THE COMPUTER IN THE POWER SYSTEM

THE ON-LINE, CLOSED-LOOP, APPROACH FOR CONTROL OF GENERATION AND OVERALL PROTECTION AT TOKKE POWER PLANTS

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SUMMARY

The increased demand for a secure energy supply, an effective utilization of the invested capital and the desire for minimizing disturbance of natural environment have speeded up the development of new methods for controlling electric power systems. The computer installation at the Tokke plants should be regarded as a contribution to this development.

Presently the system which is under commissioning in oct. 1971, involves the following functions:

- automatic closed-loop control of the instantaneous power allocation between the power plants so as to minimize total expected resource expenditure to cover a given total load,
- logging of data,
- closed-loop, automatic control to maximize system reliability of adjoining 275 kV network at any load transfer.

GENERAL SURVEY

The development within automatic control of electrical power systems have accelerated considerably during the past few years. The latest advance is the use of the process-oriented computer in plant operations for solving advanced problems. So far, however, the computer has largely been utilized for the solution of typical logging and data processing tasks without active functions and direct control of the electric power system.

The increased demand for a secure energy supply, an effective utilization of the invested capital and the desire for minimizing disturbance of natural environment have speeded up the development of new methods for controlling electric power systems. The computer installation at the Tokke plants should be regarded as a contribution to this development.

The adequate operation of the Tokke plants and the adjoining 275 kV network entails complex problems that have to be solved within very short intervals of time. Only the digital computer may give a satisfactory solution to this task while retaining an adequate operational flexibility.

Presently the project involves the following functions:

- automatic closed-loop control of the instantaneous power allocation between the power plants so as to minimize total expected resource expenditure to cover a given total load,
- logging of data,
- closed-loop, automatic control to maximize system reliability of adjoining 275 kV network at any load transfer.

The main features of the computer´s hardware-configuration are listed in Appendix 1.

Handling of Water Resources

The complete and optimal solution of the total energy handling problem of a hydroelectric power system is very extensive. It involves detailing the operation of every power plant taking into account all relevant statistical inflow data and efficiency considerations.

The complete solution of this global problem cannot be accomplished with the computational techniques available today. An approximate solution is found by separating the computations on two levels:

- A detailed planning of operation of the Tokke subsystem, based on a forecast of total output from the subsystem.
- A supervisory computation on the region or country level to obtain the desired distribution of total forecasted power on the different subsystems involved. In principle the distribution is adjusted to obtain equal level of incremental production cost for all subsystems.

Stated briefly the problem formulation on the subsystem level is as follows:

Given a detailed forecast (MW per hour) of total subsystem output for the next 24 hours, and a forecast of total output (GWh/week) for a number of weeks ahead. Determine the detailed operation of all generators of the subsystem over the next 24 hours such that the reduction of the subsystem potential of production is minimized. In terms of computational algorithms this amounts to loading the units according to the criterion of equal incremental production cost. The solution must observe all technical constraints.

An estimate of the effectiveness of the method has been obtained by reevaluating approximately 100 days of operation at the Tokke power stations. The results showed that operation according to the calculations would have given a profit in the order of 1 % compared with the operation as performed.

Data Logging

The data logging functions by and large relates to data that were transmitted to the operation centre prior to the computer implementation phase. Main functions: reports giving routinely metered values (with a weekly summary), operation reports with a resolution capability of 20 ms, and status reports following certain faults; from 10 minutes before the fault until 20 seconds after the fault (Post Mortem Review). A surveillance of critical values is furthermore carried out for selected electrical values.

Network Surveillance And Overall Protection

The electrical power system tying Tokke to the network in eastern Norway and thereby the main Nordic network, consists of three parallel transmission circuits. See figure 4.

The generating capacity that is connected to this transmission network is approx. 1400 MW. In addition comes a possible transit from western Norway of about 500 MW, i.e. approx. 1900 MW totally. The load flow within this network, is characterized by one line within each circuit becoming fully loaded by large power transfers to Flesaker. The outage of one of these lines will, in given situations, result in overload and/or loss of stability followed by cascading. The The occurence of such an outage is estimated to approx. once every three years. This is judged to be too high a risk considering the great costs and consequences that will be incurred as a result of shutdown. The cost of an outage of this kind is difficult to estimate, but evaluations performed indicate an outage cost of approx. 5 million kr for a one hour interruption of 1000 MW.

To avoid cascading, the power transfer must in critical situations be reduced within fractions of an oscillating period (3 s) or within seconds to minutes in more moderate situations. The way the power system is operated, a considerably rotating power reserve is present at any time (over 1000 MW). This reserve is hitherto utilized as a safety measure in conjunction with outage of generation. This reserve may also be utilized by allowing systematic disconnection of production units at selected sites when the transmission capability is reduced. By so doing a substitute for lack of costly transmission capacity is provided by the already available generating capacity. For the transmission system from the Tokke plants, this means that one may disconnect production and/or network parts, should a danger of cascading arise. The total power generation that may be disconnected in this way, is approaching 600 MW, corresponding to a fully loaded 275 kV simplex line.

Within the Nordic power system, undampened oscillations have occured several times during recent years. To improve the dampening in such situations it is necessary to reduce the power transport and/or disconnect distant network parts. The location of the Tokke plants, within the total network, causes at times such interventions to be very effective at this place.

The aim of the automatic network surveillance is thus to obtain a full technical exploitation of the existing transmission system while retaining full flexibility of operations and having approx. the same reliability of operation as one would obtain by erecting an extra 275 kV line between the Tokke subsystem and Flesaker.

ECONOMIC OPERATION

1. GENERAL OUTLINE

The incremental cost of stored water is given by the expected future hydrological inflow and the anticipated power market development. Given the incremental cost of water of all reservoirs, and given the generating sets that are running, the criterion of optimal power allocation says that the cost of the next kWh produced is equal for all generating sets of the system. That is to say: the inverse of incremental efficiency multiplied by the respective cost of water is equal for all units. Which of the stations and generating sets that shall be involved at any given time, must, if there are expenses involved in starting and stopping the generating sets, be determined from a calculation that evaluates and minimizes the total cost over a specific period of time (e.g. 24 hrs.).

To determine the optimum detailed plan of operation for all stations and generating sets within the whole power system, is not presently possible without dividing the problem into several levels of analyses.

To handle the problem one has chosen to calculate the detailed plan of operation for a number of separate subsystems. A computation on a supervisory level co-ordinates the distribution of total output between the respective subsystems contained in the global water value model. The allocation of total output on the subsystems is governed by the criterion of equal incremental subsystem cost of production. In principle a trial and error procedure is involved to determine the optimum distribution of desired total global hydroelectric output between the respective subsystems. The determination of total global hydroelectric generation is determined on the strategic level on which the economic utilization of total storage is considered over the season. [1 - 4]

This article outlines the planning of economic operation of the Tokke subsystem. The planning procedure may be systematized in three phases:

- Relative cost evaluation of stored water based on total sub-system generation forecasted on short as well as long term.

- Optimum power allocation.

- Surveillance and control of the assumptions that form the basis for the allocation of power.

In the following a more detailed description is given of the method of analysis and the main phases of the calculation.

2. METHOD OF ANALYSES

The method that is developed for the detailed planning of operation of the Tokke power stations, has as a basic pre-requisite that the total subsystem output is estimated at any point in time. The variables that may be influenced to achieve the optimal plan of operation are:

- Number of generating sets in operation at each site.

- Power distribution between the generating sets in operation.

The main phases of the scheme of analysis is illustrated in fig. 1 .

2.1. Cost of Stored Water

The cost of water contained in the individual reservoirs is in principle relative since total subsystem output is specified in advance. That is to say: the value evaluation only pertains to the internal distribution of draw-down among the reservoirs.
A too low incremental cost of water of one reservoir will result in too large discharge, and the reservoir sooner or later will be emptied below a desired limit. On the other hand a too high cost will result in a too small draw-down.

The cost of water contained in each longterm reservoir is found by applying an incremental loading procedure. At first minimum generation is set corresponding to utilization of expected non-regulated inflow. The pertinent risks corresponding to this generating situation is registered, and the incremental cost at this stage is computed for all resources. Now total subsystem output is incremented by ΔP, and this power is supplied by the resource having the lowest incremental cost. Risks are again registered, and new values of incremental costs are evaluated. Again total output is increased, and the increment is supplied from the cheapest resource. This procedure is continued until desired total subsystem output is reached.

Because of unequal degrees of regulation of the reservoirs, two different time horizons are defined for the main types of reservoirs:

- L o n g - t e r m   r e s e r v o i r s. These include Songa, Totak, Botnedalsvatn and Byrtevatn. See figure 2. The time-horizon is from 3 weeks to 6 months, depending mainly on the time of the year.

- S h o r t - t e r m   r e s e r v o i r s. Only Vinjevatn is a buffer of this type. Time-horizon; 24 hours.

2.1.1. Handling of Long-Term Reservoirs

Depending of factors which are discussed below, the situation to face in the operation may be one of two main types:

<u>Storage Situation</u>. In this situation the main objective on the statistical level is the handling of expected future inflow to the reservoirs. The incremental cost of generation of resource "X" is defined as $(1 - f_x + \Delta h_x) \cdot (d\bar{N}_x / d\bar{P}_x)$ where f_x is the risk of spillage of reservoir "X" within the chosen time horizon, Δh_x is a correction due to expected head variations and $\left(\frac{d\bar{P}_x}{d\bar{N}_x}\right)$ is the incremental total efficiency. The defined incremental cost of water is $\varphi_x = (1 - f_x + \Delta h_x)$. The storage situation always prevails during the filling period for which a risk horizon of 3 weeks is chosen for all weeks. In the draw-

down period the same criterion applies if total GWh storage exceeds some predetermined value which is a function of time. The time horizon in this case is always to some fixed date beyond the spring flood.

Power Deficiency Situation. This situation may occur in the draw-down period as signalled by the criterion of total GWh storage. If total storage is below some critical time-dependent value, the main statistical objective is to avoid MW shortage over the nearest weeks ahead. Correspondingly the incremental cost of generation of resource "X" is defined as $(1 + k_X \cdot p_X) \cdot (d\bar{N}_X / d\bar{P}_X)$, where p_X is the risk of running empty within the chosen time horizon. k_X is a factor reflecting the importance (ɔ: MW size) of resource "X". The defined incremental cost of water is $\varphi_X = (1 + k_X \cdot p_X)$.

On the risk level only average values of power output is considered. Thus $d\bar{N}_X / d\bar{P}_X$ is based on a description of average efficiency versus average power output of the resource "X".

Plants having non-regulated inflow and/or operating in series without long-term reservoirs in between, are handled as compact "equivalent" stations. Thus Tokke and Vinje power plants are joined into one station incorporating the effect of expected local inflow to Vinjevatn

From the risk level computations, per unit incremental costs φ are determined together with values of desired average power output from all stations.

Byrte (20 MW) and Lio (40 MW) are small power plants that do not take part in the frequency/tie-line regulation. The plants have three modes of operation: standstill, operation at best efficiancy and operation at max. output. The timing and determination of modes of operation is determined by the computer on the basis of the values of desired average output computed.

The detailed output from Tokke (440 MW), Vinje (330 MW) and Songa (120 MW) power plants is determied on the basis of the computed incremental costs φ and pertinent restrictions.

The discharge from the group of reservoirs beyond Totak is governed by a "formal" station introduced between Totak and Venemo, see figure 2. This station takes part in the incremental loading procedure discussed previously, and thus the desired relationship of risks is established between Totak and the group of reservoirs.

2.1.2. Handling of Short-Term Reservoir

The simulation period in conjunction with the optimum utilization of the short-term reservoir Vinjevatn is 24 hours. On this level of analysis each permutation of units at each station is described by its i n s t a n t a n e o u s power output versus efficiency curve. The inflow to Vinjevatn over the next day is estimated based on local data and the weather forecast. The incremental costs of water of the long-term reservoirs are considered constant over the next 24 hours.

An initial cost of stored water of Vinjevatn is assumed and the cost of optimally supplying the desired total subsystem output is computed for all possible combinations of generators during all time intervals of the simulation period. Then, considering the cost of start and stop, the sequence of combinations is found that minimizes expected total cost over the next 24 hours. The water level development as given by the planned optimum operation, is then checked. If the development is acceptable, the calculation is completed. If not satisfactory, the cost of water of the short-term reservoir is adjusted, and the optimization procedure is repeated until the technical constraints are fullfilled.

The result of the computations on this level is the per unit cost of water contained in Vinjevatn together with a detailed plan of operation over the next 24 hours. See figure 3. If forecasted total subsystem output is strictly adhered to, this would be the end of the planning procedure, and there would be no need for a on line computer to handle economic allocation.

2.2. Optimum Power Allocation

One of the computer's tasks is to function as a network regulator for the Tokke stations. Starting from observed power and/or frequency deviations, the computer calculates the total amount of power that at any given time shall be produced at the plants.

Remaining then is the allocation of this total generation on the individual generators. This is afforded applying the computed cost of reservoir Vinjevatn together with the available incremental costs of long-term storage. It is thus assumed that the cost of reservoir Vinjevatn is unaltered for moderate and stocastic deviations of total output from the forecasted values.

To avoid continously recomputing the power allocation as actual total output deviates from forecasted total output, the allocation in the vicinity of some chosen reference vector $\underline{P}_0$ (P_{Tokke0}, P_{Vinje0}, P_{Songa0}) is based on a linearization of the problem. As long as deviations from the reference is minor, a special "regulator program" allocates the power based on the reference vector together with a set of pre-calculated "regulation factors" $\underline{\gamma}$. See figure 1.

2.3. Surveillance And Control

When the optimizing program has calculated the parameters needed in the "regulator program" (reference point plus "regulation factors") its main task is to continously check the validity of these parameters.

When the deviation of total output from the reference point is greater than 10 %, the prevailing subsystem output is chosen as new reference point and a new set of "regulation factors" $\underline{\gamma}$ is calculated.

The prevailing cost of Vinjevatn φ_k is considered valid as long as the deviation of total supplied energy from forecasted value is less than 400 MWh, the deviation being accumulated from the moment φ_k is made available. If the deviation exceeds this value, a new plan has to be calculated for the next 24 hours as outlined in the preceeding section 2.1.2.

Start and stop of units is handled in accordance with the pre-calculated plan, see figure 3. The computer checks that this sequence is followed by printing out an order of starting and stopping at the given points of time. When the new combination is operating, a new reference point calculation is done, and the new values are input to the "regulator program".

Local inflow to Vinjevatn is surveyed by comparing the observed water level with the calculated value. A deviation is interpreted as being a result of having used an incorrect local inflow to Vinjevatn in the calculations. The value of local inflow is corrected, and a new cost evaluation of Vinjevatn is activated.

A new cost evaluation will always be activated with input of new assumptions to the computer. Furthermore, a given cost of water contained in Vinjevatn will not be valid for more than 6 hours; then it has to be updated regardless of the goodness of fit of the forecast. In a similar way, the cost of water of long-term storage has to be re-evaluated every week.

3. IMPLEMENTATION

All the routines and programs that appear in this scheme are written in FORTRAN.

Execution time for the respective programs are, when they are running in a multiprogrammed real time system together with all the other problems (monitor routine in the surveillance program system and data logging):

Calculation of relative costs for the long term resources	approx.	30 secs.
Calculation of relative cost for the short term resource	approx. pr. iteration	50 secs.
Average 5 iterations	approx.	4 min.
Calculation of optimal distribution	approx.	0.3 sec.

When the calculation routines in the surveillace program system are running, these execution times will increase considerably. The probability of these two program systems running at the same time is, however, very small.

The lengths of the three subprograms are approx. 1000 instructions (each 16 bits) for the calculation of optimal distribution and approx. 4000 instructions for each of the two others.

Management of this program system for optimal operation is carried out according to the following information flow to the computer:

- Once every 24 hours all "short-term data" are routinely read in from paper tape: i.e. total production prognosis, plan of revisions of generating sets, demands on operating reserve plus an estimate of local inflow to Vinjevatn.

- Once a week all "long-term data" are routinely read in from paper tape: i.e. long-term load prognosis and storage reservoir water levels.

- Short-term" and "long"term" data may be revised from the control desk at any time.

- The power production of every generating set and the water level of Vinjevatn are directly read into the computer.

Allocation of power is governed directly from the computer, apart from the guidance of Byrte and Lio which is set manually from directions via the order desk. Starting and stopping of the generating sets are also carried out manually according to directions from the computer via the order desk.

Each time a new relative cost of Vinjevatn (the short-term resource) is calculated, one receives as a by-product a calculated detailed operation plan for the next 24 hours. (Figure 3). This is always printed out on one of the teletypes. This gives an indication of at what times during the next 24 hours generators should be started and stopped. (The computer will later give a final message via the order desk). Of greatest value is, however, that the incremental costs of the production are printed at all time intervals. These incremental costs can be taken as a feedback to the supervisory planning process, which thereby can compare the costs for each subsystem and possibly thereafter correct the allocation of forecasts. For the time being one must be satisfied with a manual inspection of these costs. With unfavourable values one will request a correction of the prognosis.

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POWER SYSTEM SURVEILLANCE AND OVERALL PROTECTION

1. GENERAL OUTLINE

The surveillance encompasses part of Norway's 275 kV power network. Figure 4 . The primary aim of the surveillance is the minimizing of the operational complications resulting from definitive outages of certain transmission lines. The surveillance is carried out by a continuous analysis of the electrical consequences of such line outages. By the analyses a pattern of action to be automatically followed if a line outage occurs, is determined.

2. LIMITATIONS TO THE SYSTEM SOLUTION

2.1. Information from the Power System

The power system is inspected on the basis of information collected concerning the operational condition of the network. The information available determines how well surveillance can be carried out and must include a set of interdependent observations together with a system description.

Fig. 4 shows the tele-metered data and the Hf-channels by which they are transmitted to Tokke. The information of the switching state for the relevant circuit breakers is given to the computer via a configuration panel (scanner board) on the operator's desk. This panel must, for the time being, partly be manually updated.

It is emphasized that the computer contributes substantially in reducing the volume of information that is necessary to give the operator a complete survey of the operational situation.

2.2. Objective And Means

Based on knowledge of the power system's topology and operational situation, together with practical/economical limitations in the available volume of information, the objective is to define relevant intervention that possibly should be performed when definitive outages of certain power lines within the power system occur. Only single outages are considered.

The interventions at disposal for counteracting these outages largely involve a reduction of the power tranfer. The power deficits that therewith develop must be covered by the rotating reserve in the remaining power system. Both line tripping message and circuit-breaker control signals are transmitted over Hf-channels (coded). The transmission of the signals are arranged so that transmission over the faulty line is avoided.

The computer system is capable of performing direct interventions in the power system (closed-loop); emphasis is laid on avoiding unwanted interventions. A message of tripping of a critical line will thus not be accepted before the outage also is verified on the basis of expected system behaviour after disturbances of this character (changes in power transfer, voltages, etc.). Besides, the operator may temporarily block all or some interventions when the operational situation so requires.

The program system developed computes the stationary operation condition in the power system after the outage, but cannot simulate the dynamic behaviour of the system following such an outage. A simulation of this kind would present considerably larger demands on both the computer and on development effeort then presupposed for this project. Instead it is aimed at a (real-time) following up of the metered power swings on the lines connected to Tokke in order to establish whether further interventions are necessary or not. This follow-up is also undertaken when power swings occur from unknown reasons.

3. PROBLEM SOLUTION AND PROGRAMS

3.1. General

The developed program system is especially tailored for the power system under consideration and cannot as a matter of course be employed on power systems having different topology or other conditions of operation. This is due partly to the necessity of keeping the computing time and program space requirements down, and partly to the difficulties that lie in developing general methods of solution. The basic principles can, however, relatively simply be adjusted to other projects.

The programs are built up around a clock governed program that functions as an executive for the other programs in the system, based on the information it receives. The intention is to obtain quick response to important messages and at the same time avoid unnecessary use of computing time in time-demanding programs. The programs that frequently must be executed, are permanently located in core memory while the remaining programs are placed on secondary storage (drum). The total space requirement for the network surveillance programs is approx. 1.0 K (16 bit words) in core plus approx. 18 K on the drum. In addition there is approx. 1.0 K of fixed data on the drum.

Figure 5 shows a greatly simplified flow chart for the developed programs. Some of the most important sub-programs indicated on the chart, are mentioned below.

3.2. Estimation of Actual Operation Condition

The power system's electrical state is to be estimated on the basis of knowledge of a system description (network configuration) and certain metered values. This task is rendered more difficult because both the system description and the metered quantities may be burdened with errors and/or noise. Accordingly, a program must be designed to check the information that is received and to make sure that the computed electrical condition is correct.

The basis for this program lies in the collection of more data from the power system than would be required for determining the operational condition if all data were error-free. The program's manner of work can be outlined as follows (see otherwise (5)):

a) A system configuration and a voltage distribution is assumed.

b) The corresponding power distribution is calculated.

c) The calculated values are compared with a set of interdependent telemetered quantities. The sum of the squares of the deviations between each metered and calculated value is determined. The noise sensitivity of the measurements is taken into consideration as well as whether this noise can be transferred to other measurements.

d) A correction is related to the supposed voltage distribution such that the sum of squares of the deviations is minimized (method of least squares).

e) Calculations are repeated from point b).

Points b) - e) describe an iterative process. The process has converged and is stopped when all corrections to the voltage distribution become less than a given limit, or also when the sum of squares has reached its minimum. The sum of squares is examined at convergence. If this is larger than must be expected from an assumed noise level in the metered values, errors are present within the set of data.

If the error lies in the set of metered values, an analysis of the individual links in the sum of squares will show which measurements diverge most from the calculated values. These measurements are removed from the significant data set and a new calculation is taken, as a rule with good results, because now the error burdened measurement (or measurements) is not included in the calculation.

If, on the other hand, the error lies in network representation, it will not always point itself out in an obvious manner, and in the program a special logic is provided for attempting to sort out errors of this kind.

The ability of the state estimation program to produce a correct operation situation from an erroneous set of data is dependent on the amount of information that is collected over and above the minimum set. In our concrete case 34 metered values are at disposal while 24 are the minimum. With this redundance of data simple errors of measurement, of network representation, and certain combinations of these, may be accounted for. For more complicated error combinations, however, the program will only be able to give an unspecified error message to ghe operator.

The program occupies appr. 10 K drum space, and effective computation time for a normal operational situation without "difficult" errors is about 5 secs. High level language is used. The program will at a prescribed frequency carry out a routine calculation of the operational situation. A new calculation is also initiated each time power system operational changes occur.

3.3. Predetermination of Action Pattern

This program determines and stores the interventions (strategy) that may be necessary for certain line outages under the actual conditions of operation. Input data for this program is the estimated operational situation (load flow). Outage of each of the three critical transmission lines is simulated by modifying the network representation and calculating the new load flow. The load flow is then considered with regards to line loads and burs voltages. If the results lie out with permitted limits, one or several interventions are simulated, and the calculation of a new load flow is performed. This process is repeated until the conditions are accepted or all permissible interventions are tried. In the first instance there exists an action pattern that is to be followed in an eventual line tripping. In the other case a message is teletyped to the operator saying that with the present system condition tripping would result in an unacceptable operational situation. Then, either eventual restrictions on the possible interventions must be cancelled, appropriate changes in the load flow must be made, or the situation must be accepted.

According to the operational circumstances, the situation after an outage could be:

a) the outage gives lasting over-load in orther links of the power subsystem and immediate intervention is necessary,

b) the outage does not involve over-load, but may result in such large power swings that intervention still is necessary,

c) the outage doesn't necessarily involve intervention.

The program can only predetermine solutions of categories a) and c), while the possible interventions öf category b) is determined as need arises in other programs, based on the power swings that are observed at any time.

Tripping of heavily loaded power lines will often result in difficult voltage conditions within the remaining power system. A good representation of the MVAr balance in the power system is therefore very important for a satisfactory simulation of the new load flow. For the active loads in the system a functional connection $P = P_o \cdot (U/U_o)^A$ is assumed where P_o, U_o are the active loac and voltage before the outage, while P, U correpsond to the new stationary values. The exponent A can be specified for each node and takes into account the effect of tap-changing and voltage regulators. Corresponding expressions apply to reactive loads.

In Flesaker, which constitutes an exchange point between two interconnected networks, measurements performed show a nearby linear connection between MVAr and kV (approx. 10 MVAr/kV). The influence of voltage regulators in the generating stations is taken into consideration by assuming that the generator voltage at a certain point is maintained as far as this doesn't cause reactive overload on the generators.

The program is written in high level language and occupies approx. 7 K drum space. Effective computing time for a normal strategy calculation is a few seconds. Integer calculations are employed to the largest possible extent, due to space and computing time requirements, even if this introduces certain rounding off errors. Neither measurement accuracy nor the program inherent restrictions based on experience and judgement present appreciable claims to the numerical precision of the calculations.

3.4. Determination of Power Swings on Transmission Lines

This program shall, from metered power flow on the lines connected to Tokke, decide whether power swings exist or not in the power system.

If such swings are observed and the power at the same time are above a certain limit, the course of the swings are predicted for every line approx. 1.0 sec. ahead in time. This is done by assuming that the power oscillates according to the function $P = P_o \cdot e^{-\lambda t} \cdot \sin \omega(t - \tau)$ where P_o, λ, ω and τ are determined from the registrations in a previous time interval (0.5 s). The coefficients are calculated anew every 180 ms. The metered data are actually taken as the average of several consecutive readings to reduce the influence of random noise. The estimated power swings are classified as critical or non-critical. Critical swings constitute danger for overload relay tripping within the power system and should invoke immediate preventive actions, while non-critical swings may mean that a reduction of production should be initiated to quell the oscillations.

While power swings occur in the system, eventual new state estimation of the operational conditions will be blocked because observed telemetered values will not then, due to the time constants in the data transmission system, represent a set of interdependent values which must be the basis for such an estimation. The program further validates and/or invalidates message on tripping of lines by appraising the system's behaviour after such a message is received. This program is initiated every 180 ms and is located in the core memory of the computer. It is programmed in low level programming language, and its space need and computing time are modest.

3.5. Mode of Operation

The central program is called from the computer's monitor system every 20 ms. This indicates the resolution capability for detecting occurances within the grid and is considered to be acceptable on the basis of the existing time constants of the power system. Since this program lies on a high priority level and is initiated quite often, it is necessary to reduce its time sonsumption as far as possible. In figure 5 the "normal" way through the routine is indicated (dotted lines) e.i. no change neither in configuration in load transfer nor occurrence of power swings.

The program

a) detects critical line trippings and eventually activates the interventions stated in the strategy when the outage is confirmed

b) determines and activates relevant interventions if critical power swings occur

c) activates reduction of power production in up to two steps if moderate or increasing power swings are observed

d) initiates state estimation when this is necessary, i.e. when changes in power system configuration have been performed

e) initiates calculation of new action pattern (strategy) when this is necessary, i.e. with changes in the network representation and/or load balance

f) terminates eventual calculations tnat may be taking place if it detects changes in the system which indicates that basis for the calculations has become outdated

g) zeroes the strategy by changes in the network representation, because tne existing strategy then most often will be directly erroneous.

Figure 5 shows schematically how the solving of the mentioned problems takes place.

This program occupies 0.5 K of core and is programmed in low level language.

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4. APPLICATION OF THE PROGRAM SYSTEM

The operator communicates with the grid surveillance programs via a console in the operation's centre. Via this console he can impose various restrictions and limit values to the programs. He may also request various print-outs of, among other things, the present load flow, network losses and strategy.

As not all the information the computer requires for its calculations is updated automatically, the operator is to a certain extent responsible for the function of the program system. This applies especially to alterations in the network configuration because these can be both difficult to detect and have a great influence on the strategy. With errors in certain telemetering channels it might also be necessary to read into the computer via thumb wheels measured values which have been reported by telephone (so called pseudovalues) to avoid that the data set redundance becomes too small.

Hardware-configuration of the computer-system:

CPU (NORD-1)

Core memory 24K, 16 bits, memory cycle 1.65 µs
Mass-memory (drum) 128 K, 10 msec

3 Teletypes
1 Paper tape reader
684 digital inputs
400 digital outputs
81 analog inputs
7 outputs for step-motor operation

The power consumption of the equipment is about 4 kVA and no air-conditioning is necessary.

EFI

LITERATURE

1. Preliminary Report from "The Committee on Economical Operation of Predominantly Hydro-Electric Power Systems". (EFI - TR. Nos. 1410 and 1410E).

2. A. Johannesen and H.H. Faanes : Economic Scheduling of a Hydro-Electric System. CIGRE - 1968. Paper 32-07.

3. H.H. Faanes : Planning of Short-Term Operation. Elektro Bd. 82, 1969. No. 23, pp. 408 - 412.

4. A. Johannesen : Integrated Operation Planning. Elektro Bd. 82, 1969. No. 23, pp. 413 - 418.

5. Schweppe, F.C. and Wildes, J. : Power System State Estimation

   Part I: Exact Model

   Part II: Approximate Model

   Part III: Implementation

   IEE Transactions on Power Apparatus and Systems, Vol. Pas. 89, No. 1. January 1970, pp. 120 - 135.

LIST OF FIGURES

Fig. 1

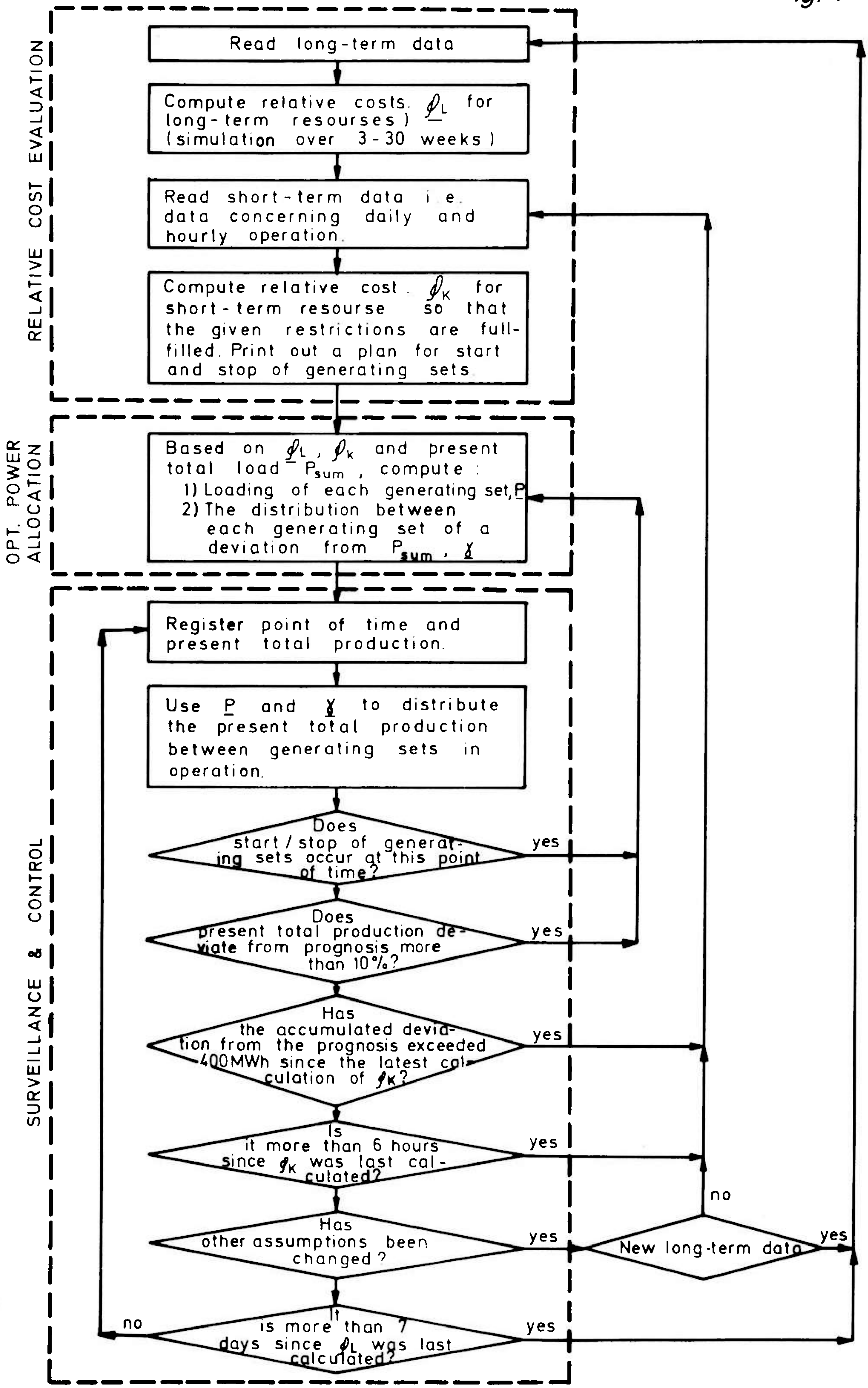
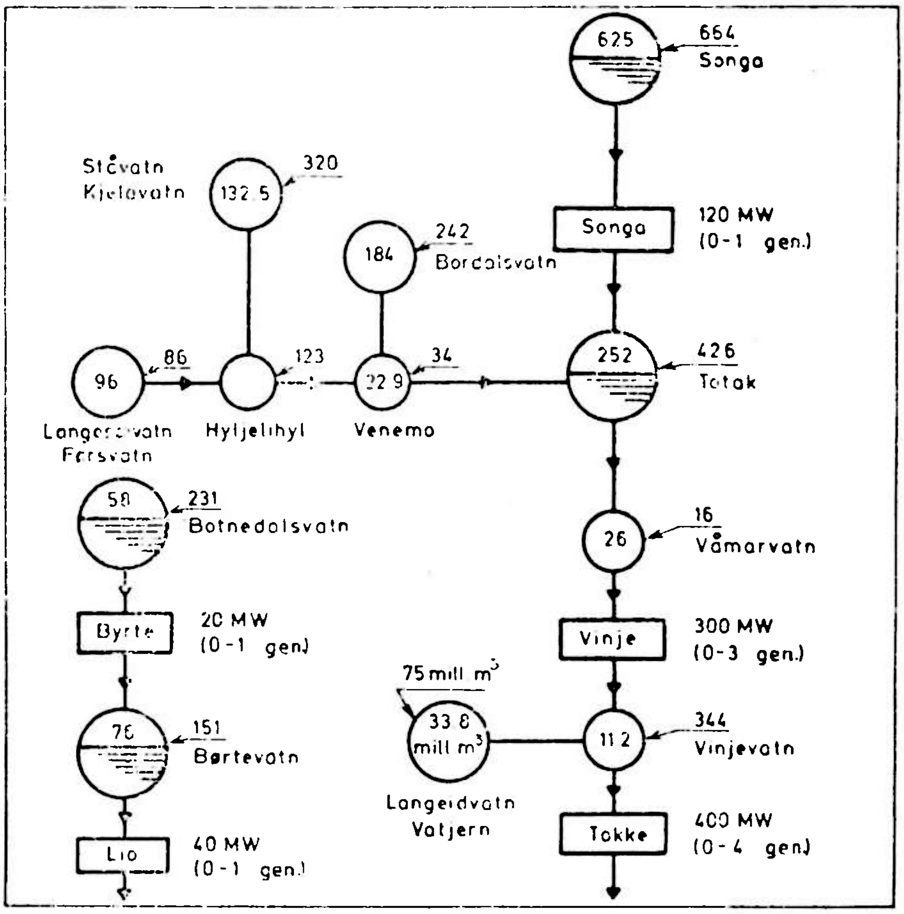

RELATIVE COST EVALUATION
Read long-term data
Compute relative costs ∮L for long-term resourses) (simulation over 3-30 weeks)
Read short-term data i.e. data concerning daily and hourly operation.
Compute relative cost ∮K for short-term resourse so that the given restrictions are fullfilled. Print out a plan for start and stop of generating sets
OPT. POWER ALLOCATION
Based on ∮L, ∮K and present total load Psum, compute:
1) Loading of each generating set, P
2) The distribution between each generating set of a deviation from Psum, γ
SURVEILLANCE & CONTROL
Register point of time and present total production.
Use P and γ to distribute the present total production between generating sets in operation.
Does start/stop of generating sets occur at this point of time?
yes
Does present total production deviate from prognosis more than 10%?
yes
Has the accumulated deviation from the prognosis exceeded 400MWh since the latest calculation of ∮K?
yes
Is it more than 6 hours since ∮K was last calculated?
yes
Has other assumptions been changed?
yes
New long-term data
no
yes
It is more than 7 days since ∮L was last calculated?
no
yes

Fig. 2

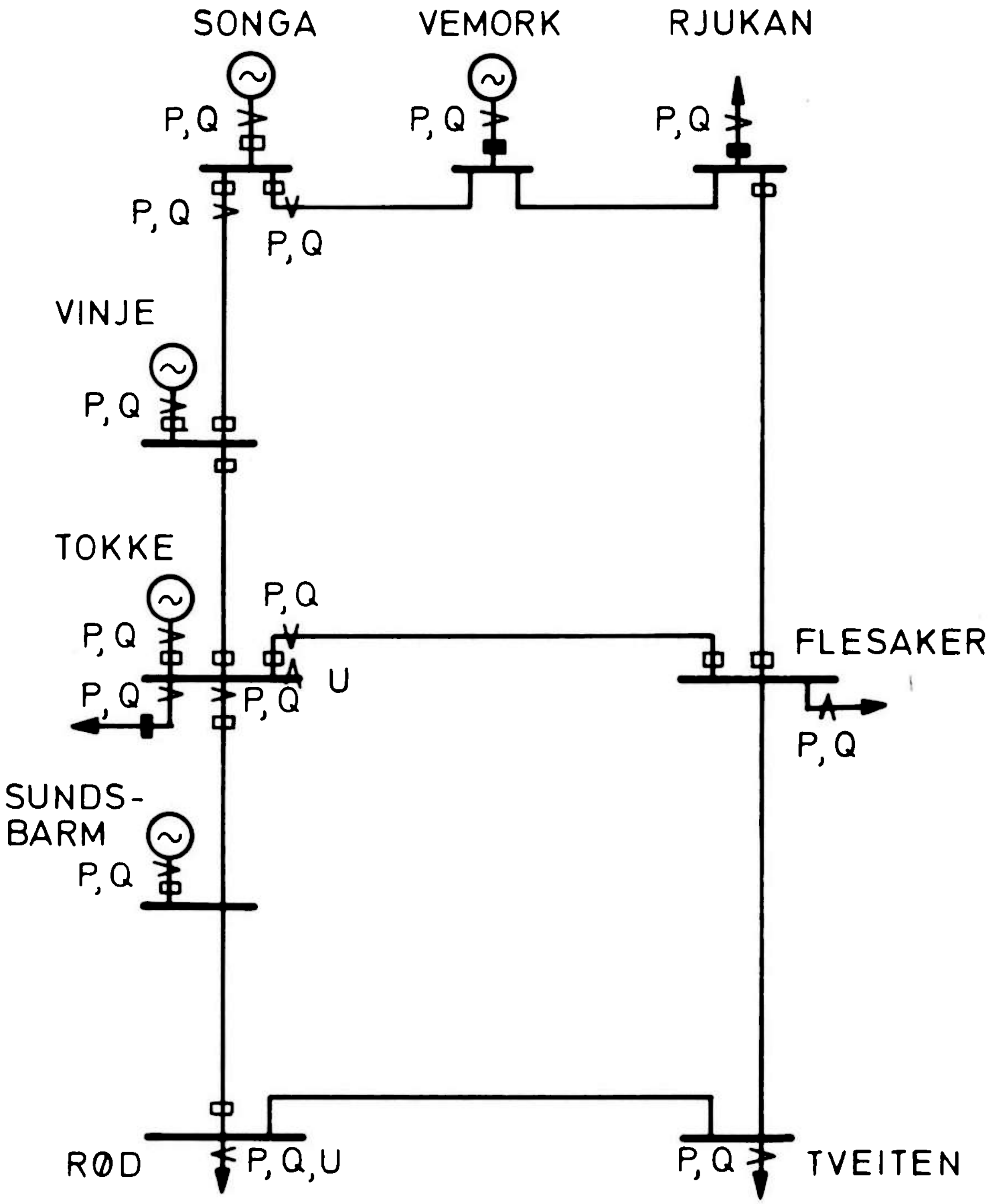


625
664
Songa
Stavatn
Kjelavatn
132.5
320
Songa
120 MW
(0-1 gen.)
184
242
Bordalsvatn
96
86
123
22.9
34
252
426
Totak
Langesævatn
Førsvatn
Hyljelihyl
Venemo
58
231
Botnedalsvatn
26
16
Våmarvatn
Byrte
20 MW
(0-1 gen.)
Vinje
300 MW
(0-3 gen.)
75 mill m³
78
151
Børtevatn
33.8
mill m³
11.2
344
Vinjevatn
Langeidvatn
Votjern
Lio
40 MW
(0-1 gen.)
Tokke
400 MW
(0-4 gen.)

TIDSINTERVALL			TOKKE		VINJE		SONGA			GR.KOST.	VANNSTAND
NR	FRA - TIL	MIN	AGG	EFF	AGG	EFF	AGG	EFF	MW		VINJEVANN
1	0.00- 2.00	0	2	200.0	1	83.0	1	97.0	380.0	1.14154	464.819
2	2.00- 4.00	120	2	203.0	1	84.0	1	98.0	385.0	1.14793	464.834
3	4.00- 5.30	240	2	205.0	1	85.0	1	100.0	390.0	1.16016	464.845
4	5.30- 6.30	330	2	209.0	1	89.0	1	102.0	400.0	1.17960	464.853
5	6.30- 7.00	390	3	254.0	1	77.0	1	89.0	420.0	1.10047	464.849
6	7.00- 7.30	420	3	265.0	1	82.0	1	93.0	440.0	1.12715	464.845
7	7.30- 8.00	450	3	276.0	1	86.0	1	98.0	460.0	1.15582	464.840
8	8.00- 9.00	480	3	276.0	1	86.0	1	98.0	460.0	1.15582	464.831
9	9.00-10.00	540	3	281.0	1	88.0	1	101.0	470.0	1.17145	464.821
10	10.00-11.00	600	4	316.0	1	77.0	1	87.0	480.0	1.09586	464.798
11	11.00-12.00	660	4	323.0	1	78.0	1	89.0	490.0	1.10231	464.773
12	12.00-14.00	720	4	329.0	1	79.0	1	92.0	500.0	1.11375	464.722
13	14.00-15.00	840	4	342.0	1	83.0	1	95.0	520.0	1.13459	464.694
14	15.00-15.30	900	4	354.0	1	87.0	1	99.0	540.0	1.16353	464.680
15	15.30-16.00	930	4	367.0	1	89.0	1	104.0	560.0	1.18744	464.664
16	16.00-16.30	960	4	373.0	1	92.0	1	105.0	570.0	1.20544	464.648
17	16.30-17.00	990	4	373.0	1	92.0	1	105.0	570.0	1.20544	464.632
18	17.00-18.00	1020	4	370.0	1	90.0	1	105.0	565.0	1.19472	464.600
19	18.00-19.00	1080	4	361.0	1	88.0	1	101.0	550.0	1.17240	464.569
20	19.00-20.00	1140	4	335.0	1	82.0	1	93.0	510.0	1.12715	464.541
21	20.00-21.00	1200	4	323.0	1	78.0	1	89.0	490.0	1.10231	464.515
22	21.00-22.00	1260	3	270.0	1	83.0	1	97.0	450.0	1.14154	464.505
23	22.00-23.00	1320	3	254.0	1	77.0	1	89.0	420.0	1.10047	464.497
24	23.00-24.00	1380	2	209.0	1	89.0	1	102.0	400.0	1.17960	464.505

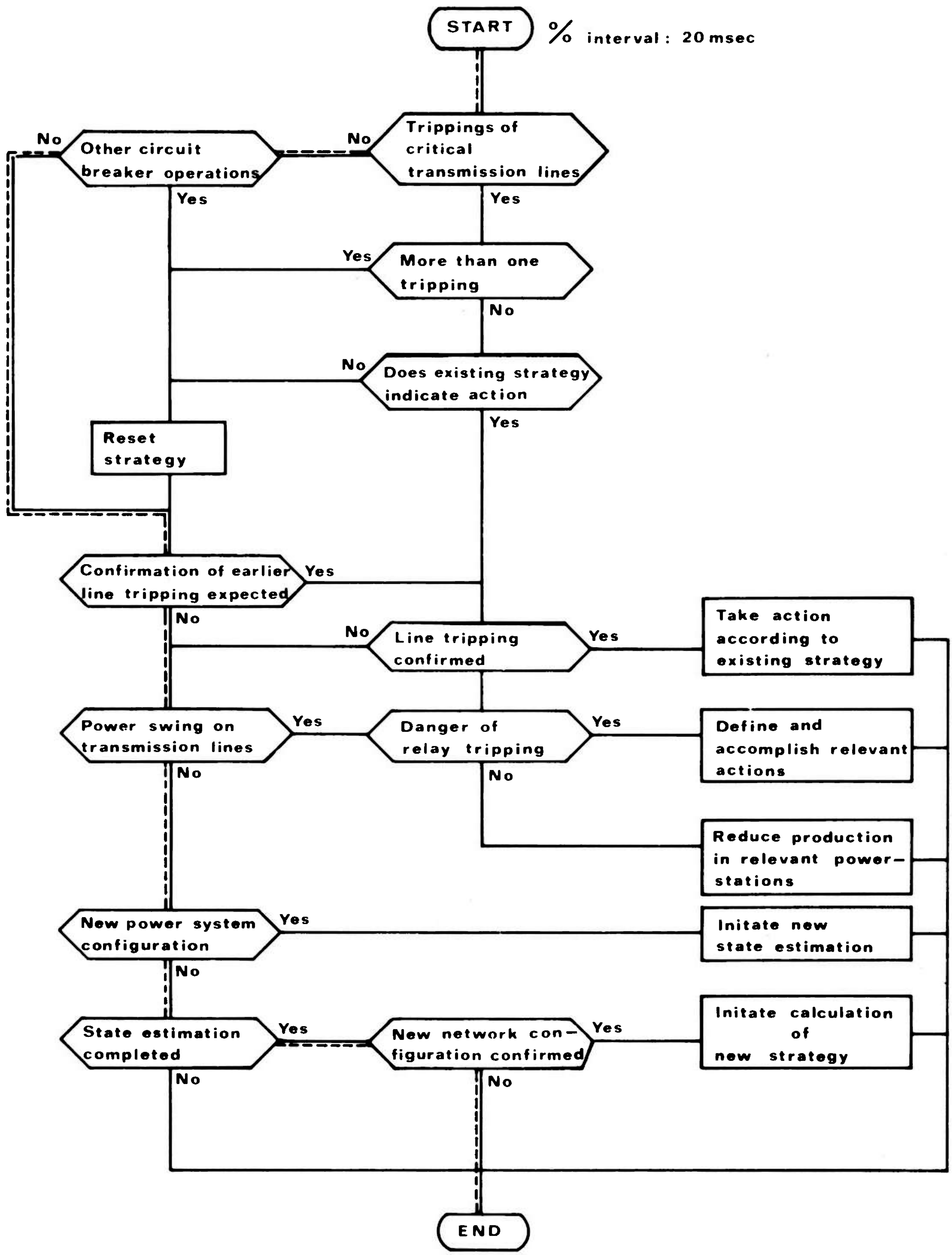
Fig. 3

Fig 4



P - active power (MW)
Q - reactive power (MVAr)
U - voltage (kV)
A - metering point
■ - circuit breaker with direct control from Tokke
□ - - - -"- - - - - - - -"- - message to Tokke

Fig 5



START
% interval : 20 msec
Trippings of critical transmission lines
No
Yes
Other circuit breaker operations
No
Yes
More than one tripping
Yes
No
Does existing strategy indicate action
No
Yes
Reset strategy
Confirmation of earlier line tripping expected
Yes
No
Line tripping confirmed
No
Yes
Take action according to existing strategy
Power swing on transmission lines
Yes
No
Danger of relay tripping
Yes
No
Define and accomplish relevant actions
Reduce production in relevant power-stations
New power system configuration
Yes
No
Initate new state estimation
State estimation completed
Yes
No
New network con-figuration confirmed
Yes
No
Initate calculation of new strategy
END