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## PROBLEMS OF LOAD DISPATCHING IN INTERCONNECTED SYSTEMS

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NOTE: This text is subject to editorial revision.

CONTENTS

## 1. Introduction

The last few years brought about further interlacing of interconnections between power supply systems on a national and international level. This substantiated the fact that operation of such a complex interconnected system is no longer possible without the provision of a central system operator office for the area systems interconnected. Such central system operator offices are divided into central load dispatch and area control stations.

## 2. The load dispatch system

Of importance for the smooth overall operation of interconnected systems is chiefly the central load dispatch office. One of its duties is to see that the energy resources of the system under its direction and the other interconnected systems are operated economically and under the arrangements made between the operating companies concerned. Another of its duties is, in case of failure of any generating units or transmission lines or unexpected load variations, to prevent the power supply to the system load centres from being interrupted and the area systems from falling out of step, i.e., to segregate them.

(a) The supervisory remote-control technique

This task can only be solved in a satisfactory manner by the central load dispatch office if, apart from the telephone service, the facilities of supervisory remote control (1)* enable it to gather continuous information on the state of power generation and distribution and the switching conditions of the extra-high-voltage system transmitting the electrical energy. A clear picture of the generation and distribution of electrical power at any moment is afforded by a telemetering system (2, 3) which above all includes the following:

(i) Summated active and reactive power outputs of the generator groups of the power stations, under its own direction;

(ii) Export or import of active and reactive power via the tie-in sub-stations connecting to the other interconnected systems;

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* The figures in brackets refer to the bibliography at the end of the text.

/(iii) Supply

(iii) Supply of active power to the system load centres;

(iv) Voltage at the important junction points and transfer sub-stations;

(v) Frequency at the transfer sub-stations;

(vi) Current flowing in the tie-lines operating at an extra-high-voltage level.

The power values can be read from indicating instruments arranged on the load dispatch desk. In this connection it is, furthermore, expedient to combine the partial sums of energy transmitted into total sums of load generated in the power stations under its own direction, and into total sums of energy imported and exported. These values are indicated on measuring instruments also arranged on the load dispatcher's control desks.

In as far as the transmitted energy values are required for subsequent evaluation of certain operating conditions or for the preparation of daily load curves, recording instruments have to be provided which can be accommodated on switchboard panels arranged on the sides and out of the visual range of the load dispatcher.

Whereas all active power values and, with certain limitations, also all reactive power values have to be continuously transmitted, part of the voltage, frequency and current values can only be indicated "as called for" owing to the long distances to be bridged in load dispatching and the consequent expansive transmission channels.

A mimio diagram, preferably of the mosaic type of construction, is used for the supervision of the switching conditions of the power supply system. This gives a continuous indication of the position of the breakers in the individual distribution sub-stations and corrects the indications automatically in the event of a change in the breaker position. Generally, the following indications are transmitted:

(a) The position of the main generator circuit breakers, the extra-high-voltage feeder breakers and the medium-high-voltage network feeder circuit breakers;

(b) The position of the associated bus isolators;

/(c) Indication

(c) Indication of earth faults, sustained and transient;

(d) Important general alarm announcements from the generating and distributing stations;

(e) If required with regard to operation:

general operational indications from the medium-high-voltage network, such as tripping of breakers, earth faults, etc.

The automatic indications received have to be identified by a flashing light which is turned to a steady light when the load dispatcher has initiated a general check. The position indications of the feeder breakers can be carried out in the form of a simplified channel indication which does not show the position of the individual breakers or switches but only indicates the fact that the relevant feeder has been connected through to the relevant bus systems.

The automatically corrected mimio system diagrams and the continuous indication of the most important measuring values gives the central load dispatcher a comprehensive picture of the switching conditions in the extra-high-voltage system.

In addition to this, he is also in a position to notice within a few seconds the nature and extent of larger disturbances and the possible consequences, and initiate the necessary counter-measures. Since it cannot be the duty of the load dispatcher to carry out directly any switching operations in the system he must delegate the execution of the necessary measure to the operating staff in the various power stations and system junction points.

If the extent of a disturbance is such that the complete breakdown of the system is to be feared the transmission of the necessary orders by telephone channels is too time-consuming, as experience has shown. The load dispatcher should, therefore, have an instruction panel at his disposal to enable him, irrespective of telephone communications, to transmit within a few seconds standard directions for loading, load shedding, starting of machines etc. to the power stations, area control stations and other attended system junction points under his supervision.

/The supervisory

The supervisory remote control equipments to be provided for the solution of the above described tasks have generally to bridge long distances in load dispatch service. Use is therefore preferably made of equipment which can transmit telemetering values, control-operation and indication signals as impulse trains over multiplex channels. The following equipment is mainly used with load dispatch systems.

(i) Telemetering equipment based on the impulse frequency or impulse variation principle, which can be operated in frequency- and time-multiplex traffic.

(ii) Equipment for the transmission of indications and control signals, which is preferably of the unit selector type and converts the indication and control signals into coded impulse trains. Relay-type transmission equipment without unit selectors is also used for pulse code transmission and this will be supplemented in the future by the application of electronic supervisory remote-control equipment.

(iii) Multiplexing equipment which enables multiplex transmission of telemetering values, indications and control signals to be carried out via voice frequency, power line carrier and wireless channels.

(b) The system regulation technique

It is the special duty of the load dispatcher continuously to supervise the system frequency and to maintain it constant by taking the necessary measures. For this the power output of the generating sets feeding into the system has to be continuously adapted to the variations of the system load, since the frequency remains constant only when the load and generation are well balanced. The generator output is in part matched to the load demand automatically by the speed governors of the prime movers. This type of regulation is, however, static so that the frequency can be maintained constant only by a corresponding re-adjustment of the governor settings of the prime movers.

When several power stations are combined to form a common inter-connected system the load peaks will result in frequency variations of a lower height since the load can be distributed between a large number

/of machines

of machines. It is therefore obvious that there is a tendency to increase the system size and that interconnection with other systems is everywhere strived for. This calls for arrangements as to the amount of power to be interchanged in normal operation at definite times. In the event of a disturbance in one of the systems all interconnected systems will immediately coordinate their operations to supply power beyond the limits agreed to, in order to compensate for a possible loss in power. Subsequently, however, the faulted system should make all efforts to re-establish its own balance between load demand and generation by adjusting the prime movers accordingly whereby the contractual interchange power is once more attained between the interconnected systems.

The task of continuously maintaining the system frequency and interchange power to the neighbouring systems at a constant value, in the event of load fluctuations in the own system, by corresponding control of the power stations feeding into the system, presents a rather difficult problem to the load dispatcher. An automatic system controller will greatly relieve the load dispatcher of this task. He has then only to take care to see that appropriate use is made of the generating sets of the system, while the delicate work connected with the continuous matching of generation to the load fluctuations in the system is carried out by the system controller. A prerequisite for such systems' control operation is, however, that remote-control connections are available to the power stations and telemetering connections to the transfer points to the neighbouring systems.

Tie-line bias control has found wide application for the control of interconnected systems (6). With this type of control the frequency and the sum of all tie-line loads to the neighbouring systems are supervised and compared with the desired values according to operation schedule. Of the deviations from the two desired values a sum is formed in proportions which are determined by the system, and this signal is fed into the system controller. This type of control only responds to load variations in the own system and therefore satisfies

/the conditions

the conditions of interconnected systems operation. If, for example, one system supplies contractual power to a neighbouring system and if the meter readings show that, with a fall in frequency, the tie-line load has increased correspondingly, the sum of the two deviations from normal is zero and the controller remains inoperative since the disturbance obviously occurred in the neighbouring system. If, however, both the frequency and tie-line load have decreased the sum of the deviation affects the system controller since the load swing occurred in the own system where corresponding control actions have to be taken.

Figure 1 shows the interconnected operation of three systems, A, B and C. Particular importance is attributed to the load dispatcher of A. From the transfer sub-stations to B and C the measured interchange power values are telemetered to the load dispatcher A where the values are summated and compared with the set normal values. The difference between the actual and set values is fed into the master system controller. The frequency is the same throughout the system. It can, therefore, be measured locally at the load dispatch station and compared with the normal value, and the difference is also fed into the master controller. Variable series resistors allow the relative proportions of the frequency difference and tie-line load difference to be adapted to the system conditions. The deviations are evaluated in the master controller which assigns to the variable power stations a definite load which is transmitted as measured value to the power stations via long distance channels. In the power stations the unit output is matched to the assigned load wherein a frequency value is added locally in order to obtain a static characteristic for the loading of the generating units.

The load dispatcher has then only to vary the desired values of the interchange powers at certain intervals in accordance with the contractual schedule arranged with the neighbouring systems and, if necessary, readjust the relative proportion of the frequency and interchange power deviations in accordance with the system conditions (7).

/(c) Most

(c) Most economic utilization of the power stations

There arises the question as to the aspects after which the total load demand should be distributed between the individual power stations. It is a logical requirement that system operation under any load condition is so adjusted that the fuel costs are kept down to a minimum, under consideration, of course, of the system losses (8, 12). Operation to the effect that the system losses alone are kept down to a minimum would be unsatisfactory since the minimum in energy costs does not necessarily coincide with the minimum in losses.

Unless the load-frequency control is automatically connected directly with optimising features it is sufficient that an analogue computer is placed at the disposal of the central load dispatcher to enable him to quickly compute the optimum load distribution at any moment, in consideration of the generating costs of the individual power stations. The load dispatcher would determine the load distribution from time to time in accordance with the daily load curve and give corresponding instructions to the power plants. A further step in operation control is the employment of such a computer for the direct control of the power stations via supervisory remote control equipment to the effect that not only the frequency of the system is maintained constant but, at the same time, a completely automatic optimum load distribution is also obtained at any moment in the daily load cycle. It is then possible to include other conditions in the optimum control concerning, for example, the inter-system flow. The inter-system flow, or import of energy from other systems, can be based on the actual costs so that such a central analogue computer and controller can consider the load conditions at the inter-connections, taking account of any contractual limiting regulations and can provide continuous automatic economy optimisation of overall system operation. It should be noted that also the transitory conditions which have to be traversed to maintain constant frequency are automatically bridged in an economical way. A condition for the safe traversing of such transitory conditions is, of course, that the frequency is to be maintained, so that this requirement is also satisfied on the basis of the economical optimum situations.

/It is

It is therefore of importance that the requirements of maintaining the frequency constant and of inter-system flow control are connected up with the optimising directions also in regard to the equipment since otherwise it would be likely that, as a result of the continuous control processes, the optimum of the operation situation at any time could only be established on very rare occasions.

Some basic requirements which have to be taken into consideration for optimum operation of the generating plants should first be called to mind. In this connection the method of equal incremental costs is well known, but this disregards the system situation and can today be considered as obsolete. If the system losses are taken into account this condition can be expressed by the following extended equation (11, 12):

$$\frac{\partial K_i}{\partial P_i} = \lambda \left( 1 - 2 \times \sum_k B_{i_k} \times P_k \right) \qquad (1)$$

$$(i, k = 1 \ldots n)$$

The left-hand term of this equation is known for each power station and represents the so-called incremental costs related to the infeed point of the system, i.e., the busbars of the power station. These incremental costs are obtained from the absolute-costs curve of each power station by differentiating it with respect to the power output. The incremental costs are then known as a function of the active power output in the form of a characteristic curve and can be set on an analogue computer. Within the brackets on the right-hand side of equation (1) we have the corrective term which takes the system losses into account. The system losses can be represented by the following equation

$$P_v = \sum_i \sum_k P_i \, B_{ik} \, P_k \qquad (2)$$

$$(i, k = 1 \ldots n)$$

where $P_i$ and $P_k$ are the real powers fed from the generating stations into the system while $B_{i_k}$ represents the well-known loss coefficients. On the

/right-hand side

right-hand side of the equation we have another quantity, the factor $\lambda$, which is a variable. In order to be able to resolve the set of equations (1) in a positive manner another requirement has to be taken into account. This is available to the load dispatcher in the form of the summated load on the system, which can be represented by the following equation

$$\sum_i P_i - P_V = P_L \qquad (i = 1...n) \tag{3}$$

where $\sum_i P_i$ is the total generation fed into the system and $P_V$ are the total system losses, while the right-hand side of the equation represents the total consumers' load, $P_L$.

Since the load dispatcher cannot continuously solve these mathematical equations with the necessary speed in order to determine the correct distribution of the kW load, a special analogue computer is placed at his disposal to help him solve the set of equations in an easy and rapid manner. The cost functions of all power stations are represented in this computer and, in addition, the system situation and, therefore, the system losses are taken into consideration. Thus the load dispatcher has only to operate one reference setter in order to adjust the desired total power. The computer shown in Figure 2 determines immediately and automatically the relevant load distribution wherein the kW loads of all power stations can be read directly in megawatts from the respective scales (10, 14).

In this form, such a computer - SIELOMAT is only a trademark - represents only a calculating means for the load dispatcher. It is, however, obvious that the computer can also be adapted for automatic control of all power stations and for automatically maintaining the system frequency constant.

In the first place consider an independent system with power stations and a complex transmission system, the problem of inter-system flow being disregarded. In this case a deviation of the load, determined by the consumers, from the initial value will affect the system frequency either by a rise or a fall. As already mentioned, the SIELOMAT computer incorporates a reference setter for the desired total power. If, now, this reference setter is influenced by a change in frequency in the correct

/sense by

sense by an automatic control, the SIELOMAT can directly influence the governors of the prime movers in the power station by remote control. The SIELOMAT contains an indicator for each power station from which the value of the control signal can be read. A frequency deviation is caused whenever the power balance is disturbed. If the frequency decreases the generation must be increased, or vice versa, and this is effected by an adjustment of the reference setter of the SIELOMAT. The SIELOMAT determines without delay the necessary new economic load distribution and accordingly adjusts the governors of the prime movers in the power stations via pilot lines. In this case frequency control is made possible, and the economical operation of the power station maintained.

If several network systems are operated to a greater or lesser degree independent of each other wherein they are linked through tie lines, the control of inter-system flow presents another problem (9, 14). The control of the inter-system flow is generally subject to some contractual conditions which fix the costs for the interchanged power. Two network systems with one interconnection may be considered as an example, it being assumed that the two network systems handle the load situations independently of each other on the basis of their own economy requirements. In this case two load dispatch centres and hence two master controllers must be provided for optimum operation. The transfer sub-station of the two network systems is then to be treated in the same way as a power station. Dependent upon the direction of power flow, this hypothetical "inter-system power station" represents a generator for one system and at the same time it works as a motor for the other and vice versa. According to the contractual requirements, cost functions can be indicated over the entire working range of the generating or motoring power to be transmitted and these depend on the load condition prevailing in every part of the system at any moment. This concerns the so-called incremental delivered-power costs which were represented in equation (1) by the factor $\lambda$. These incremental delivered-power costs refer to the load sides of each system, i.e., for any total load situation of the two systems two such factors $\lambda_A$ and $\lambda_B$ are involved for the systems A and B. When these factors are transmitted from the load dispatch equipment of system A to that of system B and vice versa, operation

/of each

of each system part is optimized and the true costs of the transfer power are taken into consideration.[1] This type of operation can, of course, also satisfy certain limiting conditions in respect of the amount of power to be transmitted. This is made possible by providing the analogue computers with steeply rising cost curves for the transfer sub-station which can be adjusted manually as desired. On a sudden frequency dip on any sides of the transfer sub-station it is nevertheless ensured that the inter-system flow is increased for a short period to the values necessary for maintaining the frequency. In the case of an emergency the cost situations for the power stations and those for the transfer sub-stations do not have such a limiting effect that all of the power stations would not help out according to their capability. On the contrary, they ensure such support beyond the normal conditions and take at the same time the mutual cost situation into account during the control process.

Another problem concerns the operation of steam turbines from the regulating point of view (13, 14). Thermal considerations result in certain limitations which can easily be provided for in the SIELOMAT controller in functional respect. This requires that the computer be equipped with limiting devices for the speed of response, for the generations dependent upon the operating range, in accordance with the relevant permissible rate of change of generation. These devices make it possible to load the steam power stations by means of the SIELOMAT, in accordance with the permissible limits, while maintaining optimum operating conditions and observing the limiting requirements of frequency control.

Since, in straight run-of-river plants, the kW output is determined by the water throughput per unit time, the real power is not an unknown variable. It is of importance in respect of the losses and of the power balance. From the optimising equations results an evaluation of the water (10). This fact is automatically taken into account by the SIELOMAT operation-optimising computer.

1/ Strictly speaking, the relevant factor $\lambda_A$ or $\lambda_B$ should be multiplied with a corrective term which depends upon certain loss components in connection with the power transmitted. Details can be seen from the literature cited.

/In the

In the case of pumped-storage plants the water must be evaluated in a different manner. It can be shown that, in this case, the evaluation of water has to be effected by introducing constant incremental costs. It should be considered that the evaluation of the water as a function of all load situations has, in each instance, to be related to the fuel costs of the other power stations carrying part of the load. For the calculating process it is of importance that, first of all, a clear picture is obtained of the operating cycle. This operating cycle is, quite naturally, dependent on meteorological conditions and this is the only uncertain quantity of appreciable influence in the process. If, however, the meteorological cycle is known and the water inflow quantities during this period are also known, a condition for the operation of a pumped-storage power station is that the sum of the total of the water quantities flowing through the generators during this working cycle and the total water inflow, which is introduced in the calculation with opposite sign, must be zero. If, now, a constant water evaluation of any desired amount is introduced and the daily, monthly or annual load curves of the system are traversed, an exactly defined working point of the hydro-electric station is found. From this preliminary study a too high hydro power, for example, amy result. From this it can be concluded that the constant incremental costs for the water evaluation have been selected at a too low value. A repeated calculation, with a correspondingly varied incremental cost value, may ultimately result by iteration in the correct water evaluation, and this is the case if the water inflow is just used up for the generation of electric power. It may, however, occur that, for example, an annual cycle has to be divided into several sub-cycles. In such studies a load-dispatch computer such as the SIELOMAT can be of great assistance.

### 3. Area control stations

To carry out the instructions given by the central load dispatcher it is necessary to set up other central control points, the so-called area control stations. These are generally installed in the control room of a large system sub-station and their task is the remote control and supervision of the transformer and distribution sub-stations of a definite area

/system, operating

system, operating particularly at medium-high voltage. Contrary to the overriding functions of the central load dispatcher, the area control stations have a direct influence on the operating condition of these sub-stations by the direct remote control of circuit breakers and on-load tap changing transformers.

In accordance with these duties such an area control station cannot be equipped with a straight supervisory mimio diagram, as the load dispatch station, but with mimio diagrams of the desk or board type in which control discrepancy switches for the remotely controlled circuit breakers and discrepancy switches for the only remote-supervised switches are incorporated. For reasons of space conservation and easy survey, control switches of the miniature type of design are preferably used. Where extensive changes in the area mimio diagram are to be expected as a result of extensions or the addition of other stations, or a change in the voltage level, it is advisable to use a mimio diagram of mosaic construction.

As compared with the load dispatcher, for whose information collective indications and summated readings are sufficient, the switching engineer of the area control station has to occupy himself with the operation of the individual equipment, i.e., the individual circuit breakers and isolating switches, the individual converter, the individual generator etc.; he has, therefore, to receive individual switch position indications and individual meter readings. The supervisory remote-control equipment at his command has to be suitable for carrying out the following supervisory remote-control operations:

(i) Remote control and position indication of circuit breakers.

(ii) Position indication of isolators. In unattended stations, and with frequent transfer from one bus to the other the isolators have also to be remotely controlled.

(iii) Transmission of special alarm announcements for the protection of individual plant components, such as transformers, rectifiers, etc.

(iv) Transmission of general alarm announcements, e.g., for auxiliaries.

(v) Adjustment of on-load tap-changing transformers and earthing reactors.

(vi) Tap position and limit position indications of transformers

/and earthing

and earthing reactors.

(vii) Transmission of earth fault indications and starting of an automatic earth fault tracing equipment.

(viii) Starting and stopping of a local automatic control for starting, paralleling and regulating the machines.

(ix) Continuous remote regulation of machines, dam gates etc., if hydro-electric stations are under the direction of the area control station.

(x) Selective telemetering.

The following quantities are generally telemetered:

(a) Active power and, in part, reactive power of the individual generators and important load feeders.

(b) Bus voltages.

(c) Load currents in load feeders or tie lines.

(d) Comparison voltage and frequency of the incoming machine in the case of remote sychronizing.

(e) Position indication of quantities continuously controlled on a measuring basis, e.g., dam gate position, water level etc., unless not covered by digital telemetering methods.

In the case of the area control station part of the necessary readings, particularly current and voltage, can, in a similar way as for the load dispatch stations, be transmitted as called for, and indicated on common instruments.

The extent of the supervisory remote-control equipment at the individual stations of the area system depends not only on the size of the relevant station but also on whether it is attended or not. If it is unattended, as is generally the case with medium and small-size stations, the supervisory remote-control equipment has to be increased, as compared with a continuously attended station, with regard to the number and type of alarm announcements and operational indications, and also with regard to the possibly necessary control of the isolating switches.

In consideration of the fact that within the range of an area control station the distances to be bridged are generally shorter than the distances to be bridged by the load dispatcher, and that often a free pair of cores is

/available in

available in a telephone cable for the individual supervisory remote-control tasks - apart from the remote control and remote metering methods enumerated for the load dispatcher - the following simple methods can be employed for area control:

(i) For remote control: single-pilot wire control.

(ii) For telemetering: measured-value transducer method with d.c. transmission for operation over lines not subject to high-voltage interference, and rectifier telemetering equipment for the transmission of current and voltage values.

On account of the shorter distances involved in the case of area control stations, equipment for multiple utilization of the transmission lines is less frequently used here than with load dispatch systems. In as far as such equipment is used it is mainly voice-frequency transmission equipment and in special cases also wireless carrier equipment which is partly combined with the line repair gang radio communication.

## 4. Practical cooperation

While the operation of the load dispatch station and the subordinate area control stations normally follows a predetermined daily operation schedule under the responsibility of these central system operators, the functions of the load dispatcher and area control stations overlap each other, in the event of a large system disturbance or a greater loss of generation. In such cases the central load dispatcher is informed within a few seconds of all disturbances on the system with regard to their extent and effect on operation. Independent of any telephone communication he can transmit within a few seconds via the standard-instruction transmitter the directives for carrying out the necessary measures to remove the disturbance, such as load sheddings, load transfer etc. to the area control stations and also to the power stations.

Since the area control stations are, furthermore, in the position to carry out within a minimum of time the general instructions of the load dispatcher, e.g. by throwing off load in the individual stations or by the use of hydro power reserves, the central load dispatcher can quickly react on operational disturbances as necessitated by the requirements of present-

/day interconnected

day interconnected system operation, and this can be attained only by the comprehensive use of the building blocks of the supervisory remote-control technique.

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/FIGURE I

FIGURE I
GRAFICO I

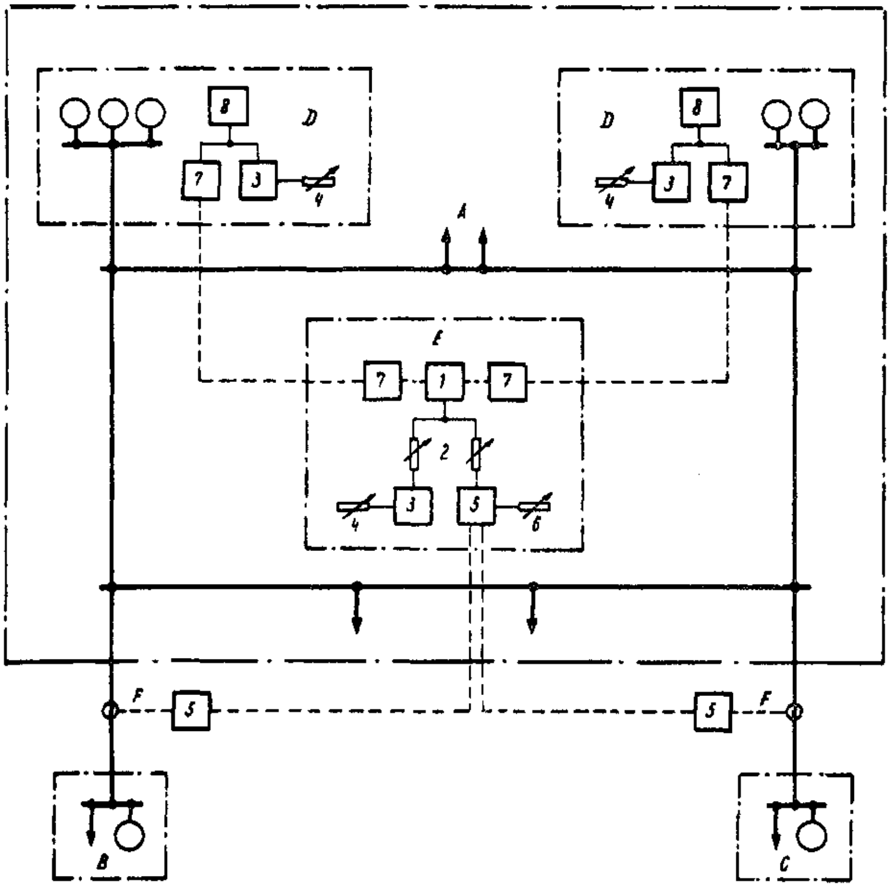


FIGURE II
GRAFICO II

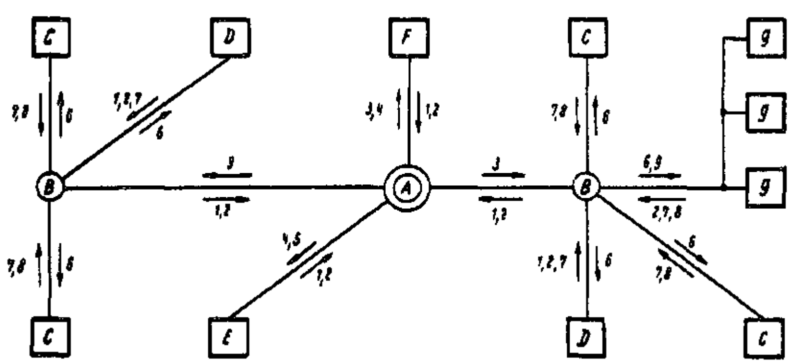

FIGURE I

Automatic power-frequency control

| | | | |
|---|---|---|---|
| A | System A | 1. | Automatic controller |
| B | System B | 2. | Area bias |
| C | System C | 3. | Frequency |
| D | Power station | 4. | Frequency schedule |
| E | Load dispatcher | 5. | Power |
| F | Transfer sub-station | 6. | Power schedule |
| | | 7. | Load schedule |
| | | 8. | Regulator |

FIGURE II

Supervisory remote control of a large power system

A Load dispatcher

B Area Load dispatcher

C Transformer station

D Transfer station

E Peak load power station

F Steam power station

G Hydroelectric power station

1. Position indicating for load dispatcher (collective indication)

2. Telemetering for load dispatcher (summated values)

3. Stereotype order by load dispatcher

4. Automatic control by load dispatche

5. Remote start up by load dispatcher

6. Supervisory remote control by area load dispatcher

7. Position indicating for area load dispatcher

8. Telemetering for area load dispatcher