E F I

THE NORWEGIAN RESEARCH INSTITUTE
OF ELECTRICITY SUPPLY

Excerpt from the Preliminary Report by the Committee on Economical Operation of Predominantly Hydro-Electric Power Systems.

Concluded at the Committee's Meeting
on January 19, 1968.

EFI - Technical Report No. 1410 E.

TRANSLATION SUMMARY.

Following is a selection of excerpts from the EFI Technical Report No. 1410 by "The Committee on Economical Operation of Predominantly Hydro-Electric Power Systems."

These particular excerpts have been chosen in an attempt to present the basic philosophy of the "water value" concept as well as the committee's conclusions concerning the application of said concept. The table of contents will indicate which sections of the original report have been omitted in the translated edition.

Notes:

The term "firm power" refers to a quantity of power designated for the normal demand and having a defined quality, usually specified by long-term contractual agreement.

"Surplus power" designates short-term power for sale or purchase by temporary agreements between the parties involved.

Translation:
H.H. & J.K. Skarholt

FOREWORD

This preliminary report from the EFI committee on "Economical Operation of Predominantly Hydro-Electric Power Systems" was concluded at the committee's meeting on January 19, 1968. The report does not attempt to present a complete evaluation, rather it tries to convey the committee's views as presently arrived at, with regards to a basic approach for system operation planning.
The report also outlines procedures on how the methods that the committee recommends can be adapted for practical operation, within the system of contracts which exists at present concerning the exchange of power. At a later date the committee will prepare an appendix that describes a practical approach in detail.

The committee has essentially worked on planning of power system operation. System operation and system expansion should be considered in relation to each other. Therefore, the committee has also had methods for planning of expansion under discussion.
For the time being these evaluations have not been included in the preliminary report.

J. Sörensen

Committee Chairman

Jan Hegge

Secretary

Xnr. 13.258/69

TABLE OF CONTENTS

Table of contents - continued.

5. PLANNING OF OPERATION EMPLOYING NEWER METHODS.

5.0. Summary.

When planning the operation of a predominantly hydro-electric power system it may be appropriate to separate the problems of operation into a long term aspect (or strategic aspect) and a short term aspect (or tactical aspect).

Long term planning concerns itself with the strategy for the overall exploitation of water power within the coming year, which in its turn implies that one must take the years thereafter into consideration

Short term planning comprises the detailed operation of every plant from hour to hour, while all relevant local conditions are considered, and while keeping the long term developments in mind. The character of the optimization problem is such that there is no reason to make a sharp distinction between long term and short term planning.
A division is, however, convenient due to the fact that the methods employed in solving the problem can be classified in two groups.
In the first group are the methods that take into account the fact that the input data are statistical variables, and as such are suitable for long term planning. In the second group one has the methods that assume known input data. These enter the picture to a greater degree where detailed operation from hour to hour is concerned, i.e. short term planning.

5.1. Long Term Planning of Operation.

5.1.0. Survey.

The block diagram of supplement H gives a survey of the problem solution for long term operation planning. Some of the blocks are explained earlier (1,2,3,4 and 5). The others will be described in the following. The methods of calculations that will be described under paragraph 5.1 are indicated by blocks 9 and 10 in the diagram (water value calculations and operations simulation).

Calculation of "water values" will undoubtedly gradually gain a stronger position in operation planning. The principle of using water values was first introduced in Sweden by S. Stage and Y. Larson. Later this has been further developed within The Swedish State Power Board (VAST) and VAST's water power committee. The method has been in use in expansion planning since about 1960. It was also used later for planning of operation. Agreements concerning price stipulation with exchange of surplus power, within the Swedish interconnected group, has since 1964 implied that the exchange price should be decided on the basis of the marginal value of power (water value) referred to the point of exchange.

The method has been studied/employed in Norway since 1962 by various parties. We are in this country (Norway) on the starting line with regards to routine use of operation planning based on incremental cost studies.

By evaluating what may happen in the future, one can compute an "expected value" of the marginal amount of power which is next in line to be drawn from storage.

In paragraph 5.1.1. the concept of "water value" will be more exactly defined. In paragraph 5.1.2. a short orientation will be given as to how the water value can be computed for a system where the production apparatus may be represented by one equivalent reservoir and one equivalent power plant.

Having exact water values for each and every reservoir in the system, the problem of operation optimization may be defined and solved in an integrated manner. As the situation is today, the reservoirs must be described in the model by a single, or by maximum two, equivalent reservoirs if one wishes to proceed according to sections 5.1.2 and 5.1.5 (dynamic programming). In sections 5.1.6 and 5.1.7 mention is made of various methods on how to treat situations where a more detailed description of the production system is desirable.

5.1.1. Introduction of the Water Value Concept.

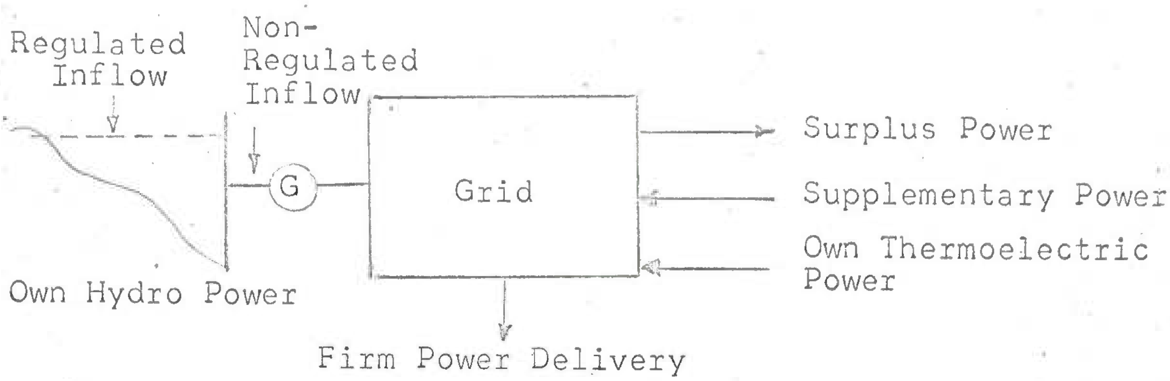

Figure 5.1. Principle model for the system which is referred to when describing the method.

Figure 5.1 shows the principle model of the system which is described in this and the next section. All plants are united into an equivalent plant and all storage reservoirs are merged into an equivalent reservoi We now wish to operate this system according to the criterion chosen in section 3.3. "The aim of the long term planning is to form a strategy of operation such that the expected value of the total variable costs is minimized."

We then suppose that an evaluation has been put forth on how the market conditions will develop during the coming year. A marginal price evaluation, corresponding to the one shown in fig. 2.2, page 2.6, is assumed set up for every week during the coming year.
As far as exchange of surplus power with other areas is concerned, the prices of hydro-electric power will to a certain degree depend on run-off conditions. One may compensate for this by employing market evaluations for the various run-off conditions. We further assume that a firm power prognosis exists, as for example, in GWh/week for the period of investigation.

At any given time the following choice may be made: Should one produce another kWh or retain it in storage for a more advantageous sale later? - The proper choice depends on the future water inflow. This we have no exact knowledge of, but we do have the run-off statistics. We assume that the hydrological statistics for a period

of, for example, 30 years is representative of the future. We further assume that the various years of run-off occur independent of each other, and that there is no law governing the succession of dry and wet years. During some periods, knowing the snow accumulation (the snow reservoir), the "ground water" run-off, etc., we could perhaps predict total inflow. This special situation is dealt with in some detail in section 5.1.3.

At a certain point in time, and at a certain reservoir level, the situation will be such that optimal action is to buy power in order to save on stored water, if the price on power offered for sale is below a set limit, e.g. 2 öre/kWh. (For simplification we here employ mean efficiency factors for the whole production and transmission system). Correspondingly it is optimal to sell power from the reservoir if we can obtain a price above 2 öre/kWh. This implies a marginal price evaluation of the reservoir water. We now introduce the concept "water value" (or "marginal water value"). The water value was in this case 2 öre/kWh. (All prices referred the point of load).

In other words, we may say that the water value is the profit one may expect to obtain in the future of an amount of energy which for the time being is not released, but left in storage. The amount of conserved water may later overflow, or it may be utilized in a crisis situation at a high price, all according to how reservoir inflow develops.

We shall now take a look at how we use the water values, before proceeding to consider how they are computed.

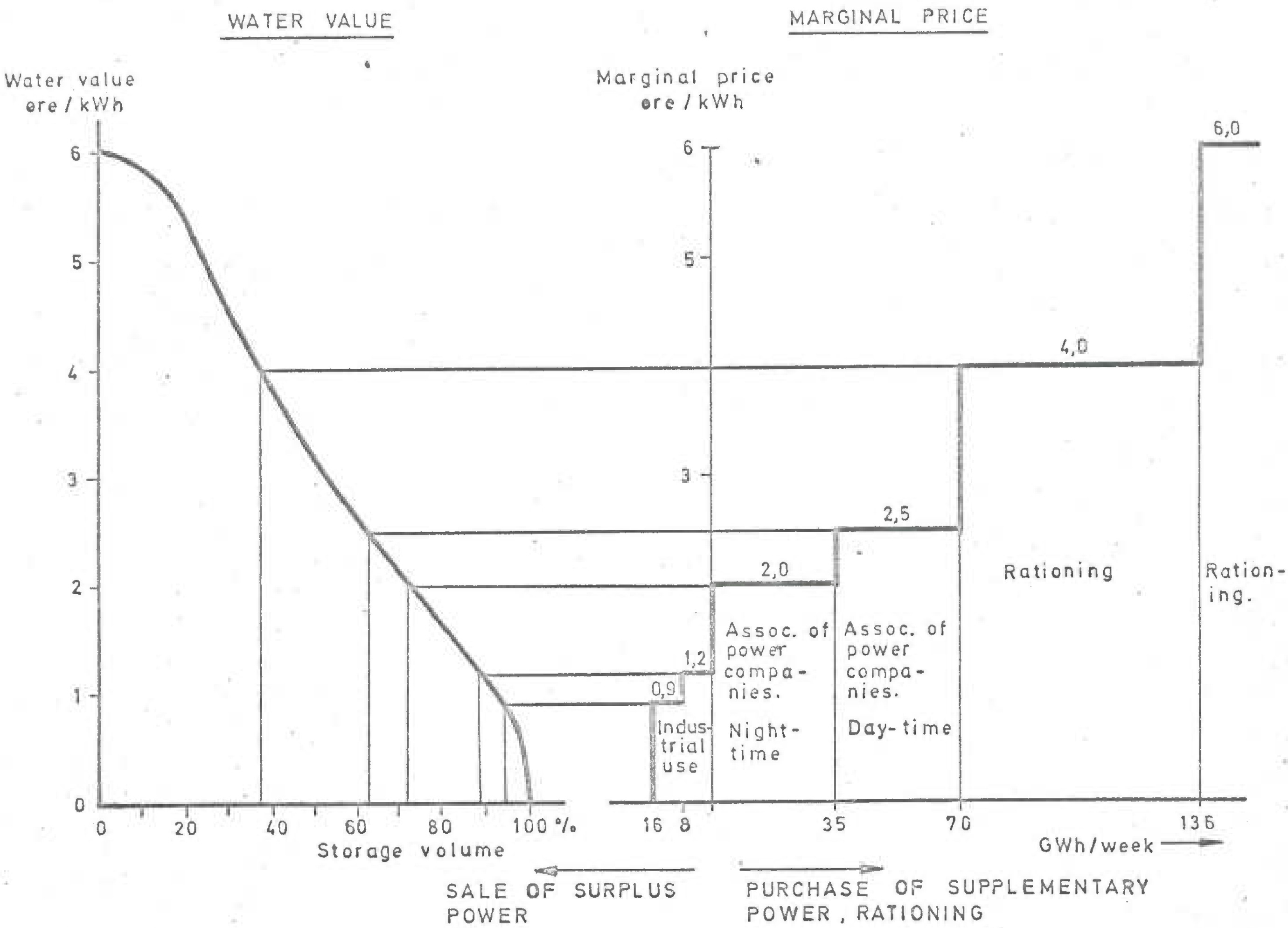

Fig. 5.2. Example of water value graph and diagram of marginal price evaluation of the power market. Strategy for reservoir draw-down is given by comparing the price diagram for the power market with the actual water value graph.

The left side of fig. 5.2 shows an example of a water value graph. The diagram on the right shows the marginal price for sale of occasional surplus power, purchase of supplementary power and rationing as a function of quantities at disposal. The magnitudes of the graphs must not be given too much emphasis; they are only valid under special conditions. If we compare the water value graph with the actual diagram representing the power market, we see that at this time the reservoir level must be over 88 % before sale of surplus power for industrial use becomes profitable. In the area between 88 % and 73 % reservoir level only firm power is delivered. In the area between 73 % and 62 % energy is purchased

EFI

from the interconnected system (power pool) during the night. In the area between 60 % and 37 % energy is also bought from the power pool during the day. If reservoir level recedes below 37 % the first rationing phase is effectuated (this is a comparatively cheap type of rationing).

It is neccessary to compute such a water value graph for each interval that the investigation concerns. The time period may be from one to two years. Draw-down strategy will at all times be given by comparing the water value with the actual marginal price on the power market.

Fig. 5.3 shows an example of a water value-storage-time diagram. The left side of the graph on fig. 5.2 represents a section through this diagram at a certain point in time.

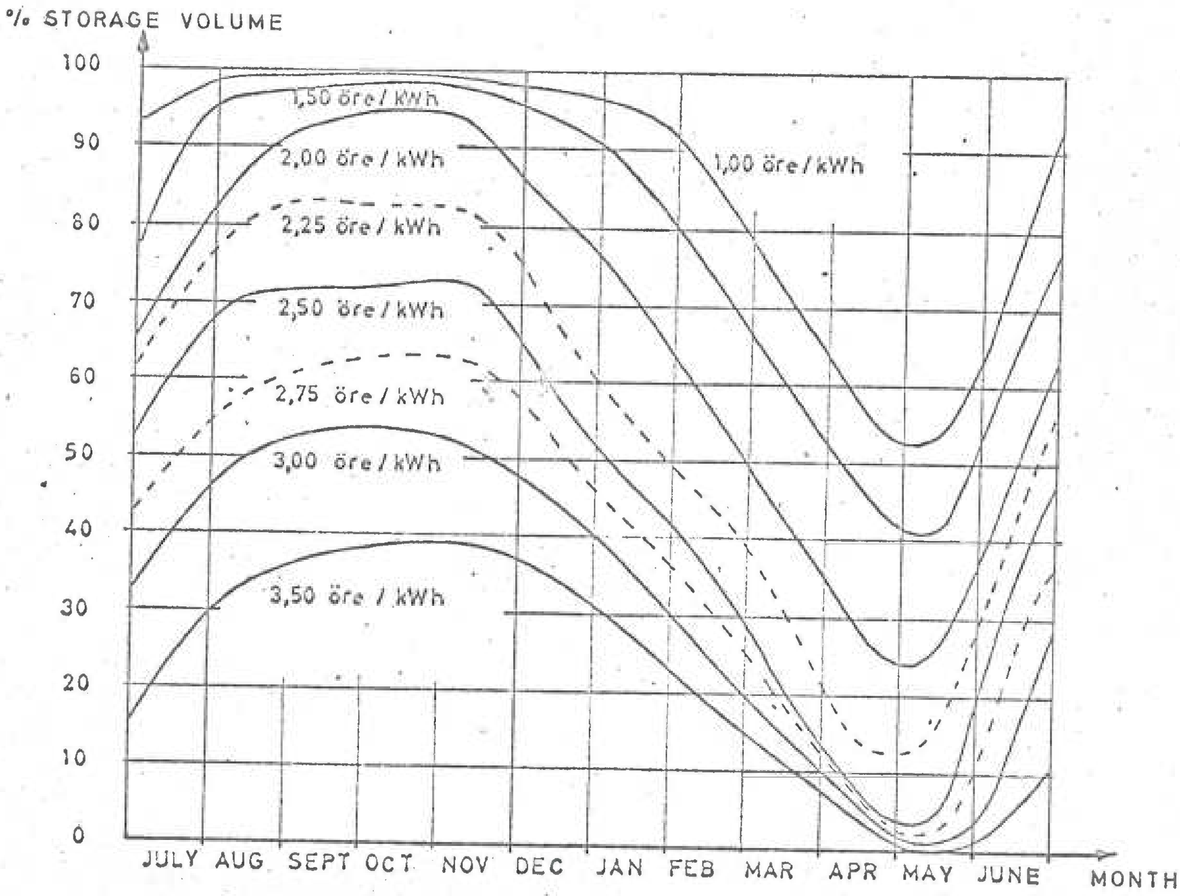

Fig. 5.3. Water value - storage level-time diagram.

6. THE COMMITTEE'S PROVISIONAL CONCLUSIONS.

The committee's first task, according to the mandate, was to determine the criterion for optimal operation. The committee shall not take a stand in connection with the politically involved question of power supply policy; this is a task for the respective authorities. The committee has interpreted as its objective to give a formulation of that policy which is sufficiently precise for a systematical treatment of the problem, and which at the same time allows full exploitation of modern remedies.

The committee has primarily dealt with the long term planning of operations, i.e. the operations' strategical dispositions concerning utilization of the reservoirs, by purchase of supplementary power, production of own thermo-electric power, and sale of surplus power.

Decision Criterion

The method that the committee recommends used for operations planning is founded on a decision criterion which states: that strategy of operation shall be scheduled such that the total variable costs is minimized.

The total of variable costs consists of:

variable cost by own production of thermo-electric power,

plus the variable cost by purchase of supplementary power,

minus income from sale of occasional surplus power

plus cost by failure to deliver firm power.

It is also assumed that the consideration given to the inconveniences and expenses incurred by failure to deliver firm power is represented in the variable cost. The meaning of the decision criterion will vary according to how one chooses to interpret "inconveniences and expenses by failure to deliver firm power." or in other words, how shall considerations with regards to supply quality be represented in the calculations. This is further treated in paragraph 5.1.8.

The committee believes that the shades of difference in views which exist, concerning power supply objectives, are not too great to allow the methods (that build on the aforementioned criteria) to be adapted for the problem situation at the individual power companies and interconnected areas, by variations of input parameters.

Long term planning of operation.

Practical results of computations.

The results of computations following the methods that the committee recommends, appear as a "water value." By comparing the water values with the actual power prices, one arrives at an answer as to which dispositions correspond with the agreed policy.

Organization.

No changes are required in either the organization or the price mechanism to be able to use the method mentioned as support for operation management's decisions. This holds both for amalgamated power systems and power company operational planning.

Price stipulation by aid of water value calculations. Distribution of fixed and variable cost between the individual power plants.

The water value is an expression of the operation dependent expenses. If the water value of individual power companies shall by itself constitute the base for accounting of the surplus power exchange, one should be assured by contract that the fixed costs are reasonably divided among the individual power companies (including the State owned plants). This can be done, for example, by requesting the individual power companies, by aid of their own expansion and fixed contracts, to fulfil their firm power obligations with certain requirements to safety - before they are allowed to participate in the exchange of surplus power with price stipulation exclusively on the basis of operation dependent cost.

Long term considerations with regards to improvement of price mechanism.

Within the amalgamated power pools one has until now attempted promotion of a reasonable distribution of the production apparatus'fixed costs, by setting the nominal prices of exchange power to about the same level as the average prices of the government's firm power contracts.

Since one has, for various reasons, choosen to take the fixed costs into consideration by an increase in the variable cost

during occasional exchange of power, when negotiating transfer fees etc., one has arrived at a price mechanism that can be a hindrance to reasonable economical dispositions with regard to exchange of surplus power. The committee hopes that the approach which is recommended, will prepare the ground for a greater separation of fixed and variable costs by agreements on exchange of occasional surplus power.

Comparing conventional and new operation ethods.

Concrete results cannot be presented that shows to what extent operation following new methods will result in better adherence to company policy, than operation following conventional procedures carried out by a management with long experience. Such a comparison is for the time being less relevant, since the operations experience that is accumulated will continue to be used after introduction of the new methods. The new method will, according to the view of the committee, give operation management a better survey of the operation situation and give clear guide lines for surplus power exchange. With the large sums that are involved, a relatively small improvement in operation strategy over a short period of time, would pay for the effort in question.

Short term planning of operation.

The committee has also collaborated during development of methods for application during short term planning of operations (planning of operation from hour to hour during the coming day).
In paragraph 5.2 of the report there is a description on how this approach is applied to a concrete project.

Integration of operation and expansion.

The integrated problem statement encompasses minimizing of the total cost (sum of fixed and operation dependent variable cost). The committee has until now first treated the operation dependent cost. Traditionally, operations planning and expansion planning are considered to a certain degree as two separate fields of work. Operation and expansion planning ought to be considered in relation to one another, such that guide lines in both instances would be prepared according to the basic policy.