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ECONOMIC AND TECHNICAL ASPECTS OF THE INTERCONNECTION OF ELECTRIC POWER SYSTEMS

submitted by the
Union of Producers and Distributors of Electrical Equipment (UNIPEDE)

NOTE: This text is subject to editorial revision.

CONTENTS

/Introduction

Introduction

The International Union of Producers and Distributors of Electrical Equipment (UNIPEDE) was glad to accept the invitation of the Economic Commission for Latin America to attend the Electric Power Seminar in Mexico City in January 1961 and has asked the members of its Committee on International Interconnections to contribute to the work on the basis of the experience made in Europe in the field of national and international interconnections.

In this report the European interconnection of systems is outlined and the deriving advantages with regard to both low cost and reliability are illustrated.

General considerations based on the European experience in the field of interconnections are made and the deriving economic advantages with regard to electric power generation and transmission and to systems operation are shown. The necessary technical characteristics of the systems in order to ensure satisfactory interconnection are briefly described.

Much progress has been achieved in all European countries during these last two decades so we deem that the Latin American engineers who are responsible for the development and operation of the electric power systems in their countries should be interested in European experience.

1. Interconnection of systems in Europe

What follows refers especially to western Europe, though the development of electric power systems in eastern Europe was subject to the same technical and economic rules.

In practically all European countries the total interconnection of electric power networks has been carried out more or less recently. This is true both for small countries such as Belgium, the Netherlands, Portugal and Switzerland as well as for medium size countries, such as France, the Federal Republic of Germany, the United Kingdom and Italy and also for countries where the geographical features demand transmission and interconnection systems of wide extension, as in Finland and Sweden.

It is necessary to point out that the interconnection of networks was carried out independently of the policy on power generation and distribution followed in each country, that is to say, either through state owned

/electrical industry

electrical industry, such as in France and the United Kingdon, or through private management such as in Italy and the Federal Republic of Germany or else through both private and nationalised management, such as in Portugal, Sweden and Switzerland.

Different factors have led to the creation of national interconnections in the various countries: for France, the Federal Republic of Germany, Portugal and Sweden the main factor was the necessity of transmitting large quantity of hydro-electric power, for Italy it was the necessity of hydro-electric seasonal compensation, while for the United Kingdom it was the opportunity of burning coal on the spot and fully utilizing the steam power plants of higher efficiency. However, whatever the reason may be, the fact is that all European countries have network interconnections which in the long run have become of greatest importance for electric power supply, both with regard to sound utilization of the generated power and to reliability of operation. We can say that the electric power systems of a country are as much a primary factor for the development of its economy as railways or road networks.

Until a few years ago electric power systems in the various countries consisted of high voltage lines up to 220 kV, while during the last years new higher voltage transmission lines (380 kV on the European continent and 275 kV in the United Kingdom) have been built.

In addition to national interconnections there are international ones, which are becoming more and more important. International interconnection is, in the context of this report, even more interesting than national interconnection. As a matter of fact, apart from the interconnection between the Federal Republic of Germany and Austria, when international interconnection is concerned the factors mentioned with regard to national interconnections are virtually unimportant (transmission of large amounts of power generated by hydro-electric plants, regular seasonal compensation, better utilization of steam power stations). There are other factors which we might define as the "intrinsic benefits" of the interconnection, namely, possibilities of occasional power exchange which could take place at any moment, mutual stand-by, better frequency control and so on. The above might seem to be factors of secondary importance but they are not; on the contrary they can justify the installation of electric transmission lines of a voltage up to 220 kV and up to 380 kV in the immediate future.

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These international interconnections in western Europe form an integrated whole, whose total power is steadily increasing. In the winter of 1959-1960 it exceeded 47 million kW. The technical and economic results obtained through international interconnections are considerable and mainly consist of a better system of operation and of a reduction in generating costs. It is highly significant that, in the six countries most closely interconnected, that is to say, Austria, Belgium, the Federal Republic of Germany, France, Netherlands and Luxembourg in the years 1950-1957 the energy produced increased by 87 per cent and the installed power capacity increased only by 70 per cent, while in countries with no interconnections the proportion is generally reversed. Other results due to interconnection are better exploitation of the available hydro-electric resources, better operation, especially with regard to meeting target frequencies and the rapid elimination of breakdowns. European frequency nowadays is generally kept within $\pm$ 0.05 Hz as regards nominal value.

The development of interconnections did not require a special international organization since bilateral contacts between the national organizations are sufficient to deal with the problems inherent in the operation of interconnected systems.

Substantial help in the study and regulation of the European interconnections was given by the organizations working in the electric power field. In addition to UNIPEDE, mention should be made of the Union for the Coordination of Generation and Transmission of Electric Power (UCPTE) sponsored by the Organization for European Economic Cooperation (OEEC).

A very important economic achievement of the OEEC and of the other organizations has been the international free exchange of electric power, which is exempt from customs duties and is subject to neither foreign exchange restrictions nor to currency adjustments.

We can therefore say that at present, so far as electric power is concerned, we have a genuine common market in Europe. It might be asked if, in this favourable picture of European international and national interconnections, there are no black spots which offset the great technical and economic advantages. As a matter of fact, there are negative sides also, although these are of little importance. Extensive interconnections of very high

/voltage systems

voltage systems provide great short-range power which, in turn, requires equipment and apparatus of appropriate capacity. This is not an unsolvable problem for modern engineering. We just want to underline the fact that widely extended interconnection require detailed study and very careful and accurate planning. In these interconnections, after periods of very extended breakdowns, to restart the operation is not an easy matter, but such difficulties have been overcome by multiplying the means of control, which are complex and expensive, but of great help.

It was feared that great difficulties might be met in connecting large systems through lines, the transmission capacity of which was limited in comparison with the power of the systems. This was particularly so in the case of the interconnection between France and the Federal Republic of Germany. However, with the adoption of power frequency control with a sufficient number of regulating sets the trouble was avoided.

In the long run the technique employed for the construction of modern systems eliminates the inconveniences that might arise from a widely extended interconnection, and nowadays European interconnections work to perfection to the satisfaction of all the nations involved. It might also be pointed out that, in Europe, differences of nationality or language notwithstanding, we now share a common European feeling regarding the problems of electric power, which arises from the frequent contacts among engineers of all nations and it is thanks to such contacts that fruitful information can be easily exchanged.

2. General remarks on the interconnection of electric power systems

As was said in the introduction, the aim of this brief report is to try to present, on the basis of European experiences in interconnecting electric power systems, some criteria of general value. We do not lose sight of the fact that the problems in other continents are on a different scale as compared with the problems we have to deal with in Europe and that their extrapolation is not possible. The large countries of Latin America are of such size that it would be mere nonsense to think of applying to them the same criteria as are adopted in Europe for the interconnection of systems. But even in the extensive Latin American countries there are regions where the situation may be similar to that we have to face in

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Europe. Besides, our Latin American colleagues know very well to what extent European achievements can be successfully applied in their countries.

The most important problem of interconnections is the standardization of frequencies and voltages. With regard to frequencies we have very little to say: the whole world is divided into two large areas, one using 50 Hz and the other using 60 Hz, and therefore unification is not possible. However, in so far as difference of frequency affects only countries where interconnection is not practicable, it is not a very important matter. Very often equipment can operate on both frequencies and, in any case, where a continent-wide market is concerned, the need of two different types of equipment (that is, one type for each frequency) is quite an insignificant problem.

It is much worse when different frequencies are adopted in countries that, at least theoretically, could be connected, because then interconnection could be effected only by means of expensive and complex conversion. In Europe great success has been registered thanks to the standardized frequency value we have in every country, and this has been achieved despite the countless difficulties arising from the heterogeneity of languages, units of measure and so on. Thus, in Europe, where there is the possibility of linking countries through overhead lines, electric power systems may be interconnected.

The problem of standardizing voltages deserves special consideration. Theoretically, there are no technical obstacles to interconnecting electric power systems of different voltages through transformers, but in practice all the interconnections obtained by means of transformers are of very little importance. We have in Europe interconnections between systems of different voltages but, as said before, they are of little importance.

Interconnection has spread on a large scale throughout Europe since standardization of voltages took place, and the best results were reached after the choice of 220 kV as the high transmission voltage. For instance, the countries lying near the Alps, by using lines some ten kilometres long, were able to interconnect their 220 kV systems. On the contrary, if transformer stations had been required, with the ensuing installation

/expenses and

expenses and operation costs, the interconnection would certainly not have been made and these countries would thus have been deprived of its great advantages. It should also be borne in mind that interconnection through transformers, by limiting the possibilities of overloads, also diminishes the possibilities of mutual help among neighbouring networks in case of large generation losses.

So far standardization of voltages in Europe has produced very satisfactory results, especially where high voltages, i.e. from 120 kV upwards, are concerned. Lower voltages are not suitable for international interconnections, except for small countries. Hence so far as these voltages are concerned, standardization is important only with regard to the equipment.

Since all western European countries have adopted the 380 kV as the new highest voltage level, future international interconnection at this voltage level could be easily achieved.

Recently, eastern European countries also decided to adopt 380 kV, while in the USSR, owing to the great distances and large amounts of power in that country, lines of 500 kV have been installed. This was facilitated by the possibility of utilizing the same insulation as adopted for the first 380 kV transmission lines.

We think it useful to underline the mistakes incurred in the past in the development of systems because an important principle regarding the choice of the values of voltages was neglected.

The engineer who plans a transmission system generally chooses the value that, according to calculations, seems to be the best for the system he is planning, while, as a matter of fact, this only leads to confusion in the field of voltages. It should be remembered that the cost of transmission of electric power, when the optimum value of voltage is altered, changes very slowly. Furthermore, a system should be studied as a whole, due account being taken of the evolution to which loads and generation are subject. So, the optimum voltage for each given transmission should not be considered but rather the optimum series of values to be installed in the course of time in a region. We know by experience that these values have to be considerably spaced.

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We should therefore recommend that the values of the voltage for the systems to be installed should be selected from among the series of values standardized by the International Electrotechnical Commission in order to ensure a well-ordered development and to facilitate the interconnection of national and international systems.

3. Economic possibilities offered by interconnection with regard to generating plants

Hydro-electric generation depends on seasons, climate and the geographical position of the plants. To regulate hydro-electric generation very expensive water storage systems are necessary, but even so, it is never possible to regulate the entire production of an area owing to the fact that there are plants which offer very little possibility of water storage. A great quantity of power would be lost were it not for seasonal compensation through plants situated in hydrologically complementary areas.

An interconnected system in such cases enables the water energy, that would otherwise be wasted, to be shifted to another area. A typical example of seasonal compensation is offered by Italy. The average distance of 500 kilometres between the power generation centres of the Alps and those on the Apennines is sufficient to ensure economically advantageous complementary climatic conditions.

As regards steam power generation, interconnection plays a prominent part because it enables improved utilization of the plants with better efficiency to form the basis of the load diagram, which ensures an appreciable saving in fuel. The difference in efficiency between very modern and powerful plants and those built only ten or so years ago is well known. The possibility of utilizing less efficient plants only for seasonal compensation or, where possible, for load modulation (gas turbines, quick starting plants), is one of the results of well coordinated interconnection of systems.

The growing use of nuclear power generation should also be briefly mentioned: economically speaking, it still cannot offer competition and in many countries nuclear generating stations are being built only for experimental purposes. However, to achieve at least relatively low-cost power generation, such plants should operate with very high load factors. Nuclear

/power stations

power stations should therefore be linked to extensive interconnections for which the power of the nuclear plant is included in the basis of the load diagram.

The problem of providing spare equipment to ensure routine maintenance or deal with breakdowns is common to all types of power generation. The figures quoted regarding the increase in energy produced and installed capacity in Europe during these last years show how much interconnection has contributed to the better utilization of existing generating capacity and to savings in stand-by equipment.

4. Economic possibilities offered by interconnection with regard to power transmission and control

If, in a given country, there are various organizations for generating and supplying electric power without well defined geographical boundaries, as for instance in Italy and Switzerland, interconnections can appreciably reduce transmission losses thanks to the common utilization of parallel lines. Interconnection is also instrumental to a great extent in achieving target frequencies. It is clear that the more extensive the interconnection, the greater are the possibilities for statistical compensation of the random load fluctuation which causes variations in frequency. When interconnection is as extensive as in western Europe, it is possible to keep variations in frequency to a minimum level that is insignificant from most practical points of view.

As regards the compensation of slow changes in load which are overcome through the automatic control of each individual system, interconnection does not offer any special advantages if each single interconnected system is under automatic control. However, the greater the network, the easier is automatic control, because the power of the regulating set does not increase in proportion to the peak power of the network. This is noticeable not only in the large European national networks, as for instance in France and the United Kingdom, but also in partial large-scale national networks as in Italy and the Federal Republic of Germany.

5. Technical

5. Technical requirements of the interconnection of systems

As was said earlier, if an interconnection has been carefully planned and some necessary technical requirements have been complied with, the advantages greatly exceed the drawbacks. The technical requirements can be roughly divided into the following three categories:

(a) The equipment should be in accordance with the short-range power required by an extensive interconnection. Circuit breakers should therefore have a high breaking capacity and the equipment, especially the transformers, should be able to withstand great electrodynamic stresses due to short circuits. The relay equipment should be very accurate and very quick in operation so that breakdowns may be kept within limits and the supply can be maintained even with lines overloaded in emergency cases.

(b) So far as control is concerned, it is necessary to adopt for each network a system for the automatic control of frequency and power exchanges. Besides the centralized system controller, the most important elements are remote control and regulating signal channels; both must operate uninterruptedly and be of the highest reliability.

(c) The personnel responsible for load dispatching must have very efficient telephone links with all points of the system and with the other load dispatching centres. These links must be integrated with the most up-to-date remote control equipment available, that is, display boards, code orders and so on. The progress registered by modern techniques and especially by electronics makes for a satisfactory solution of the problems we have just mentioned. It is, nevertheless, of the utmost importance to devote great attention to the instruction and training of staff which should include all the specialists necessary to ensure the efficient operation of all the equipment involved.