of the snow melting season when it falls off again~~. (This applies under Scandinavian climatic conditions; in other climates the curve would be somewhat different, depending as it does upon the annual flow pattern of the rivers.) The area below this curve is called the "minimum zone" and the method is often referred to as the "minimum-zone method".

Since the minimum-zone curve represents the "acceptable" risk of power shortage it follows that whenever the actual reservoir contents falls below this curve, all available thermal plant on the system is loaded to full capacity as long as the reservoir contents remains below the minimum curve.

Above the minimum curve each increment of reservoir contents is assigned a value equal to the cost of an equal amount of thermal generation. Since thermal plants usually differ in (variable) cost, and it is assumed that the cheapest thermal units are loaded first, this marginal value of the water in the reservoirs increases with falling reservoir contents.

The other school, chiefly proposed by Vattenfall (the State Power Board) maintains that, instead of fixing, somewhat arbitrarily, a certain minimum zone or a specified "acceptable" risk of power shortage, one should try to assign economic value to power shortage itself. In a model developed by Vattenfall engineers the value function or value in terms of the amount of shortage (in kWh) is a two-step function. In treating power shortage in the model, shortage may be looked upon as an expensive thermal plant. The two step power shortage function then comes latest in the sequence, after all thermal plant has been loaded to full capacity. In this way every drop of water in the reservoir is assigned a value, all down to maximum draw-down. On account of the much higher value assigned to power shortage than the cost of even the most expensive thermal plant, the water values near the bottom of the reservoir tend to be very high.

In both schools water values for a specified reservoir contents vary with time of the year, on account of the varying demand.

The various aspects of the "minimum zone" procedure of optimizing the operation of a hydro system were discussed with SEV engineers, as well as some associated computer programs, copies of which were given to me.

The SEV engineers also showed me a program they have written for computer studies of the availability of thermal plant in a mixed hydro-thermal system, based on a probabilistic treatment of forced outages statistics from existing systems (mostly foreign since Sweden does not as yet have much thermal plant).

Another point discussed at SEV was power transfer over the Swedish National Grid. Individual power undertakings usually subscribe to a specified amount of transfer, expressed in megowattkilometres (MWkm), the distance being taken as air-line distance between the point of input to the Grid and output from it. For this basic subscription the power company pays a certain anual rate, mostly fixed, regardless of whether the subscription is used to its full extent or not. The basic subscription may be increased at a short notice, usually for a lower rate pr. MWkm of power transfer, provided the Grid can overtake such additional transmission at the time requested, to which the Grid is in no way obliged.

The Grid is treated as an entity in respect to power transfers, irrespective of ownership.

It is customary for a power company to exchange power with the National Grid (or the State Power Board that operates it), selling power to it at periods of abundant power, and buying power from it at other times. This exchange takes place at a pure kWh-rate, which is variable. The sales rate to the Grid is based upon (but not necessarily equal to) the marginal water value for the company in question, mentioned above, and this varies with both time of the year and hydraulicity (river flow).

Finally, I had some discussions with the manager of the Electrical Engineering and Operations Department of SEV about various topics concerning calculations of power cost, such as "calculation rate of interest" and economic life, as applied by SEV in their power cost calculations.

3.

The next place I visited in Sweden was Vattenfall, The State Power Board. This is a large institution, located in a vast new building complex in Råcksta, a Stockholm suburb. I spent two weeks here, which were fully utilized. There is a lot of things to see at Vattenfall for a power engineer.

My stay at Vattenfall was divided roughly equally between (1) the Staff Department, that is mainly concerned with (long-term) planning of Vattenfalls generating system and additions to it, and with related subjects such as load forecasting, and (2) the Operating Department, the responsibility of which is primarily the hour-by-hour operation of the actual system and power exchange with other utilities as well as with the neighbouring countries Finland, Norway and Denmark, and via the KONTI-SKAN HVDC link, with the European continent (Germany).

At the Staff, besides acquainting myself with the general responsibilities and duties of that Department, I specifically studied their long-term planning procedures. In order to use the available time more effectively I confined my studies to the production planning section, leaving out althogether the transmission planning. The transmission problem in Sweden is in many ways peculiar to that country, with limited abblicabability to other countries owing mainly to the geographical distribution of the hydro-resources (which are located mainly in Northern Sweden) and the power market (which is mainly in Middle and Southern Sweden).

4.

Long-term planning of the generating system of Vattenfall is accomplished by optimization at a given stage of system development (corresponding to a given total load or a given year in a specified load forecast), which then is repeated at successive stages (e.g. corresponding to five years´ interval). An optimal system at a given stage is here defined as that combination of alternatives which render the sum of the variable costs (i.e. which depend on the mode of operation) of the entire system and the fixed costs of system additions at that particular stage, a minimum. The variable costs of each alternative to be included are those pertaining when the system - including the addition alternative under consideration - is operated optimally i.e. at the lowest variable costs for that particular alternative.

For determining the optimum mode of operation and thereby the minimum of variable costs for a particular alternative of system addition, the Staff engineers are using a computer programme that was originally developed by the Operating Dept. for optimization of their hour-by-hour operation of the system, with however, some of the shorter-term details omitted, since they are largely irrelevant to the general planning. This program is just the one that I was told of during my stay at SEV, which is based on the use of water values throughout, also in the case of a power deficit, which then, as previously noted, must be assigned an economic value.

5.

In addition to this program, which is used to compute the minimum variable cost (of operation), Staff engineers have developed another one to compute plant availibility for both hydro plants (which is limited chiefly by factors like river ice troubles and alternative water use such as for floating of timber) and thermal plants (where availability is limited chiefly by forced outages). The program computes expected energy deficit resulting from plant non-availability, given total plant capacity, including reserve plant. By adding this expected energy deficit to that resulting from low hydraulicity, computed by the first program, total expected energy deficit is obtained, which then may be multiplied by the unit cost of such deficit, mentioned previously, to obtain total system cost of energy deficit (which in this method is one of the items of variable costs of system operation).

In this way the minimum operating cost of the system is determined for a given alternative of system additions. Adding thereto the fixed cost of the additions and selecting the alternative with the lowest sum of these two items, optimization for a given stage (of system development) is thereby achieved.

6.

An important point to note in connection with long-term planning, the Staff engineers pointed out, was that if the operation-independent cost items did (or were assumed to) vary with time, then a sequence of system additions, each optimal according to the above criteria, does not have to be optimal when considering an extended period as a whole. A case in point here, it was noted, was nuclear power. Considering a given stage in a relatively near future an optimal alternative of system additions might include some nuclear capacity. If a longer period, 15-20 years say, was considered as a whole, on the other hand, and assuming that the installation cost of nuclear plants will gradually decrease as a result of technological improvements, then it might well be found optimal to defer the installation of such plant to the later part of the period considered, when the cost of installation has become lower. Similar considerations, of course, apply equally well to other types of plant, provided that their cost varies with time.

7.

The procedure employed by Staff engineers in this connection consisted of several steps. First, optimalization for a given stage was carried out at reasonably close intervals, say 5 years, and the sum of system cost i.e. total system operating cost plus fixed cost of system additions at the particular stage determined. Second, similar costs for the intervening years were determined by interpolation, creating a sequence or "stream" of annual system costs, anyone of which was at minimum (optimal) for the stage of the system as of that year. Third, this "stream" of annual costs is discounted to a common time point at the beginning of the period considered, and their present values added. This gives, for the planning period, the result of a sequence of "sub-optimizations" i.e. individual stage optimizations. Four, possible deviations from this result, due to variations in the fixed cost of system additions with time, are considered, one assumption at a time.

The program used for long-range optimization was described to me. It resembles the one developed at SEV for the same purpose, mentioned earlier, except that power deficit is assigned a value instead of specifying a priori a certain maximum acceptable probability of such deficit. The model is essentially a lumped storage -- lumped stations model with capacity constraints for the equivalent station, but includes subprograms for allocating generation between groups of station on various rivers and between individual stations. A step curve of the cost of supplementary power is applied. Supplementary power consists of thermal power, subscriptions from the Grid (occasional; in addition to basic subscriptions if any) and sales of surplus power (as a negative- cost category). The program first computes water-value curves for the water stored in the reservoirs by an iteration process, and afterwards simulates the operation of the system, using as a rule a 30 years record of hydrological observations.

Up to 104 periods may be included in the optimization process. They need not be all of the same length. The load within a period is represented by a straight-line approximation of a duration curve. The slope of the line is different for different periods.

The allocation program, instead of being a separate program, is included into the main, lumped-storage and station program, as subroutines.

It allocates the generation and storage release determined by the main program, between individual rivers and subsequently between individual "elements" on a river. An "element" is defined as a power station with accompanying reservoir or intake pond, together with associated regulable and irregulable inflows.

8.

In addition to this general methodology for the planning of the generating system, I also acquainted myself with the methods by which the underlying data and information were obtained. The various cost items are estimated on basis of the best evidence available. Cost of hydro stations is obtained from estimates of the construction cost of the plants actually under consideration in each case, since cost of such stations depend very much upon local conditions. This cost, I learned, will go up in the future as the available economic water power in Sweden is gradually nearing exhaustion. Operating cost of hydro is based largely on past experience. Owing to the growing scarcity of water power, more and more consideration is being given to thermal plant, especially oil-fired plant (Sweden does not possess any domestic fuel reserves, and imported oil is less expensive than coal). Some of the people I met on the Staff were whole-time concerned with thermal plants. The cost of such plants is assumed to decrease in the future (calculated at a fixed price-level, of course), as well as the price of oil. Nuclear plants of various design are also recieving careful consideration, as well as combined or dual-purpose plants for power generation and space heating.

I also acquainted myself with the underlying economic assumptions, such as rate of interest; economic life of the various plant types and so forth. Since Vattenfall is state-owned the Government specifies a minimum rate of recovery of the invested capital, but Staff engineers, in their computations apply a somewhat higher rate, on level with that prevailing in the private and municipal sector of the power industry. This "calculation rate of interest" is at present around 7% and has shown an upward trend in the past few years.

Finally, since all long-term planning in the power industry ultimately rests on the assumed rate of load growth, I studied Vattenfall´s methodology load forecasting rather thoroughly and read some of their

recent forecasts, a copy of which was given to me. Special care is taken in forecasting the industrial load, which for the time being comprises 65% of the total load of Vattenfalls.
A variety of factors are considered when making load forecasts for industry; some only qualitatively though. Among them are industrial production methods and their probable evolution with time; general technological developments in the appropriate field (which in some cases may render present methods obsolete); cost of competing energy sources relative to that of electricity, where such competion is a factor (like industrial process heating for example), and the probable time evolution of these cost relationships within the forecasting period ; general economic conditions and outlook in the industrial sector involved, especially competetivity of the industry and a number of other factors.

Of the non-industrial consumption sectors I asked specifically about electric space heating and how it was included into the general forecast, since this sector may be important in the Icelandic power industry in the future. I got valuable information on that point.

9.

The latter half of my two weeks´stay at Vattenfall (The State Power Board) was spent in the Operating Department. There, I studied the methods in use to optimize the operation of Vattenfall´s generating stations within a period of one week, and got a description of a computer program written by Vattenfall´s engineers for that purpose.
This optimization takes place within the framework of the long-term (i. e. seasonal) optimization program mentioned earlier in that the releases from the various reservoirs for the week as a whole is determined by that program. The present (short-term) program then allocates this total release to 14 periods within the week. Each day is divided into a 14 hour "day" period and a 10 hour "night" period.
The problem is to vary the hydro-generation between these periods in such a way that the cost of supplementary power over the week as a whole is at a minimum, observing all constraints. "Supplementary power" in this connection, besides thermal power, also comprises power deficit; purchase of surplus power from the Grid and sales of such power to the Grid (where the cost becomes negative).

Subdivision of the thermal generation between different categories of thermal plant is done by linear programming, using the so-called gradient method.

All computations are performed on Vattenfall´s CDC 3300 electronic computer.

Another program, for an hour-by-hour generation allocation, instead of using the "day" and "night" periods only, was under development. A particular difficulty with such a short time unit was that flow times between stations in series the same stream could no longer be neglected, which greatly complicated the computations.

A copy was given to me of the several forms and formulars used for the input data to the short-term optimization program, as well as of an output print.

At the Operating Dept, I also visited Vattenfall´s Load Dispatching Centre, from where the generation of all of Vattenfall´s plants is controlled. The actual hour-by-hour generation of all plants and various operating and hydrological data are punched on tape and afterwards processed by the computer into tables, for one week at a time.

Another topics studies at the Operating Dept were the Swedish tariffs and the rate structure and the procedures in use by Vattenfall in the operation of the Swedish National Grid, as well as the pooled operation of the power plants of several owners.

As I learned at the SEV, power companies wishing to tranfer power over the Grid subscribe to a certain amount of transfer, expressed as a product of the max amount of power (in MW) and the distance, in km. Subcriptions are put forward to Vattenfall 5 - 7 years in advance in a tentative form, and final values are fixed about 3 years in advance. These so-called basic subscriptions, together with local generation where appropriate, shall in principle be sufficient to cover anticipated so-called prime load i. e. total load minus sales of secondary or surplus power.

All power exchanges over the National Grid takes place with Vattenfall acting as an intermediate, even when the power is not produced in their plants, or used by them. Furthermore, exchanges over the Grid are limited to 8 members of the Power Pool, comprising Vattenfall and several large private or municipal power companies, or group of such companies. To be eligible to the Pool a power company must fulfill certain requirements as to size; plant availability; capability to meet its own maximum demand with a specified degree of reliability and so forth.

Each undertaking in the Pool is requested to make running calculations of its marginal water values and corresponding marginal power values at specified feeding points to the Grid. Sales of secondary power to the Grid or purchase from it takes place at a price that is the average of the marginal values calculated by Vattenfall and the seller/buyer at the point in question.

10.

After completing my studies at Vattenfall I went to the Electricity Supply Authority of Stockholm (Stockholms Elverk) for a two days visit. That undertaking is primarily concerned with distrubution and my studies there were therefore largely confined to that part of system planning. They do, however, own several generating stations of their own, both hydro and thermal. An interesting variety of the latter are the combined or dual-purpose thermal plants, intended both for power generation and space heating. Among them is a neclear plant, Agesta located underground in a Stockholm suburb. A problem with this type of plant is that the heating and power load are only to a limited extent coincident. I studied various methods used by Stockholms Elverk to overcome these difficulties, among which are combinations of back-pressure and condensation units ; electric boilers to supply part of the heat load when there is surplus of power at times of high heat load ; artificial heating loads coupled parallel to the district heating loads at times of power peaks. I also studied the relation between district heating and electric space heating. It appears that in Stockholm these two heating methods are complementary rather than competitive ; each being superior in a certain type of buildings.

I visited the Load Dispatching Centre of Stockholms Elverk, from where the generation of their plants is controlled. The LDC is located adjacent to a Network Control Room, where the distribution network within the city is constantly monitored.

It was interesting to learn that Stockholms Elverk, in planning their generation system, make use of the optimization program for plant operation developed at SEV and mentioned earlier.

Finally, I inspected one of Stockholms Elverk's combined power and district heating plant, the Hässelby Plant, an oil-fired plant located in the Stockholm suburb of Vallingby.

11.

My last study visit in Stockholm was a one-day visit to VAST, a Swedish short for the Establishment of the Swedish Water Power Association (SWPA). The SWPA is an organization of private and municipal power producers in Sweden; in some respects a counterpart within the municipal and private sector to Vattenfall, the State Power Board, which is not a member of SWPA. There is, however, very good cooperation between Vattenfall and VAST in great many fields.

I studied the organization of VAST, which is subdivided into two main department viz (1) Civil Engineering Dept. and (2) Electrical Engineering Dept. The principal objective of VAST is to study technical questions relating to the power industry. Their staff is relatively small, and much of their work takes place in ad hoc committees consisting of people from VAST's member companies, with a secretary from VAST's staff. Much of the committee works is thereby transferred to the staff of the members, although a considerable part of it falls on the secretary, especially administration and coordination. Sometime the help of outside consultants is also hired. A so-called Research Council, comprising 10 of VAST's members supervises the activities and decides on formation of new committees or disolution of existing ones.

The SWPA has a long and eventful history. Through VAST it has played a leading role in initiating and promoting a great number of innovations and improvements in the power industry. It was partly at the initiative of their so-called Power Balance Committee that the engineers of SEV developed their optimization program mentioned earlier, and VAST was presently promoting their current work on plant availability, also mentioned earlier. The outages statistics required for this study was being collected by VAST.

The VAST committees report their findings in a publication series "Publications of the Swedish Water Power Association". In this series many important innovations have first been reported.

12.

I left Stockholm on Sunday Oct 2 for Malmö, where I went the next morning for a week's study visit to South Sweden Power Company, Sydkraft, who have their head office in that city.

After a general information about Sydkraft and its operation, I learned about the Krångede Power Pool, which consists of 5 municipal and private power companies, of which Sydkraft (that is mostly owned by municipalities and cooperatives in Southern Sweden) is the largest. As mentioned in connection with my visit to Vattenfall, all power exchanges that require transfer over the Grid must take place with Vattenfall, even when two members of the same power pool are involved. Therefore, the Krångede Pool appears as an entity in all external exchanges (i. e. with Vattenfall). Within the Pool, however, power exchanges take place directly between members. The operation of the Pool is partly, but not fully integrated. There is a common Load Dispatching Centre, LDC, that determines the optimal mode of operation for the Pool as a whole if it was fully integrated, and report the resulting station loadings to the individual plants as "recommended loadings". It is not compulsory for the members to follow these recommendations of the LDC. In most cases they do so, but deviations do occur. I got the impression that in the future the operation would be fully integrated and individual loadings finally determined by the LDC. Before that, I was told, some practical ways had to be found to divide the benefits of pooled operation between the members. Presently, with each member retaining full freedom to load his stations, no attempts are made at dividing the benefits of the cooperation.

The LDC also computes the average marginal power costs for the Pool as a whole, referred to the points of exchange with the Grid.
The price of the power exchanges with Vattenfall is - on the part of the Pool - based on these costs.

13.

My most important single subject of study at Sydkraft was their methods of planning the operation of their power plants. It were two Sydkraft engineers, Mr. Stage and Mr. Larsson, who originally, in Sweden at least, devised and formulated the principles of optimal operation of a combined (hydro-thermal) system, like that of Sydkraft. A computer program of their original method was in use by Sydkraft till 1963/64. A special version of this program was used to plan system additions.

Presently the whole of the Krångede Power Pool, of which Sydkraft is member uses the program developed at SEV, mentioned earlier. A limitation in this program, Sydkraft engineers felt, was that it did not take into account as a constraint the limitations in transmission capability of the Grid, as fact which affects Sydkraft in particular, which is located near the southernmost tip of Sweden, but owning hydro plants in Northern Sweden.

Another program for the same purpose is presently being worked out at Sydkraft, I learned, the first part of which was intended for short-term operation planning. This new program includes such items as start-up costs and fixed (i.e. load-independent) running costs in addition to the MWh-costs. Here, limstations in transmission capability are also included.

In the short-term part of the program, each week is subdivided into 5 identical weekdays, a Saturday and a Sunday. Each weekday may in turn be further subdivided into 8 periods and the Saturdays and Sundays into 2 periods each. Whereas in older short-term programs duration curves were used to represent load variations within the unit interval of the corresponding long-term program e.g. a week, in the new one the time identity of load variations is retained by the use of a chronological curve instead of the duration curve.

The length of the individual periods within a day my vary as long as their sum is 24 hours. A seperate subroutine determines the length of each sub-period (within which the load is assumed constant) by dynamic programming in such as way that the sum of squares of the deviations of the resulting load curve from the actual one on which the calculations are based, are a minimum.

In addition to this program, which is now about ready for use, it was intended, I learned, to develop two others, for different time lengths. All three might then be combined if necessary. The complete program would then comprise three component programs :

1) A short-term part, up to 24 hours. Number of periods up to 8. Wholly deterministic, with releases from seasonal storages predetermined. This part determines the optimum allocation from period to period.

2) Medium-term part, to determine optimum generation a week or so ahead.

3) Long-term part, covering up to two years.

14.

Still another subject studied at Sydkraft was the application of gas turbine plants in a mixed hydro-thermal system, like that of Sydkraft. Sydkraft engineers were engaged in studies of the various aspects of this problem. Among them: light-fuel versus heavy-fuel plant; noise; starting times ; maintenance; effect of number of starts on the time between overhauls and plant life ; synchronous condenser application of gas turbine units; optimal combination of number of starts and idle running time, and others.

15.

Load forecasting methods in use by Sydkraft were also studied in some detail. It appeared that the most used method was an extrapolation of the growth curve for the aggregate load. The inquiry method, widely employed by Vattenfall for industrial consumers was little used by Sydkraft, chiefly on account of the large number of relatively small industrial consumers in their supply area.

16.

Electric space heating and company policy in that respect was studied to some extent. Sydkraft does promote electric space heating mainly through their service personnel although it does not drive much open propaganda for it. The space heating load is growing rapidly, mainly through replacement by this heating method of coal- or oil-fired central heating in older houses with inefficient or outmoded heating systems, as well as through space heating installations in newly-built single family homes.

There are no tariffs specially designed for space heating and no restrictions are imposed upon the consumer in respect to maximum demand or time of the day when the heating system may be used. It appeared that the company did not try to promote this heating method so much on the basis of economy to the consumer as on basis of such factors as ease of application, comfort, cleanness ; air pollution reduction etc.

As to the effect of space heating upon the distribution systems and the possible need to reinforce them to carry the heating load, the prevailing attitude seemed to be that space heating was in no way peculiar in this respect. Any load growth necessitated gradual reinforcement of the distribution system, something every utility had to accept and prepare itself for.

17.

The calculation rate of interest employed by Sydkraft was the subject of some of my questions. It appeared that Sydkraft uses very much the same procedures in arriving at this quantity as were in use at SEV, which I had been informed about during my stay there. Both companies raise a substantial part of their capital on the same market, mostly by the issuing of bonds. Such issuing is subject to permission by the National Bank. No Government guarantees are normally on such bonds.

18.

My last day at Sydkraft was devoted to an inspection trip to Sydkraft´s Öresundsverket 400 MW steam plant near Malmö, the largest thermal plant in Scandinavia, and a 400 kV transformer station, Sege, also near Malmö.

19.

On the following day, Oct 8, I left Sweden by train to Oslo, Norway, where I arrived in the evening of that day. The Norwegian Agency for International Development, NORAID, sent a man to recieve me at the railway station and follow me to a hotel where they had reserved a room for me.

The following Monday morning, Oct 10, I was met at the hotel by Mr. Cappelen who had recieved me at the railway station on behalf of NORAID. He took me to the head office of the Norwegian Water Resources and Electricity Board, NVE. There, I was introduced to Mr. Tor Skjervagen, NVE's Information Consultant. The NVE had, at the request of NORAID, undertaken to arrange my study program in Norway, and had assigned that job to Mr. Skjervagen.

20.

I visited a number of departments and sections within the NVE. I learned that power system planning is a subject of thorough and vigorous study there, and that various approaches are being tried out.

First, I visited the Dept for Investigations of the Water Power Resources, VU, under the Watercourse Directorate. The Dept is lead by Mr. E. Wessel, the Project Manager of the Iceland Special Fund Project. The VU takes care of site investigations; collection of available existing data, like stream-flows, and engineering studies, primarily feasibility studies and project evaluation studies of new power projects which the State Power Works, SPW, (another Dept. within NVE) might undertake. The VU furthermore prepares concession statements required from NVE by the Government and the Storting (parliament) in connection with concessions to power companies to construct hydro-electric power plants. The VU people evaluate the proposed projects for which concessions are requested.

At the VU I studied procedures, developed by VU engineers, for statistical treatment of stream-flow series prior to its use in power system planning. Basically, these procedures are the same as presented by Mr. Wessel during the Iceland Project, and described in his report, but some modifications of these are being tried out. Starting by May 1st, the normal distinction between draw-down and fill-up of seasonal reservoirs in Norway, the stream-flow series of - normally - 30 years is used to compute accumulated inflows to the reservoirs counting backward from May 1st for a period of 2 or 3 years. A series of such inflows is computed, each with a specified exceedance probability.

For example the curve with 95% exceedance probability then shows the amount of water required in the reservoir at any time if the probability of an untimely emptying of the reservoir (i.e. before May 1st) which would entail power shortage is not to exceed 5%. In this way a prescribed risk level of power shortage is incorporated into the hydrological basis for all subsequent calculations.

21.

The model used in this method is the single plant, single reservoir model. There remains the problem of allocating the output between the various plants and reservoirs. This is accomplished much along the same lines as used by Vattenfall in Sweden, i.e. equal spill-over probability at all reservoirs is the goal sought after.

Theoretically, the reservoirs may be empty at time zero in the calculations, the start of the fill-up period. But in order to account for the fluctuations in the actual date that marks the distinction between these two periods, a certain "residual storage" - usually about 5% of total reservoir volume - is prescribed at computation time zero.

22.

Next at NVE I visited the Electricity Dept. of the Electricity Directorate. I was first given a brief historical outline of the development of the Norwegian power industry and utilization of the country's big and cheap hydro-electric power potential. The cheapness of hydro-electric power has put Norway far ahead of all other countries in the world in consumption of electric power per capita, mainly through the large consumption of the so-called power consuming industries, which are very important to the Norwegian economy, but also through the wide-spread use of electric space heating, which, in turn, owes its existence to the cheapness of the power.

The Norwegian power industry traditionally consists of a fairly large number of power undertakings of all possible kinds from pure private companies over municipal to 100% state-owned undertakings.

In recent years, with the advent of interconnection, the large number of power undertaking has created a great need for coordination of future power developments. Precisely this coordination - in the widest sense - is the chief objective of the Electricity Dept. It is endeavoured to bring about the coordination by establishing and reinforcing co-operation between the existing power undertakings, under the general guidance and with the help of the Dept. The Dept. takes care of various activities, which are assigned to appropriate sections within it, such as accumulation and processing of data and information of various kind pertaining to the planning of the power industry, and distributing the results to all concerned ; general load forecasting and so forth.

One of the sections under this Dept. is concerned with a study of the optimum allocation of power generation in Norway in the future between various energy sources or type of plant, such as hydro, gas turbines, steam-turbines of various categories and so forth.

This study aims primainly at the future, since electric power generation in Norway is presently almost 100% by hydro, a situation that is expected to change somewhat before long, although hydro is expected to play the dominant role for a long time to come. A computer program is presently being developed that will automatically select various allocation patterns by cut and try methods and compare them. Optimal operation of the existing system will constitute a sub-problem in this study.

The approach used is basically similar to that used by Vattenfall. It was felt, however, that evaluation of power shortage played a greater role here than in Sweden, owing to the fact that thermal power was practically absent in Norway, so that water values would primainly be based upon the evaluation of power shortage. This was a most difficult problem, since the value of a power shortage varies widely between various categories of consumers ; probably between 7 and 100 N. öre pr. kWh for industrial consumers. For domestic consumers the evaluation would be still more difficult. Attempts were being made at obtaining information on this point through questionnaires to consumers.

An obvious consequence of the variation in the cost of power shortage, i.e. the value of power to various consumer groups ought to be that the power is first cut off from those groups to which it has the lowest value. Apart from purely technical difficulties of such a procedure, this is, however, in direct conflict with a basic axiom of a democratic society, viz that all consumers have equal right to the access to electric power, regardless of its value to them. Therefore, some sort of a wighed average cost of shortage would have to be used.

For the planning it was proposed to assume first a given load, i.e. to consider a given stage of development. The various alternatives to meet this load are considered and the fixed (i.e. operation-independent) costs of each determined. Then for each alternative the mode of operation of the system is optimized to bring the operation-dependent costs to a minimum. Adding the fixed costs to this minimum gives the total costs for each alternative. The alternative with lowest total costs is then the optimal one for the given stage. The general philosophy thus seems to be the same as adopted by Vattenfall.

The model used is that with a single equivalent plant and a single equivalent reservoir to represent the whole system. No satisfactory methods of allocating the output from this model between the individual plants and reservoirs had been worked out, I was told. The allocation, it was felt, was considerably more difficult in Norway than in Sweden, for various reasons, among them the larger variations in the degree of regulation (reservoir volume in relation to average annual inflows) in Norway than in Sweden, and to the usually larger number of stations in a single river system in Norway.

Still another section is concerned with evaluations of power projects for which concessions are sought by power companies. Coordination considerations weigh heavily in all such evaluations which therefore is an important tool for achieving the objectives of the Department.

23.

I also paid a visit to the Computation Centre of NVE. The Centre carries out all kinds of computations and data processing for the various Departments and sections of the institution, except very large and elaborate ones, for which more powerful equipment is needed. Processing of hydrological data constitute a large part in the present work of the Centre, the workload of which has grown very rapidly over recent years.

24.

Next to be visited at NVE was a section of the Department for Government Aid and Control, also under the Electricity Directorate, called the Office of General Questions. This section is above all concerned with financial problems and rationalization measures within the power industry.

In Norway the Government has long maintained a control of the domestic capital market in that Government concent is required for the issue of bonds or other forms for capital raising on the inland market, and the Government specifies the interest and other borrowing conditions. A certain part - in the past a considerable one - of the capital to be raised on the domestic market is earmarked for the power industry. It is the duty of the Office in question here to distribute this amount between the various power undertakings. Since the demand is usually higher than the capital available, this is a difficult task. For this purpose proposed power projects are ranked by the Office in descending order of priority. Various criteria are used for this priority ranking - and it is attempted to effect this ranking to the largest possible extent from the point of view of large communities or areas rather than from that of the initiators of individual projects. In other words the importance of the projects to an area or a region is given more weight than its importance to the individual power undertakings sponsoring them.

Another important activity of this Office for General Questions is rationalization of the power industry, especially structural rationalization. Traditionally there is a large number of relatively small power undertakings in Norway, many of which are now considered too small in relation to the modern emphasis on "economy of size" and interconnection. Therefore, attempts are being made at creating larger and economically stronger undertaking. through merger of the smallest one. What is aimed at is not nationalization or even a predominant State role, but rather a suitable number of reasonably large power undertakings, economically and financially strong, supplemented by State undertakings, to which is assigned the function of creating a balance between the private and municipal sectors of the power industry, as well as that of equalization between various parts of the country, above all in respect to power costs.

It is attempted to bring about the merger largely voluntarily, through persuasion and help from the State. When necessary, however, a certain amount of pressure is also exerted from the side of the Government - through the priority ranking mentioned above and through administration of State subventions to the power industry in the economically weaker parts of the country, where the smallest power undertakings are also found.

25.

After this followed a visit to one of the sections of the Sales Department of the State Power Works, SPW, the largest of the Directorates of NVE. This section is known as the Office of Water Economy. It has several function, among them collection and processing of hydrological data for use in planning of the operation of SPW plants. The most important function, however, was the actual operation planning.

For practical purposes this planning is subdivided into two categories, long- and short-term planning, although no clear-cut line of demarcation between them exists. Usually the term short-term refers to periods of a week or two; long-term up to 1-2 years. The Office is, in cooperation with the Power Industry Research Institute (EFI) developing an algorithm for short-term optimization, and a computer program has been prepared. Up to now the program treats only one plant, except in a few cases where a group of plants may be treated, lumped as an equivalent plant. The optimality criterion used is the minimum use of "natural energy" (i.e. water x head) to supply the given load over the period considered, up to 1-2 weeks. The total generation of the two weeks period is either determined empirically or with the aid of a long-term program, mentioned below.

Up to now, only a proto type of the short-term program, comprising (as an equivalent plant in long-term planning) a group of three power plants and reservoirs has been worked out. What this proto type does is (1) to subdivide the total 14 days generation and draft of the group between the three plants of the group, and (2) to determine the hour by hour generation of each plant. The first part is undertaken separately from the last. The philosophy is here that the risk of spill shall be essentially the same at all three plants. The procedure applied is pure simulation, i.e. a tentative plan of operation is adopted; a simulation over 40 years of hydrological record undertaken and the resulting spill probability for each plant computed. If the three spill probabilities differ from one another by more than a specified amount, a new plan of operation is tried, a new simulation undertaken, until the probability differences come within the tolerance limit.

26.

The second part of the procedure, determination of the hour by hour generation of each plant is then undertaken, using as a constraint the total 14 days generation determined by the first part. A load for the entire group must also be specified hour by hour. No account is here taken of either thermal generation or sales of secondary energy ; they are assumed to be implied in the long-term strategy adopted (and showing itself in the 14 days generation specified). Optimization criterion is minimal use of "natural energy" for the generation. Both the number of units in each generating plant, their size and variation of their efficiency with loading is hereby taken into account. The procedure adopted consists essentially of dividing the total load into a suitable number of discrete steps, and for each step, determining all possible combinations of units in operation and their loading, and computing the total natural energy use for each combination. In computing total "natural energy" account is taken of the fact that the starting of a unit involves a certain waste of water until it has picked up load; i.e. a certain start-up cost, in terms of natural energy, is included.

For a given hour - and consequently a given total load - the computer automatically selects that combination of units in operation and their loading, which satisfies the given load with minimum use of natural energy. This process is repeated for all 24 hours of the day.

The computations involved are too elaborate to be carried out by NVE´s own computer. Instead they are run on a UNIVAC 1107 at the Norwegian Computation Centre, Oslo.

The program is not yet in operational use, I was told, but was expected to become so very soon.

27.

The problem of long-term optimization (a year or more ahead) has also been taken up by the Office of Water Economy, and work on that is now in progress. The basic methodology adopted appears to be similar to that used by Vattenfall, with a single-plant model and subsequent allocation for equal probability of spill at all reservoirs. An interesting feature of the proposed method is that it is intended to take the temperature - dependency of the load into account in the simulation undertaken after water values have been computed. Since the procedure is intended primarily for operational planning rather than system planning, continuous simulation over the whole period of stream flow record is not contemplated. Instead, a three year simulation will be undertaken, starting with actual reservoir contents. All three years periods contained in the stream-flow records are run through, and the results treated statistically, i.e. values of generation, power shortage etc. corresponding to specified probabilities are computed.

Some tests have already been undertaken of this program.

28.

My final visit within the NVE was to Mr. H. W. Bjerkebo Deputy Director-General of the Agency, who gave me an excellent overview of the functions of NVE, especially as regards general policymaking and its role as an adviser to the Government.

29.

Another institution to be visited was the East Norway Power Pool (Østlandets Samkjöring; "Samkjöringen" for short) or its head office in Oslo. The Pool, which is a company with limited responsibilities, does not itself own power plants, transmission lines, or for that matter, any physical plant, unlike Sweden's Vattenfall. Furthermore, it is not at all concerned with fixed, contractual power exchanges. It merely serves as a kind of power market or stock exchange for surplus power which cannot be guaranteed with any reasonably high degree of availability. The purpose of the Pool is to help its members, which are power undertakings in the Eastern Norway Interconnected System, to get maximum economic benefits from their plant. It achieves this purpose by maximizing the income from sales of surplus energy;

in fact this is the only means available to the Pool since there is no thermal plants in the East Norway Power System.

All power sales from the Pool to its members take place at a fixed rate (for a year at a time) pr. kWh, irrespective of the time of the year. The price contains a base price plus a certain percentage - fixed, inespective of actual loadings - to cover transmission losses, and a 6% contingency for the Pool itself.

Each member announces to the Pool how much energy he wishes to sell to the Pool at any specified time. Formally, all this energy is "sold" to the Pool, even if some of it may actually not be generated, in which case it either appears as spill in the total System, or it is stored (as water) in the reservoirs of some of the members.
The Pool maintains a Load Dispatching Centre, LDC, which determines the loadings of the various plants and releases from individual reservoirs in the System. It is compulsory for the members to load their plants in accordance with LDC instructions, but the LDC is not entitled to undertake any physical manipulations of the System like breaker operations, governor or exciter adjustments etc. in Member Stations.

In addition to sales to its members at a fixed rate the Pool may also sell surplus energy to outsiders at a variable (and usually much lower) rate, depending upon the actual market situation. The only domestic non member market for surplus energy is sales to industrial plants for steam-raising purposes in electric boilers. Another possibility is sale to the State Power Works for resale to Sweden (the SPW only is entitled to undertake power exchange with foreign countries).

Income from power sales from the Pool in a given period is, after deduction of loss contingencies and Pool earnings (6 %), distributed among the members in proportion to the amount of energy each has announced as available (and which is formally "sold") to the Pool during the same period.

30.

I paid a short visit to the Pool's LDC which is situated in a main transformer station near Oslo. The function of the LDC is twofald, viz

(1) to determine loadings of stations and releases from reservoirs, and (2) to supervise the operation of the East Norway Grid in respect to voltages at various points and other such factors. Under this supervision also comes collection and processing of data on forced outages of System elements like generating plants, transmission lines and substations.

Each member of the Pool makes his own plan of operation for his plants and makes it available to the LDC. Usually, these plans can be followed by and large, but if necessary or desirable the LDC can modify them. Normally, such modification is effected through persuasion by contact between the LDC and the operators of the stations in question rather than by direct order from the LDC, which is used only as a last resort.

The guideline used in distributing the total generation between stations is that the probability of spill shall be essentially the same at all reservoirs - or at least that there shall be no great differences in this respect. This objective is achieved largely empirically, by loading reservoirs in order of descending "degree of regulation" (i.e. size in proportion to annual inflow) of the reservoirs. Computer - based optimization procedures have as yet not been used.

31.

The East Norway Power Pool maintains a Hydrological Section that collects hydrological data from members and from other sources (primarily NVE´s Hydrological Dept.) but does not maintain a hydrological network of its own. The work of the Section is in many respects similar to that of the Office of Water Economy of the NVE. The Section prepares annually forecasts of reservoir contents, based on the actual situations at the time the forecast is made, plus the statistical parameters of a 30 years hydrological record. Usually three separate forecasts are made, based on (1) median, (2) lower quartile and (3) "determining" (i.e. 90% exceedance probability) conditions. In addition to actual contents the number of reservoirs in the system also varies from year to year so that annual forecasts are warranted, even though they are statistical in nature.

These forecasts are made for each reservoir and intake dam in the System.

Attempts have been made at making these forecasts somewhat less statistical, or to combine statistical forecasts with those based on direct observation. In this case inflows from liquid precipitation are treated statistically, in the manner just described. In addition inflows from snowmelt are estimated on basis of actual observations of the snow cover and added to the others, to give total inflows.

The statistical treatment of the hydrological data is very similar to that undertaken by the VU-department of NVE, described above, viz. that curves of flows accumulated backwards from April 15 are computed for each year of record, creating a family of curves, from which another set of curves, each pertaining to a given value of a statistical parameter instead of to a given year of record, is determined. These curves are applied in the above mentioned statistical forecasts.

32.

Still another section of the Pool is the Accounting Section which takes care of weekly accounting of the power bought and sold by the Pool.

For accounting purposes the concept of the Central Grid (Hovednettet) is used by which is meant that part of the East Norway main transmission network which lies within the Pool´s operational area. The Grid is owned to 80-90% by the State Power Works ; the remainder by other members of the Pool. Inputs to and outputs from the Grid are measured at certain points which are agreed upon beforehand. For power transfers across the Grid losses as preliminarily computed at 4% and any deviations of actual losses from this figure are in the first instance absorbed by the SPW, to be finally distributed once a year. Annual losses in the Central Grid are difined as the difference between annual inputs to and annual outputs from the Grid.

The Pool takes a transfer charge for power transferred over the Grid proportional to the amount of power (in MW) times the air distance (in km) between points of input into and output from the Grid.

A special feature to be considered is the storing of energy by the Pool.

The Pool can store energy in the reservoirs of its members, for release later. The stored energy is included in the accounting for the period in which it is stored by placing on it a sales price zero. The member, in whose reservoir the storing takes place is entitled to a store charge from the Pool. This charge is paid in kind, i.e. in energy, instead of money. It amounts to 25% of the stored energy, irrespective of the storing period, which means that the Pool can take out 75% of the stored energy and sell it during such periods when the demand for secondary energy exceeds the amount announced as available by the Members during the same period. The remaining 25% belong to the owner of the reservoir in exactly the same way as energy stored there by himself instead of by the Pool.

33.

The organizers of my study programme in Norway, NORAID and NVE, had provided a visit for me to Mr. Mellum, Under-Secretary in the Ministry of Industry, who is the chief of a Department within the Ministry that is concerned with watercourses and electric power.

Mr. Mellum briefly outlined to me the principal laws and regulations pertaining to flow regulation in streams and hydro-electric power developments.

In principle, only the State is entitled to regulate the flow of rivers, but the Government can transfer this right to public or private bodies through the so-called concessions, in accordance with the provisions of the Concession Act.

Municipal bodies do not require concessions to buy or otherwise acquire ownership of riparian rights or watercourses. But they do require concessions to regulate the flow, even if they own these rights. Once the flow regulation concession is obtained, no further Government permissions are required to develop hydro-electric power, except where expropriations of real estate are involved.

I asked about the Government's regulation of the capital market and the implications of that regulation for the power industry.

The general administration of the Government's policy in this field is in the hands of the Ministry of Finance, although in all matters relating to water power development the details were left with the Ministry of Industry. It has been the policy of the Norwegian Government all the time after World War II to keep the interest rate on capital low. For this purpose the Government has had the whole Norwegian capital market under control and there was no market mechanism working. In the first post-war years there was an excessive supply of capital on the market and the interest rate was very low. It has gone up considerably since then, and is now fixed at 5% for Government bonds and other bonds with Government guarantee; at 5.5% for bonds issued by municipal undertakings and at 5.75% for privately issued bonds.

The Government also decides who shall be allowed to raise capital on the domestic market in a particilar year. As far as the power industry is concerned Mr. Mellum's Department in the Ministry of Industry, with the aid of NVE selects the power undertakings that are admitted to the market. Attempts are made to coordinate the administration of this matter with the issue of concessions so that a power undertaking which recieves concession for a project in a given year is also permitted to raise capital in the same year, to avoid delays in the implementation of projects for financial reasons.

The interest rate is fixed on basis of broad evaluations by the Government of the country's financial and economic situation at any particular time.

These measures apply to the whole economy and are in no way restricted to the power industry.

The low interest rate and the low price on electric power in Norway has entailed a very low degree of self-financing in the Norwegian power industry. With growing shortage of capital, both on the domestic and international market, voices are being heard that the degree of self-financing must be raised through raising of the power prices. However, up to present there have been strong objections to higher power prices, especially from municipal undertakings where higher prices of electricity may be a delicate political question.

34.

A visit was also arranged for me to the Oslo office of the Power Industry´s Research Institute (EFI). EFI is an independent organization operating under a Governing Council of representatives from the power industry, Government institution and the Norwegian Research Council for Science and Engineering, NTNF. EFI has its headquarters in Trondheim where it maintains a laboratory on the campus of the Norwegian Technical University.

Among the duties of the Oslo office were literature studies; technical and economical evaluations of various kinds, statistical studies and documentation services. The Trondheim Laboratory, on the other hand, is concerned with both laboratory and field measurements and testing, as well as with more theoretical studies, where the expertice available at the NTH is freely drawn upon. While entirely a seperate organization EFI cooperates closely with the Technical University.

I was given at the Oslo office an excellent overview of the spectrum of activities of EFI. Here are a few examples : (1) Apparatus and material testing for Norwegian manufacturers and importers who want such testing by a neutral institution and under Norwegian climatic and other environmental conditions. (2) Grounding problems in power systems. (3) Ice formation on overhead lines and mountain peak radio link stations. (4) Interference between power and telecommunications lines, both from a technical and legal point of view. (5) Design and sizing of rural lines. (6) Application of large electric motors on farms and their influence upon the rural network. (7) Registration of lightning strokes on power systems. (8) Registration of forced outages in high-voltage distribution systems. (9) Stability studies. (10) Various technical and economical evaluations. (11) Optimization studies. In this last category several reports have already been written, and EFI is presently working on this problem in cooperation with NVE.

The power industry participates in many of these studies through ad hoc working groups with members from power undertakings but the EFI providing the secretary for the group and performing most of the actual job. The Members are selected from undertakings or institutions that are really confronted with the problem under study, to secure active participation in its solution by the Members.

Another institution to which I paid a short visit is the Institute of Atomic Energy, IFA at Kjeller, near Oslo.

IFA was formed in 1957, but was preceeded by the Joint Establishment for Nuclear Energy, JENER, formed in the early fifties, as a cooperative Norwegian-Dutch undertaking. Before that, however, the Norwegians had started their nuclear work and incidentally IFA operates one of the first reactors to be built anywhere outside the USA, an experimental and testing facility.

IFA is concerned with a wide range of activities, but for practical reasons I confined myself to only one field : Power reactors.

IFA is since 1965, in cooperation with one of the largest industrial concerns in Norway, Norsk Hydro, working on a feasibility study of a nuclear power plant in East-Norway for construction in the mid-seventies. I was informed quite comprehensively about this study, which to-date has consisted mainly of comparative analysis of various reactor types. It emerged clearly from the study that the outlook for economical, competitive nuclear-generated electric power in the near future is closely associated with the trend towards larger units, 500-1000 MW or even more in a single unit. Since such unit sizes will be far too large for Icelandic conditions for a long time to come, I asked about the prospects that moderate or small-sized nuclear plants - say about 100 MWe - may become competive in a foreseeable future. The answer was that it was very difficult to assess the future evolution in the nuclear power field. The present trend was definately towards "economy of size". There were certain reactor types emerging, however, like the SGHWR (Sodium-graphite heavy water reactor) which in a way looked promising in the smaller-size range. Units of this type, 100-150 MWe, would be much cheaper, according to estimates, than units of similar size of the more common reactor types. No reactor of the SGHWR type has been built to date, however.

To some astonishment I learned that the economic comparisons between reactor types were based on an assumed useful life as long as 25 years for the nuclear plant, exclusive of the heavy-water inventory in the HW reactor types, for which 40 years life was assumed. Interest was assumed 7% p.a. I was told that such lifetime assumptions were a common practise in nuclear power estimates.

36.

In view of the prominent importance of so-called power-consuming industries for the electric power industry everywhere such industries are found, a visit was arranged for me to two Norwegian firms in this category. They were Norsk Hydro, one of the largest industrial concern in Norway and one of long history (it dates back to about 1905), and an aluminium smelter at Sunndalsöra.

The Norsk Hydro is primarily an electro-chemical firm with a wide range of products. I paid a short visit to its head office in Oslo. The most interesting thing I learned there was that Norsk Hydro was going away from its traditional electrolysis methods for producing hydrogen, over to petrochemical methods which recent technological developments and lower oil prices have made more economical. I gathered the impression that electrochemical methods in general were losing ground to other non-electrical methods. On the other hand, according to the views held by Norsk Hydro, electrical reduction methods still held their position in the production of non-ferrous metals, and probably would continue to do so for a long time. Norsk Hydro have plans to extend its activities into the metalurgical field (in which the firm has not been involved hitherto) by taking up production of aluminium, using some of the power that would be freed from the electrochemical production after the switch-over to other methods there.

The aluminium smelter I inspected is located at Sunndalsöra at the bottom of a long West-coast fiord some distance south of Trondheim. It is owned by the Årdal-Sunndal Aluminium Company. It is fed from the near-by Aura Power Plant, about 5 km away, at generator voltage via a great number of overhead lines. Besides inspecting the plant under the guidance of engineers from the Works, I also learned there about the load characteristics of this type of power consumers ; the relationsship between power consumption and output and the special requirements imposed by a consumer of this characteristics and magnitude on the power supplier.

I also seized the opportunity to inspect the Aura Power Plant, a

300 MW plant owned by the State Power Works. The machine hall is blasted out of solid rock 300 m inside a steep hillside, and the general layout is more or less typical for Norwegian high head plants.
The head is ab. 800 metres. Since the drainage basin from which the plant draws its water is at so high an altitude most of the winter precipitation falls as snow. Storage requirements are therefore high but the plant has also plentiful reservoir space in two mountain lakes. An interesting feature of this plant is a "roof gutter" or a system of tunnels high up along nearby hillsides which tap mountain brooks and feed the water into the seasonal storage, thereby considerably increasing the are providing water to the plant.

37.

Finally to be mentioned is a visit to the Norwegian Computation Centre in Oslo where I was informed about the activities of the Centre and inspected their computation facilities.

The purpose of the Centre is threefold : (1) Service computations, (2) system analysis service and (3) research. The Centre cooperates closely with the SI, the Norwegian Central Institute for Industrial Research and is located ajacent to the main buildings of that institute, although it is an entirely independent institution. The bulk of the Centre´s activities goes to jobs for outsiders on a service basis, although a considerable time goes for program testing for the staff and for research computations undertaken by staff members. The charge for commercial consumers is around Nkr 3600 per hour for the computing unit itself plus a small charge for the periferic equipment. Research institutions recieve various reductions in the charge.

Most of the outside jobs come from industrial firms. I was given two examples of such jobs undertaken lately. Both involved simulation of the operation of industrial plants. I was also given examples of research work now in progress at the Centre, such as (1) development of a large program for linear programming and (2) development of a computer language to describe simulation processes.

The Centre maintains a staff of system analysts and programmers.

Total number of employees is around 100.

The Centre´s "hardware" consists primarily of a UNIVAC 1107 digital computer with a core memory of 32 kilowords of 6 characters or 36 bits each. In addition it has a magnetic drum random access memory with 1.5 million words of 36 bits each. Access time around 8 ms.

The input-output equipment consists of one card reader; one on-line printer; a card puncher; 4 magnetic tapes with a reading speed of 60 kilocharacters per second and 6 (older) tapes with a speed of 25 kilocharacters a second.

Furthermore, the Centre also has a satellite computer of type UNIVAC 1004, connected to the central unit,the 1107. The satellite may be connected via usual telecommunication channels to a similar unit at a remote location and be used to transmit or recieve data. During such remote operations the main computer is occupied only during actual computations; receipt of program and data, as well as transmission of results are taken care of by the satellite and other periferic equipment.

The satellite computer has two magnetic tapes connected to it.

A device known as MODEM is required for the actual connection of the 1004 to a telephone or other telecommunication channel.

7. CHRONOLOGICAL LIST OF INSTITUTIONS AND AGENCIES VISITED

1966

Sept 12-13	Skandinaviska Elverk (SEV), (Scandinavian Power Company), Kammakergatan 7, Stockholm, Sweden
Sept 14-27	Statens Vattenfallsverk (Swedish State Power Board), Råcksta, Stockholm, Sweden
Sept 28-29	Stockholms Elverk (The Electricity Supply Authority of Stockholm), Tulegatan 13, Stockholm, Sweden
Sept 30	VAST (Establishment of the Swedish Water Power Association, Vasagatan 9, Stockholm, Sweden
Oct 3-7	Sydkraft (South Sweden Power Company), Malmö, Sweden
Oct 10-13	Norges Vassdrags- og Elektrisitetsvesen, NVE, (Norwegian Water Resources and Electricity Board), Middelthunsgate 29, Oslo, Norway. (Water Resources Directorate, Dept. of Investigations of Hydro Resources; Electricity Directorate, Dept. of Electricity)
Oct 14	Norsk Regnesentral (Norwegian Computation Centre), Forskningsveien, Blindern, Oslo, Norway
Oct 17-19	Östlandets Samkjöring (Samkjöringen), (East-Norway Power Pool), Majorstua, Oslo, Norway
Oct 19	Industridepartementet, Avd. for Vassdrags- og Elektrisitetsvesen (Ministry of Industry; Dept. of Water Resources and Electricity)

Oct 20-25	NVE (Electricity Directorate, Dept. of State Aid and Control; State Power Works, Sales Dept.)
Oct 26	Sunndalsöra Aluminiumverk; Årdal-Sunndal Verk A/S (Sunndalsöra Aluminium Smelter; Årdal-Sunndal Aluminium Company), Sunndalsöra, Norway
Oct 26-27	NVE, Statskraftverkene, Aura Kraftverk (NVE, State Power Works; Aura Power Plant), Sunndalsöra, Norway
Oct 28	Elektrisitetsforsyningens forskningsinstitutt, EFI; Oslokontoret (Oslo Office of the Power Industry's Research Institute), Gaustads allé 30, Blindern, Oslo, Norway
Oct 31	Institutt for Atomenergi, Reaktoravdelingen (Power Reactor Dept. of the Institute of Atomic Energy), Kjeller, Norway
Nov 1	A. B. Berdal, Consulting Engineers, Hegdehaugveien 31, Oslo, Norway
Nov 2	Norsk Hydro, Hovedkontoret (Head Office of Norsk Hydro), Oslo, Norway
Nov 3	NVE, Generaldirektoratet; adm. direktör H. W. Bjerkebo (NVE, General Directorate ; Mr. H. W. Bjerkebo, Executive General Manager)

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