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RATIONALIZATION OF ELECTRIC POWER PRODUCTION AND CONSUMPTION

(Note by the secretariat)

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<u>Introduction</u>

Electric power is a particularly valuable form of energy because it is capable of being converted at a very high efficiency rate into almost all the forms of energy which are used. That is why it is electric power which is most often the intermediate agent between the primary forms of energy such as hydro power or fuel, and the final forms in which energy is consumed without further conversion as, for instance, light, mechanical power, heat and chemical energy.

From the point of view of the general energy economy; the rationalization of electric power production and consumption helps, in the first place, to provide, in the most economical way, the electric power necessary to satisfy requirements and, in the second place, to develop electric power consumption for purposes best suited to this form of power.

As regards electric power production, an important point is that the choice of equipment and site should depend on the primary resources which, from the point of view of the national economy, are most suitable for conversion into electric power. Examples of such resources are coal by-products, lignite and hydraulic power, and also, in some cases, natural gas and fuel oil, if available in the country concerned, or fuels of high calorific value, such as petroleum products, if the energy required has to be imported and these fuels have to be brought over long distances.

The expansion of electric power consumption within the general economic framework aims at the substitution of this form of power for others, if that is of advantage to the national economy, as for example, if the country is rich in energy resources that can be economically converted into electric power, such as hydraulic energy, geothermic energy in the form of steam, and lignite. If, on the other hand, the bulk of the primary energy on which electric power production is based has to be imported, the general energy policy may aim at confining the consumption of electric power to purposes which are justified from the point of view of the national economy.

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In the more limited framework of the electric energy economy, rationalization means the introduction or adoption of all measures designed to obtain the maximum benefits at minimum expense.

The production, transmission, distribution and consumption of electric power involves a number of complex processes, so that if the maximum economy is to be achieved, these processes must be controlled under optimum conditions.

Since the electric power industry is characterized by its large capital outlay, producers and distributors should try to obtain the highest returns from the capital invested in their enterprises. So far as the consumer is concerned, the problem is to obtain at the lowest possible cost the useful energy into which electric power is converted.

The rationalization of electric power production and consumption therefore makes it possible to reduce the capital requirements of electricity enterprises, to reduce fuel consumption by thermal plants and to provide the electric power consumer with better service at lower cost.

The present document summarizes the measures by which electric power production and consumption can be rationalized. These measures are discussed under the following three headings:

- Rationalization of electric power production
- Rationalization of electric power transmission and distribution
- Rationalization of electric power consumption.

The first two headings are the exclusive responsibility of the electricity enterprise, whereas the third is the responsibility of the enterprise and the consumer alike.

CHAPTER I

Rationalization of electric power production

1. Rational planning of production equipment

Rapid expansion is a characteristic of the electricity economy.

Electric power, wherever it is introduced, stimulates the development of industry and of the economy in general and this in turn increases the demand for electricity. Every electricity enterprise therefore faces the problem of constantly extending its production and transmission equipment in order to keep pace with the increase in demand. However, since it takes a long time (4 to 6 years) to prepare and carry out plans for new plant, particularly in the case of large-scale hydro projects, construction programmes based on long-term demand forecasts must be drawn up.

In many cases it is impossible for the developing countries to base these forecasts on past trends, owing to the lack of adequate statistics. The sectoral method, which takes into account plans for industrial and agricultural development and for the resultant development of trade, seems more suitable and gives more reliable results.

Since the losses to the economy resulting from a shortage of electric power are even more serious than those caused by excess capacity, it is advisable to base plans for the expansion of the electricity supply system on optimistic, rather than pessimistic, forecasts, even if their implementation has to be slowed down should development lag behind the forecasts.

2. Hydro power plants

The advantage of hydro projects is that operating costs are very low. Construction costs, on the other hand, are relatively high. Furthermore, since suitable construction sites are frequently remote from the consumption centres, the amount which has to be invested in the construction cost of hydro power plants often includes an item relating to the transmission of the power produced.

In many cases, a hydro power plant can be designed as a multi-purpose project for flood control, waterway improvement and irrigation. However, the amount of electric power produced by a large-scale hydro plant operating at optimum capacity often exceeds by a large margin the requirements of a country or region in which electrification is in its initial stages. In such cases, it might be more economical first of all to stimulate consumption in the region through the use of small Diesel power plants or, if the watercourses are suitable, small hydro plants.

The construction of the large-scale project would then be deferred until demand had increased to such an extent that the large plant could be rationally used. The small power plants which thus became redundant could be used for the same purpose in other suitable areas. Lastly, some watercourses can be developed to support a series of power plants so that a comprehensive plan can be carried out in stages as demand increases.

Since the output of hydro power plants depends on river flow, they can be operated rationally only in co-ordination with other power plants.

As hydro power plants can often be used for peak load purposes within the framework of the co-ordinated operation of a number of plants, it may be advisable, at the time when the hydraulic works are constructed, to provide for the possibility of expanding capacity in the future.

3. Thermal power plants

The technological progress achieved in the construction of steam plants has enabled their thermal efficiency to be considerably increased and their specific construction costs reduced. These results are mainly due to the following measures:

- the introduction of large-capacity generating units (100-500 MW);
- the use of high steam pressures and temperatures and the introduction of the re-superheating system;
- steam bleeding at several pressure levels for reheating the water supply.

Where load conditions are favourable, therefore, it may be worth-while to replace a number of small obsolete plants of low efficiency by one or more large power plants; this practice will also lead to savings in operating manpower.

The efficiency of an existing steam plant designed for the use of steam at relatively low pressures and temperatures may sometimes be increased by replacing the boilers by others designed for higher pressures and temperatures, and by installing topping sets. Providing that the site is suitable and that adequate supplies of cooling water are available, a steam plant can be constructed anywhere. If it is erected in the consumption centre, power transmission costs can be reduced; on the other hand, its erection near the mines which are to supply the fuel means that such fuel need not be transported. It is an economic problem to decide which of these alternatives is the more rational; the choice will depend on local conditions, the quality of the fuel, etc.

In industrialized areas, where industries use large amounts of heat in their production processes, the construction of a combined heating and electricity plant offers possibilities of producing electric power in an extremely efficient manner.

Lastly, in certain industries, as for example the cement industry, the heat obtained in the production process can be used to produce steam, which in turn can generate low-cost electric power.

The construction of a large thermal plant in the hope that consumption will expand rapidly in the areas where electrification is only in its initial stages is obviously risky from the economic point of view.

As in the case of large-scale hydro-electric projects, it is better first of all to stimulate consumption by meeting demand through small Diesel plants which are cheap but of low efficiency and which, after the large-scale project has been constructed, can be used in other regions for the same purpose.

4. Interconnexion of networks

Another method that can be used to rationalize power production is the interconnexion of regional or even international networks, providing that the distances to be covered by the interconnexion lines do not make the project prohibitive by means of the capital investment required.

Interconnexion permits an economic distribution of the load between electricity plants of different types, and at the same time enables hydro plants to be used to their full capacity and thermal plants to be loaded in the order of their specific fuel consumption.

In this way, the cost of producing electricity can be reduced. Interconnexion also enables the reserve capacity to be considerably reduced, because, owing to the large number of units interconnected, the breakdown risk declines even though the incapacity factor of the individual units remains the same.

Such interconnexion and co-ordination of production should not, of course, be limited to public electricity services. On the contrary, it should be extended to industrial plants, particularly if they are equipped for combined electric power and heat production. Furthermore, interconnexion, particularly of networks extending over large distances from east to west, tends to reduce the total peak load and to equalize the load curve owing to the way in which the load curves of the individual regional networks differ from each other.

Inversely, the existence of an interconnected network supplied by a large number of plants can affect the design of new plants.

For example, it will tend to result in hydro plants being equipped for peak power production, while the equipment of thermal plants will be designed mainly to ensure high output at full load.

Where the possibilities of developing hydro power are limited, use is sometimes made of pumped storage installations which can be used for pumping during off-peak hours, thus filling troughs in the load curve, and for producing peak power when operated as hydro-electric plants.

The economy of pumped storage installations operated in conjunction with base power plants is still, however, under discussion; and some experts are of the opinion that if the natural conditions are not suitable for the construction of hydro plants, it is better, instead of using pumped storage installations, to build thermal plants which can be economically adapted to load variations, for example, by fixing their maximum efficiency at some 60 per cent of their maximum capacity.

CHAPTER II

Rationalization of electric power transmission and distribution

(1) Rationalization of the construction of lines and substations.

The construction costs for transmission lines and substations can be considerably reduced by standardization.

Such standardization makes it possible to construct pylons, the equipment of substations, such as circuit breakers and transformers, and the stations themselves, according to the same plan, and to use mass-produced equipment.

There is an optimum economic ratio between the distance, voltage and transmission capacity of a conductor; the rationalization of electric power transmission therefore requires that transmission and distribution systems should be extended and gradually strengthened as consumption expands. This leads to the introduction of increasing voltage steps corresponding to the steady increase in the power transmitted. These voltage steps are chosen from among the standardized voltages adopted by the International Electrotechnical Commission (publication 38 and revisions). As a rule, it is often assumed that if a higher voltage step has to be used owing to an increase in demand, the voltage of the new step should be about double that of the previous one.

It should also be noted that the standardization of the numerical connexion index for the transformers used for connecting networks at different voltage levels is very important, for it enables networks at different voltage levels to be interconnected simultaneously. The advantage of this is felt, for example, when the interconnexion is restored after being broken by an operational accident.

The rate at which lines can be erected and cables laid may be speeded up considerably by mechanization.

Such mechanization can be achieved through the use of tractors, winches for the erection of overhead lines, power-driven augers for boring pole holes, and excavators for digging trenches for cables.

Helicopters are now sometimes used for erecting poles and even pylons if conditions are unsuitable for transport by other means.

These modern technical methods often enable construction costs to be reduced considerably, provided, however, that the machinery utilization factor is high.

(2) Reduction of losses

Since transmission losses are proportionate to the square of the current value, electric power must be transmitted at a power factor as close as possible to unity. In other words, any transmission of reactive power should be avoided, and for this purpose, synchronous compensators have sometimes been used at the consumption centres in order to offset the reactive power load, so that only active power is transmitted from distant plants.

It is also clear that the proportion of electricity transmission losses tends to diminish as load variations decrease, and that the equalization of load curves therefore helps to reduce such losses.

(3) Maintenance of electricity networks

In the past, maintenance work on electric power lines and substations involved the shutting down and grounding of the section of line in question. Particular areas, and even entire regions, were thus deprived of electric power for several hours; as a result, the population was considerably inconvenienced and, when industry was involved, the economy suffered heavy losses.

In order to overcome these disadvantages, methods have now been devised whereby repair work can be done with special tools without interrupting the service. The operations in question include the following:

- the testing of line insulators and the replacement of defective ones
- the installation of vibration dampers
- the replacement of cross arms
- the replacement of wood poles
- the replacement of damaged conductors
- the painting of pylons, cross arms, etc.

There are two different methods by which live lines can be maintained and repaired; either the work can be done with special tools attached to long insulated sticks, or the linesman is placed in an insulated bucket, from which he can touch the conductor and do his work with bare hands.

CHAPTER III

Rationalization of electric power consumption

Rationalization of consumption means, in the first place, using the most efficient electric machines and appliances as efficiently as possible.

However, electric power has to be produced at the time when it is consumed, and consequently the load and, therefore, the equipment required for production and transmission purposes are determined by consumer demand alone. Since the losses entailed in electric power consumption, transmission and distribution depend on the load factor and the power factor, the rational consumption of electric power will also tend to improve these two factors.

The rationalization of consumption therefore requires that the interests of consumers, producers and distributors should be balanced against each other, so that reasonable allowance may be made for the way in which the characteristics of electric power consumption affect the efficiency of the production and transmission of electricity.

There are thus four aspects of the rationalization of electric power consumption:

- the improvement of the load factor
- the improvement of the power factor
- the efficiency of conversion into useful energy
- the promotion of efficient use, publicity and information for consumers.

These various points will be discussed below.

It should also be noted that these questions were discussed in detail at a Symposium on The Rationalization of Electric Power Consumption, held at Warsaw in May 1962.

The main theme of this Symposium was sub-divided into the following four groups of problems:

- means of reducing load fluctuations by shifting certain peak loads or developing certain types of consumption during off-peak hours
- means of promoting the rational use of electric power for lighting, transport and industrial and domestic use
    - (a) means of promoting the rational use of electric power for transport and industrial use
    - (b) means of promoting the rational use of electric power for lighting, domestic use and agriculture

- technical, economic and organizational methods to promote the rational use of electric power by consumers.

Volumes I and II of document ST/ECE/EP/13 contain detailed information on the organization of this Symposium, as well as a list of the 108 reports submitted and a summary of the debates which followed the consideration of these reports.

(2) Improvement of the load factor

The habits of consumers are reflected in the load curve, which shows the typical daily, weekly and annual variations. To a certain extent, however, electric power distributors can influence these variations by means of tariffs which encourage the consumer to limit his use of power during peak load periods and to increase his consumption during off-peak hours. Thus almost all countries have applied tariffs designed to equalize the load. Under the two-part tariff, for instance, the price of the electricity consumed comprises a component proportional to maximum demand and another proportional to the amount of kWh consumed. It is therefore in the consumer's interest to restrict variations in consumption, thereby reducing the average price of the power he consumes. A similar effect results from the progressively decreasing block tariff rates applied from the point at which consumption reaches a certain level, the price per kWh then depending on the quantity used.

Other tariff measures aim at reducing consumption during peak hours by setting the rate per kWh at a high figure, while encouraging consumption during off-peak periods by giving low rates. In Greece for example, the price per kWh consumed is reduced according to a two-part tariff if the load is voluntarily reduced during the peak hours. In other countries, electric power is available during off-peak hours at extremely low rates, under the so-called "night" tariffs.

A heavier night-time load is often encouraged by fixing extremely low rates for certain uses of electric power, e.g. water heaters. Sometimes also a direct effect is exerted on the load curve by using a remote control system with acoustic frequency signals superimposed on the normal frequency of the network for the purpose of switching on groups of water heaters during the off-peak hours.

Another method of increasing the load during off-peak periods is to make arrangements with certain industries, such as the chemical and metallurgical industries for example, whereby certain processes requiring very heavy electric power consumption are carried out at off-peak hours. Such arrangements are facilitated by automation. Also by agreement with the industries concerned, certain plant which places a heavy burden on the network can be shut down during peak hours, continuity of work in the industry being assured by the formation of buffer stocks of semi-manufactured products.

In the case of certain industrial equipment which requires a constant high load, such as aluminium smelters and arc furnaces producing calcium carbide or processing metals, the load can be reduced during peak hours without halting the process and at the cost of only a slight loss in production and a minor increase in specific electric power consumption. In this way, an adjustment of daily, weekly and seasonal peaks becomes possible. In Hungary and Poland for example, in the interests of the general economy, certain heavy industrial consumers are compelled to take electric power from the networks in accordance with a pre-determined load diagram previously established on the basis of the detailed consideration of their industrial establishments.

It is sometimes possible to equalize the load curves of heavy industrial consumers by making a study of the separate load curves of all the electrical machinery and on the basis of such data to establish an operating programme in which individual peaks are offset by individual troughs. Poland and Romania refer to such studies. Lastly, for certain consumers, Austrian electricity undertakings use load-limiting devices which cut off the current when the maximum load is exceeded.

(3) Improvement of the power factor

Transformers and asynchronous motors, which owing to their simplicity in operation and the small amount of maintenance they need are used in large numbers by industry, require a certain amount of reactive current for the purposes of excitation. Since this reactive current depends to only a very small extent on the load upon the machine, any under-load, or even idling, tends to reduce the power factor. However the reactive current required to excite such machines can be offset by capacitors which, in order to avoid losses in the electrical equipment, are connected as near as possible to the machine whose reactive current they have to offset. If, however, the motor and transformer are constantly run at their rated capacity, their power factor is generally quite good and it is unnecessary to install compensation capacitors. The same result can sometimes be achieved by using a large number of individual motors, each of a power corresponding exactly to that required by the machine driven. Transmission systems which permit several machines to be driven from a central motor should be avoided because of the frequently very low load factor and also on account of high mechanical transmission losses.

It is also a good idea to install synchronous motors for driving high power equipment which is in almost constant use. The reactive power load of any asynchronous motors and transformers installed in the same plant can thus be offset. Sometimes the whole reactive current required by a factory is offset at some central point by a synchronous capacitor set. In certain countries, including Hungary, the installation of such capacitors is required under the regulations laid down for industrial plant.

Lastly, for driving machines whose speed has to be regulated, it is better to use commutator motors on account of their high efficiency and power factor.

In some countries, the use of the electricity supply system at a power factor below a given value (0.8 or 0.85) is penalized by a progressive increase in the price per kWh or even by cutting off the supply. Sometimes the improvement of the power factor by consumers is encouraged by the use of kilovar-hour meters, the consumption registered by which is charged for at a special rate.

(4) Improvement of efficiency of conversion into useful energy

In most countries, industrial consumption amounts to more than two-thirds of total electricity consumption; it is this sector in particular that must be rationalized by improved efficiency.

The first means of improving the efficiency of machines powered by electric motors is to avoid friction losses. This calls for careful maintenance and adequate lubrication; but in addition considerably improved efficiency can be obtained by the elimination of any avoidable mechanical transmission. Each distinct movement should be powered by a separate motor.

In industrial circles there is a tendency to select motors and transformers of a higher power rating than that required by the normal load in order to avoid any overloading which might cause an accident and upset the running of the factory. As has already been noted, this method should be rejected owing to the low power factor obtained. Another disadvantage is the effect on the power efficiency of the installation, since under-loaded transformers and motors are relatively inefficient. From this point of view also, it is desirable that the power rating of transformers and motors should be strictly commensurate with their normal load.

In many factories development of internal electric systems has not kept pace with the extension of the uses of electric power in the factory. Consequently, such systems are continually overloaded with resultant losses which might easily be reduced by adapting the systems to the increased requirements.

The efficient planning of a factory's internal electric system - by suitable choice of voltages and rational protection of the distribution system and of the machines connected to it - is important from the point of view of limiting not only power losses but also production losses in case part of the electric system breaks down.

The effectiveness of certain means for improving efficiency is shown, provided that new electrical processes have not replaced non-electrical ones, by a reduction in the specific electric power consumption per unit used. This criterion, therefore, can be used as a measure in this field. Research on processes using large amounts of electric power, such as the electrolytic production of aluminium and electro-thermic arc furnace processes, has resulted in considerable reductions in electric power consumption.

Several reports submitted at the Warsaw Symposium on the Rationalization of Electric Power Consumption give detailed information on this subject (see Bibliography).

(5) Promotion of the efficient use of electricity, publicity and information for consumers

Even today, in certain countries, large amounts of electric power are wasted through carelessness or through motors idling. The first means of increasing electric power consumption efficiency in industry is therefore to avoid the idle running of motors by improved organization of work.

In most cases, however, an over-all critical study of the technical processes in a factory or workshop will reveal a number of other possibilities of saving electricity. It is for this purpose that collaboration is required between electrical and technological experts. Large industries sometimes have their own organization for this purpose, but smaller undertakings have to depend on consultants, outside experts, etc. The specialized technical Press sometimes publishes articles on improvements of this kind, but a specific exchange of such information appears to have been organized in only a very few countries.

Certain countries, including the Federal Republic of Germany, Hungary, Poland, Romania, Sweden, the USSR and the United Kingdom, have specialized bodies set up to promote the rationalization of energy consumption and electric power consumption in particular. These bodies deal with publcity to stimulate consumer interest in the efficient utilization of electric power; they give technical advice and undertake specialized research for industrial and agricultural consumers; in some of these countries they are authorized to order consumers to adopt certain measures in order to avoid wasteful power consumption.

In countries where there are no specialized bodies, the electricity undertakings, their associations and the electrical industry associations often deal with the rationalization of power consumption. In particular, the public information services of the electricity undertakings establish direct contact between electric power suppliers and consumers and are thus most favourably placed to promote the rational utilization of electric power. It appears, however, that the aim of these services is rather to promote the use of electricity than to further the rationalization of its consumption, and that their educational activities are addressed rather to domestic and agricultural than to industrial consumers.

There are also a number of international professional organizations dealing with the problem:

- the World Power Conference
- the International Federation of Self-Producers (FIPACE)
- the International Union of Producers and Distributors of Electric Power (UNIPEDE).

The last-named has two study committees particularly concerned with the rational use of electric power:

- Study Committee on the Promotion of the Application of Electric Power
- Study Committee on the Optimum Use of Electric Power.

These various bodies and organizations possess extensive documentation on the experience acquired in these fields.

This documentation indicates that very often the changes made in the equipment of certain plants in order to ensure the more efficient use of electric power are not very costly. It has frequently been observed that the expenditure thus incurred is covered in less than a year by the reduction in the cost of electric power consumed.

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