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CONSIDERATIONS GOVERNING THE SELECTION AND DESIGN OF WATERWHEEL GENERATORS WITH SPECIAL REFERENCE TO THE CONDITIONS OBTAINING IN LATIN AMERICA

by Siegfried Rois and Hans Troger

NOTE: This text is subject to editorial revision.

In the selection and design of hydroelectric power plants consideration must also be given to geographical and economic conditions. By reason of its great expanse, Latin America embraces almost every kind of geological and climatic region. Thus, it can be said that the conditions found in the Latin American countries also obtain in varied forms and combinations in other overseas countries and even in European countries, i.e., there is actually no special trend of development which is peculiar only to Latin America.

Nevertheless, there are certain decisive factors which derive directly from the peculiarities associated with Latin America. These include the following main points:

(a) The presence of large river systems whose water power potential remains for the greater part unexploited;

(b) The great distances between the points where the power stations could be erected and the centres of gravity of the load;

(c) The difficult transport conditions involved in the erection of power stations due to the distances from proper transport systems;

(d) The varying climatic conditions;

(e) The rapid industrial development which creates enormous demands for electrical energy;

(f) Small isolated consumers which have to be provided with a power supply independent of large supply systems;

The large river systems on the South American Continent lend themselves to the application and thus the development of large generating units. The mountainous coastal regions give rise to the unusual condition of large rivers flowing inland. This generally makes it necessary to erect the large power stations in the relatively scarcely populated inland districts. Typical examples are the Urubupunga project in Brazil and the El Chocon project in Argentina. By way of contrast the main populated areas and the industrial centres are chiefly concentrated in the coastal areas. This means that not only the electrical energy, but also the material for the erection of the power stations have to be transported over appreciable distances, both factors having a decisive effect on the selection and design of the generators. The industrial development in the Latin American

/countries, particularly

countries, particularly in recent years, likewise increases the trend towards the construction of large generating units. The far-sighted policy of the competent authorities and bodies fully takes into account this trend in development, as can be seen for example from the Furnas power station at present under construction, which is to be equipped with eight 160-MVA generators, and the Orinoco and Lake Titicaca projects. Thus it can be seen clearly that the conditions in Latin America excercise an appreciable influence on the development of large generating units, predominantly for low speeds.

Of course the same general physical, electrical and mechanical directives apply to the design of large generators, irrespective of the location of the station for which they are intended. But in addition to these, account must be taken of special conditions which are decisive for the site and which are ultimately reflected in the design of the generator.

In the electrical design of generators for Latin America consideration must be given to the following characteristics.

The electrical energy can be transported over the long distances between the generator and the consumer only by extra-high-voltage overhead lines. These transmission lines in turn introduce the need for high capacitive charging power, the probability of high voltage surges due to atmospheric effects and special stability and regulating problems. Obviously these factors greatly influence the design of the generator.

If, for instance, a generator can be designed for a certain speed and output independently of any of the aforementioned special conditions, it can be optimized as far as weight, dimensions, electrical characteristics and price are concerned. However, the high capacitive charging power required for long transmission lines makes necessary an abnormally high no-load short-circuit ratio. A no-load short-circuit ratio which is higher than the optimal value makes necessary a wider air gap, greater excitation power and thus a higher price. The influence of the no-load short-circuit ratio on the cost of the generator can be seen from figure I[1/].

In order to render ineffective any voltage surges due to atmospheric effects, the insulation of the generator must be suitably dimensioned

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1/ Taken from a publication issued by the Westinghouse Corporation.

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FIGURE 1
GRAFICO 1

INFLUENCE OF THE NO-LOAD SHORT-CIRCUIT RATIO ON THE PRICE OF GENERATORS

INFLUENCIA DE LA RELACION EN RACIO-CORTOCIRCUITO SOBRE EL PRECIO DE LA MAQUINA

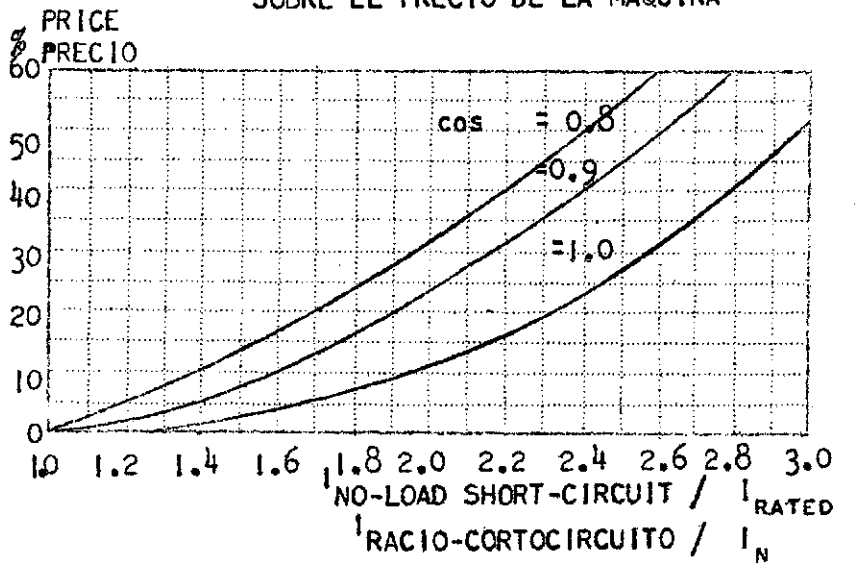
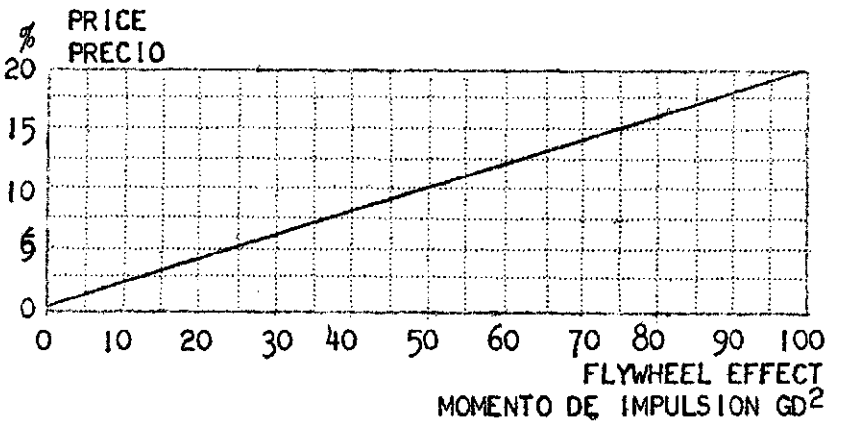


FIGURE 2
GRAFICO 2

INFLUENCE OF THE INCREASE IN FLYWHEEL EFFECT ON THE PRICE OF GENERATORS

INFLUENCIA DEL AUMENTO DEL MOMENTO DE IMPULSION SOBRE EL PRECIO DE LA MAQUINA



and measures taken on the machine such as the installation of lightning arresters and protective capacitors. Normally the stability conditions are studied on a network analyzer. The magnitudes of the reactances and the time constants obtained help serve as a basis for the design of the generator. The excitation system and the voltage regulators, too, must be designed to suit the transmission conditions. For this calculations must be carried out on analogue computers to determine the optimum values.

The influence exercised in Latin America by Europe and the United States is also reflected in the field of electrical engineering. Among other things this explains the employment of 50 c/s for supply systems in some areas and of 60 c/s for systems in other areas accompanied also by mixtures of both. In some cases this results in the requirement that generators be designed for both 50 c/s and 60 c/s to permit subsequent changeover to the final frequency in the course of standardization. A typical example of this are the generators for the Temascal plant on the Rio Papaloapan in Mexico. Each of these has a rating of 49 MVA, the stator winding being reconnectable for operation at 50 c/s and 60 c/s. Added to this of course are the multitude of problems associated with exchange of power where systems with different frequencies are to be coupled.

In view of the trend towards large generating units, it is essential that a careful study be made of the problem of unit operation, i.e., the connection of two or more generating units to a transformer bank, from the standpoint of standby power and outages. These studies take into account not only the transmission conditions but also the conditions brought about by large local consumers which in turn affect the selection of the actual size of the generator.

In the design, special consideration must be given to the local transport conditions. This generally leads to lower permissible transport weights and smaller dimensions of the individual parts than is the case in Europe. These limitations are of course contradictory to the trend of development towards large generators. However, the introduction of the light-weight type of construction, the employment of special materials

/and also

and also sectionalizing have progressed to such a degree that these limitations imposed on the construction of large units have been removed. It was realized at an early stage that the development of large units, particularly for low speeds and high rates of flow of turbine water, could only be achieved by assembling the generating units on the site and not in the works. This led to the design of generators with laminated rim rotors which for the first time made it possible to transport the rotor in parts without reducing the mechanical strength. Ever since the transition was made to the welded type of construction it has been possible to sectionalize the stator. The competent authorities in Latin America have also correctly foreseen the problems associated with the transport of heavy parts and have appreciably reduced the difficulties involved in transport by showing forceful initiative in the construction of traffic systems.

The absence of extensive interconnected networks in Latin America raises special requirements with regard to the regulation of generating units and the maintaining of constant frequency independent of load surges produced by large individual loads. To alleviate these conditions the generators must be provided with the maximum possible flywheel effect. In many cases similar requirements are made on the generator from the hydraulic side owing to the high rates of flow of water at relatively low heads. The deviation from the so-called natural flywheel effect of the generator to higher values is inevitably accompanied by an increase in price. With the laminated rim rotor, the extra flywheel effect can be accommodated in a simple manner at a relatively low additional cost. Figure II[2/] shows guidance values for the influence of the flywheel effect on the price of the generators.

The enormous expenditure for the civil engineering work in large power stations gives rise to the requirement that the cost of the building work be decreased by reducing the height of the generating unit. Although this requirement is generally made in the construction of all power stations, it is a particularly important cost saving factor in the large projects in Latin America. The development on the generator side has also brought new solutions in this respect. The height has been reduced appreciably by

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2/ Taken from a publication issued by the Westinghouse Corporation.

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replacing the conventional type of construction having the main and auxiliary exciter built on top of the three-phase generator by a construction with which an auxiliary generator is incorporated in the generator housing and a separate exciter set is employed. A further advantage of this arrangement is the possibility of selecting high exciter set speeds independently of the speed of the synchronous machine. The dimensions of these high-speed machines are much smaller and the excitation response quicker, a characteristic which positively assists voltage regulation. The exciter sets can be arranged at any point in the power station completely independent of the three-phase generators.

The greatly varying climatic conditions are of course likewise reflected in the design and construction of the machines. For example, the high altitudes encountered on the west coast of the South American Continent make necessary a reduction in the output owing to the reduced cooling effects of the air. On the other hand, tropical climates in the lowlands with high humidity make it imperative that the materials be specially selected. Non-metallic materials must not swell under the effect of high humidity, i.e., they should not be hygroscopic. The cooling system for dissipating the heat produced by the losses must be designed to suit the higher ambient temperatures. Special measures are necessary to prevent the formation of moisture condensation during long periods of shutdown and thus to suppress the ingress of additional moisture into sensitive areas of the generator. For this reason, heaters are arranged inside the frame of the generator which where possible should be automatically switched on when the machine is shut down.

The most recent development in the field of insulation is materials with a base of synthetic resin. These are employed mainly for tropical regions where the humidity is high and provide a very high degree of reliability. Even under these unfavourable climatic conditions, windings with synthetic resin insulation do not age appreciably and are also proof against termites. The new insulating materials also permit a considerable increase in the hitherto conventional generator voltages; this is very important in the case of large generating units with high outputs since it makes it possible to keep the magnitude of the current

/within economical

within economical limits.

The transport from the European manufacturer to the site makes it essential that special attention be paid to the packing. Important points which must be considered are sea transport, repeated transhipment, possible river transport on small barges, impeded road transport, narrow gauge railway transport, long storage times and the climatic conditions obtaining during transport. For both the sea transport and tropical climate at the site, special protective measures are required to prevent the ingress of moisture or even water. Included among the most effective measures against the effects of moisture are protective coatings bright parts, the lining of the inside of the packing with tar board or other similar material and the provision of additional covers for the individual parts. Where the equipment is likely to be stored on the site for a long time it may be advisable to provide sensitive parts with cocooning. It does not appear to be expedient to provide cocooning for the actual transport since there is a great risk of mechanical damage which in this case could produce an effect opposite to that intended. In view of the repeated transhipment, the frequent lack of suitable lifting tackle and the generally difficult transport to the site, all parts must be provided with a robust outer packing. For the packing of heavy parts, for instance, the planks on the underside and the outer edges are reinforced with metal bars so that where necessary they can be moved over the ground on rollers. Various lifting eyes permit different tackle to be used for lifting. The frequent change of the form of transport exposes the equipment to the danger of particularly hard impacts, a condition which must likewise be allowed for in the selection of the packing. It goes without saying that the given load gauges must be conformed to.

The entire complexus of erection in these areas brings into the foreground standpoints very much different from those in Europe. In organizing the erection programme, allowance must be made on the one hand for the distance from the manufacturer's works and on the other hand for the local conditions. The effect of the former is that erection is carried out under the supervision of only a few specialists from the manufacturing firm, the majority of the remaining staff consisting of local skilled

workers and assistants. Since the difficulties involved in transport of the turbine hall crane also have a decisive influence on the cost of the erection of large power stations, an endeavour is made to keep the capacity of the crane to a minimum. This likewise affects the method of erection. In the case of Furnas power station, for instance, a method was devised for transporting the generator rotor in two halves on the turbine hall crane.

The design must be adapted to local conditions in that erection can be carried out with a minimum of complicated and expensive equipment; this represents a sharp contrast to Europe where transport plays only a secondary role and where special erection equipment is generally available in adequate quantities from the manufacturer.

Early in the planning and design stage efforts must be made to eliminate complicated equipment in order to obtain smooth operation with a minimum of staff and maintenance work.

In Latin America, power plants with generators of medium output are, of course, also built in addition to the large power stations dealt with so far. These have no distinctive characteristics since the basic conditions are similar in all parts of the world. This leaves only the field of small and very small hydroelectric power plants the design of which is again dependent on the peculiarity of the conditions obtaining in Latin America. A consequence of the thin population of large areas of land is the absence of closely interconnected medium-high-voltage systems. Since it would not be economical to construct such systems owing to the widely scattered consumers, the only method of supplying these small consumers is to erect small power plants.

The requirements made with respect to these power plants are simple, robust construction, very limited maintenance and servicing and favourable prices. These can generally be met by instaling induction generators, synchronous generators with built-on exciters or constant-voltage synchronous generators. Complete units have also been developed in which the turbine, generator and switchgear are assembled in a completely enclosed housing and dispatched as such. All that remains to be done at the site is to connect the head and tailwater installations and the electric cables. Here, of course, attention must be paid to high

water conditions. In some cases dispatch of the unit as a whole is prevented by transport conditions and parts have to be delivered separately and assembled on the site. The multitude of combinations which are possible permit an optimum arrangement to be selected from case to case. To what degree the plant is to be provided with additional regulating equipment for the maintenance of constant voltage and frequency over the complete load range is of course determined by the justifiable expenditure and the load conditions. It should be noted that the individual components of these units are taken from standard type ranges and are adapted to the conditions obtaining in Latin America simply by selecting the appropriate combinations.