UNITED NATIONS

ECONOMIC
AND
SOCIAL COUNCIL

LIMITED

ST/ECLA/CONF.7/L.2.10
17 November 1960

ORIGINAL: ENGLISH

LATIN AMERICAN ELECTRIC POWER SEMINAR

Held under the joint auspices of the Economic Commission for Latin America, the Bureau of Technical Assistance Operations and the Resources and Transport Economics Branch of the United Nations, with the collaboration of the Government of the United Mexican States

Mexico City, 31 July to 12 August 1961

EVALUATION OF A POTENTIAL HYDROELECTRIC PROJECT AS AN ADDITION TO AN EXISTING POWER SYSTEM

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NOTE: This text is subject to editorial revision.

CONTENTS

Introduction

In the present discussion of the problem of evaluation of hydroelectric projects as sources of system power supply, consideration will be given to water power as derived from the development of rivers, and to thermal power as developed by the conventional steam plant utilizing fossil fuels. The conclusions can be applied to other alternate power sources provided that their output can be made available with the same continuity as that of the steam plant, and that proper values are attributed to their capital and operating costs.

Accordingly, the problem of evaluation of a hydro project as discussed here, will consist of determining whether the hydro project in question should be built in lieu of some other hydro project or an equivalent steam plant.

Methods for the determination of hydro project capacity, and the relative functions and merits of hydro and thermal power as sources of utility system supply, have been extensively discussed by authorities on the subject in a vast existing literature, so that hardly anything new can be presented here. Furthermore, in view of the individualities of hydro project characteristics, the subject can only be analysed conclusively and with complete thoroughness when considering specific cases. However, a review will be made below of certain aspects of the problem which, as the writer sees it, should be given special attention in planning the economical development of system generating capacity.

1. Hydro versus thermal power

Hydraulic energy is made potentially available to man by nature, at a certain location, in a current or run-of-river form. Its storage is only practicable on a small scale as compared with its total quantity over a period of years. Most of it will thus be wasted unless used at the time when it is presented. Wherever available, and granting its fluctuations, it can be considered as being practically inexhaustible, since it will be present long enough to give man adequate compensation for its development,

/provided that

provided that this has been done economically and rationally. Its exhaustion will only be brought about by extensive climatic changes, which operate only in geological ages.

These caracteristics distinguish potential hydraulic energy from that derived from fossil fuels, since the latter are stored by nature and are available without any significant deterioration for usage by man at any future time. Fossil fuels are thus expendable, so that their unnecessary consumption will be tantamount to waste.

Therefore, looking at it from the standpoint of conservation of natural resources, it would appear that priority should always be given to the development of water power, as against burning the expendable fossil fuels. But the concept of conservation includes that of economy, since the uneconomical development of water power, although conserving fossil fuels, would waste natural resources elsewhere, under some other form of loss of wealth. Therefore, as a conclusion from the above it should be correctly stated that no thermal power should ever be developed if in lieu of it equivalent water power can be developed at equal or less cost to the user, i.e., to the customer. Whenever reference is made here to the cost of hydro or thermal power, it will be understood that it includes the cost of related transmission.

A too narrow concept of "conservation of natural resources" has been frequently used as a political argument for the unrestricted development of water power, irrespective of its cost. This, and the attribution of multiple purposes to river regulation projects, added to the legitimate reluctance of private utilities to develop uneconomical water power, have been major motives for public ownership of power supply sources. Furthermore, there seems to be a natural tendency on the part of public opinion to favor "a priori" any water power project; an attitude perhaps explained by the obvious form under which hydraulic energy is presented by nature, such as found in a water fall, or in any torrential river, and by the monumental features shown by many hydro electric projects.

The possibilities of water power development should thus always be given thorough and unbiased consideration by private utilities, to assure

/the participation

the participation of private capital and initiative in the development of power sources. On the other hand, the contribution of adequate government policies is also indispensable to give private initiative the encouragement and a fair chance for developing water power.

These comments are considered pertinent here because private utilities, led by financial contingencies often due to inadequate government policies and to inflationary economic conditions, are liable to resort to thermal power development without giving exhaustive consideration to water power possibilities. The following well known reasons contribute to this attitude:

(a) Thermal plants ordinarily require less initial capital investment and less time to build than hydro projects.

(b) Where low cost fuels of adequate quality are available (which is the case in most of the well advanced areas of the world), well designed thermal plants are generally able to supply power at reasonable and acceptable costs, very little study being thus required to determine whether they can be justified financially.

(c) As a rule extensive and costly investigations, often of a complex nature and taking a long time, are required for properly evaluating a hydro project.

(d) The demand for thermal plant equipment, specially for steam plant equipment, occurring in areas of high technological development, encouraged and promoted remarkable improvements in plant design and efficiency, whereby thermal power became more and more attractive.

(e) Regulatory bodies in most countries agreed in the adoption by utilities of the "fuel adjustment" rate clause, whereby increases in fuel cost are automatically transferred to the customer through a rate surcharge. On the other hand, unfair regulation, whereby rates are based upon the "original cost", frequently prevent private utilities from having adequate compensation for the effects of inflation upon the heavier investment on water power development. Even when such compensation is provided by regulation, it often becomes effective too late, after a lengthy process of rate revision.

/(f) The fast

(f) The fast growth of system load, and delayed system expansion due to financial or other reasons, often give the private utility little time and disposition to indulge in the intricacies and cost of hydro scheme investigation and evaluation.

Among the above reasons, that referring to the complexities of hydro project evaluation places on the shoulders of the hydraulic engineer a large share of the responsibility for the disregard by utility management of the opportune hydro development. In fact, management can not adopt a hydro solution unless, when the time comes for system expansion, which as a rule must be carried out in a hurry, the engineer is not ready with a hydro project convincingly economical.

2. Coordination of hydro and thermal power

An important characteristic of water power in its current or run-of-river form is its seasonal and plurennial variation caused by hydro-metereological factors. Due to the limitations imposed upon the construction of reservoirs by topography, land development and costs, such fluctuations can be equalized only partially and, as a rule, in a relatively small scale.

If an electric system uses only hydro sources for its power supply, its effective installed generating capacity must necessarily be based on the lowest streamflow liable to occur at the time of system peak load, increased by whatever regulation is available from seasonal storage. In any case, the total amount of energy that the system can use will represent only a very small fraction of that available in the river's total run-off. Since hydro projects include works such as improvements to site, dams, reservoirs, operators' quarters, roads, etc., the high cost of which is fixed irrespective of the installed capacity, the cost of power thus generally becomes high per unit of dependable capacity. For these reasons, only in areas where exceptionally favorable hydro sites of sufficient low water capacity are available at reasonable transmission distance, can an electric system rely exclusively on hydro for its economical power supply.

Under the above conditions all the river runoff exceeding dependable flow must be wasted, unless the development of some part of it can be

/justified as

justified as a source of secondary power to serve other utilities or industrial customers that could afford to use it only in high water periods. Such opportunities are the exception rather than the general rule, particularly in areas where system interconnection has not yet reached full development.

By adding thermal capacity to the above hydro system, the economy of hydro utilization may be improved in two ways. First - assuming that adequate pondage is available - low water hydro peaking capacity can be increased by carrying base load with thermal and allocating hydro to a portion of the load curve with lower load factor. Secondly, the increased hydro installed capacity thus justified will be able to utilize a larger portion of the runoff in periods of high water, thus increasing the total usable energy from the hydro plants. This way a reduction in cost of hydro power will be obtained, per unit of both dependable peaking capacity and energy output. A seemingly contradictory statement might thus be correctly made, that by adding thermal power to a hydro system, a more complete utilization of hydraulic natural resources is made possible.

Conversely, if a system is supplied exclusively or predominantly from thermal sources, the addition of hydro to it may be justified, sometimes merely in terms of saving in fuel consumption. In the latter case the added hydro may be either from a cheap new development - though not necessarily justified as a source of additional system peak load carrying capacity - or from additional capacity installed at an existing hydro development with low incremental cost.

For the above reasons, among others of an operating nature, the advantages of combining hydro and thermal power are today undisputable. It is a well accepted principle today in power engineering that the lowest overall cost of power production is generally obtained through the judicious coordination of both hydro and thermal generating plants. The most economical hydro-thermal ratio of any specific system will of course depend on the availability and cost of fuels at its location, and of the existence at reasonable transmission distance of suitable hydro sites.

/Therefore, the

Therefore, the evaluation of a hydro project as a possible addition to a power system should be made having in mind that the problem is not one of competition of hydro and thermal power as sole sources of system supply, as it might be inferred from the use of thermal power costs as a yardstick, but rather one of economical combination of the two sources of supply.

3. Evaluation of hydro projects

Let us consider the load of an electric system fully carried by a number of existing sources of supply, including the system's own hydro and thermal plants, as well as possible sources of purchased power.

For simplification of the present discussion, the following definitions will be adopted:

System peak demand: Maximum system hourly load, in kilowatt-hours per hour (simply expressed in kilowatts), occurring in a given year.

System peak load: Load represented by the system load curve that includes the system peak demand, covering a period of 24 hours, one week, a month, a season, or the whole year. Such a load is thus characterized, not only by the system peak demand, in terms of which it is stated, but also by the system load factor and shape of load curve pertaining to the period considered.

System load carrying capacity (system LCC): The maximum system peak load that can be fully carried by the combination of the existing sources of supply under the lowest streamflow conditions at the hydro plants, and lowest purchased power supply available during the period considered.

Plant or project load carrying capacity (plant or project LCC): The load carried by an existing generating plant or by a proposed project as a component of the system LCC. Although stated in terms of the kilowatt component of the system peak demand, it inclused the energy component of system LCC, with the load factor and shape of that portion of the system load curve assigned to the plant or project.

If the load in the above system is being carried efficiently and economically, each source of supply is then allocated to a different portion of the system load curve, so as to obtain the necessary system LCC and the

/lowest overall

lowest overall operating cost. Under these conditions, during the dry season the thermal plants and the run-of-river hydro plants are assigned to the base of the load curve, while the storage and pondage hydro plants carry its upper portion, where the load factor is lower. In the wet season the base load is generally carried by all the hydro plants, and the thermal plants are allocated to the peak load. At any time, the load assigned to the thermal plants will be distributed among them so that the most efficient generating units will operate at the highest load factors within the section of the load curve assigned to thermal, and the allocation of purchased power will depend on the load factor and cost at which it is then available.

The problem of evaluating a hydro project as an addition to such a system arises when a decision must be made as to which additional source of supply should be provided to carry some future system peak load determined by some appropriate method of load forecasting. In order that the new project could then be considered as an adequate solution, it should provide the necessary additional system LCC at the time when it will be needed, and constitute the most economical solution possible. These two conditions will be discussed separately.

4. Project load carrying capacity (project LCC)

If the system load curve is projected up to the future system peak load under consideration, and all the existing sources of supply, thermal, hydro and purchased, are allocated to it and so arranged as to obtain, under lowest streamflow conditions, the fullest possible utilization of their installed and energy capacities, and, concurrently, the lowest overall operating cost, - then a vacant portion of the load curve will remain, which should be taken up by the new hydro project being evaluated. The latter will be considered as having sufficient LCC if, under its lowest streamflow condition, it will be able to carry the load thus assigned to it, both in kilowatts and kilowatt-hours.

The above criterion follows the principle that all the existing resources should be utilized up to their fulles possible capabilities before making any addition to the system, thus avoiding duplication of investment.

/An exception

An exception to this will be the consideration of reserve capacity or the provision of a new source of supply to replace a less efficient existing one, i.e., to cut down on operating costs. The justification of reserve capacity constitutes a separate problem which will not be discussed here, whereas that of a new source to replace an existing one falls under the problem of economics discussed below.

The LCC of any hydro development provided with storage or pondage will depend on the portion of the system load curve assigned to it. This results from the different load factors at which it will operate, as illustrated by the curves presented in figure I, which also show the pondage capacity a plant must have for load factoring on any section of the load curve.

On the other hand, if the hydro development is run-of-river, i.e., devoid of pondage or storage, its LCC will be the same whatever its position on the load curve, and will be always equal to the kilowatts equivalent of its minimum flow at the time of system peak demand.

The addition of a new hydro project to the system may obtain an additional overall system LCC exceeding that of the project itself. This will occur when, through the rearrangement of the existing plants on the load curve, made possible by the addition of the new project, a larger part of their installed capacity becomes usable as a component of system peak demand. A new project must thus be evaluated, not exclusively by its individual capacity, but by the overall additional system LCC that it may provide.

In view of the above, the possible contribution of an existing development or of a potential site to system LCC may vary with system load growth. Since, as the load grows, the LCC corresponding to a fixed amount of energy used on the top portion of the load curve will tend to increase, the value of a hydro site as a source of additional system LCC will also tend to increase.

The determination of the LCC of a new hydro project consists thus of the calculation of the power and energy components of its capacity to see whether they fit on the portion of the system load curve allocated to

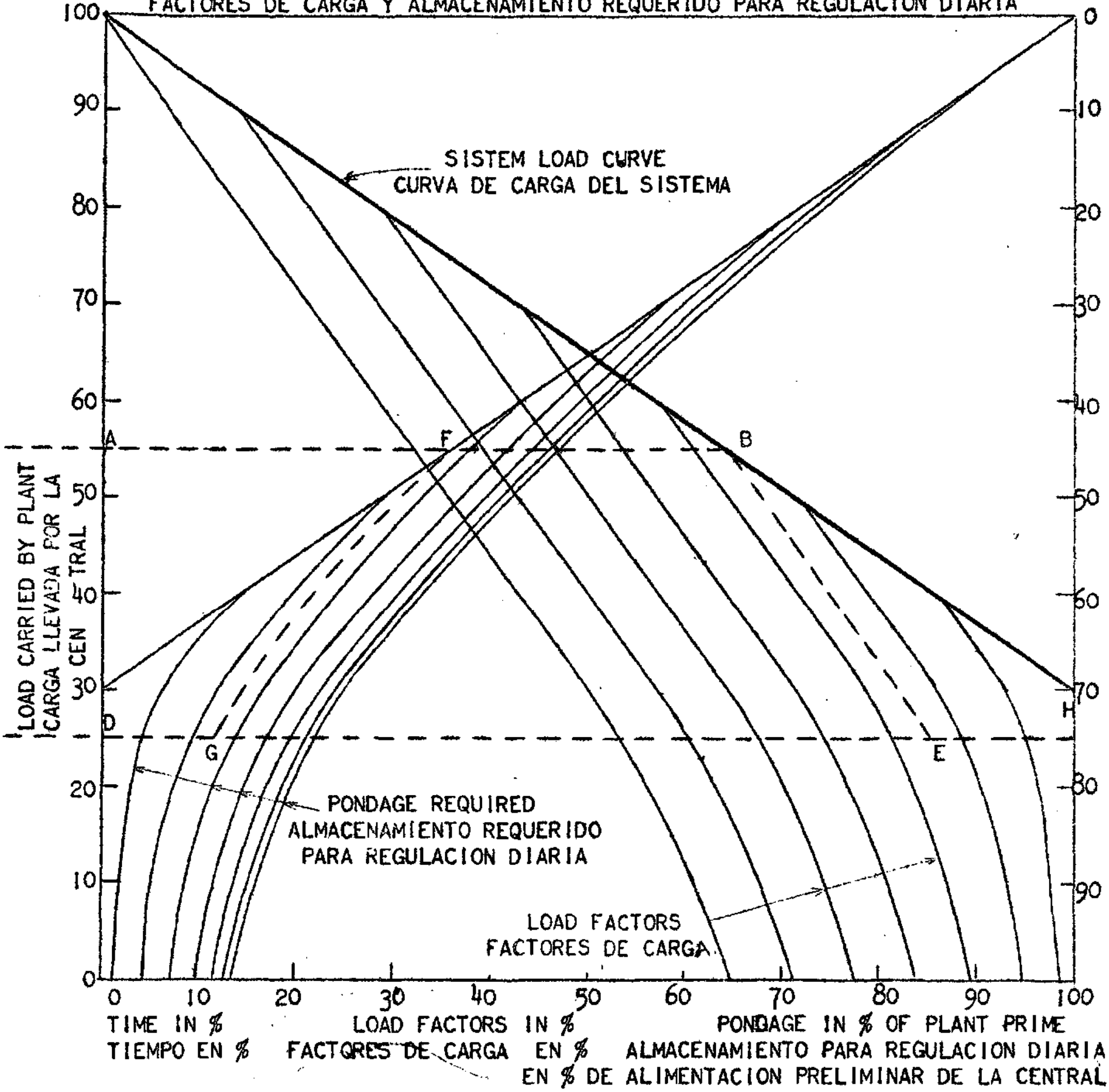
/the project.

FIGURE 1

GRAFICO 1

SIMPLIFIED SYSTEM LOAD CURVE (LOAD FACTOR = 65 %)
LOAD FACTORS & PONDAGE REQUIRED

CURVA DE CARGA SIMPLIFICADA DE UN SISTEMA (FACTOR DE CARGA = 65%)
FACTORES DE CARGA Y ALMACENAMIENTO REQUERIDO PARA REGULACION DIARIA



ASSUME HYDRO PLANT ALLOCATED TO LOAD COMPRISED BETWEEN HORIZONTAL LINES AB & CD
PLANT LOAD FACTOR IS SHOWN BY INTERPOLATING ALONG LINE BE, OR ABOUT 85 %
PONDAGE REQUIRED IS SHOWN BY INTERPOLATING ALONG FG, OR ABOUT 12 % OF PLANT PRIME, IE, ABOUT 12 % OF ENERGY IN LOAD CURVE BETWEEN LINES AB & CD

SUPONGAMOS QUE LA CENTRAL HIDRAULICA ESTA DESTINADA PARA LA CARGA COMPRENDIDA ENTRE LAS LINEAS HORIZONTALES AB Y CD
EL FACTOR DE CARGA DE LA CENTRAL ESTA SEÑALADO POR LA INTERPOLACION A LO LARGO DE LA LINEA BE O SEA APROXIMADAMENTE 85 %
EL ALMACENAMIENTO REQUERIDO PARA REGULACION DIARIA ESTA SEÑALADO POR LA INTERPOLACION A LO LARGO DE LA LINEA FG, O SEA APROXIMADAMENTE 12 % DE LA ALIMENTACION PRELIMINAR DE LA CENTRAL, ES DECIR APROXIMADAMENTE 12% DE LA ENERGIA DE LA CURVA DE CARGA ENTRE LAS LINEAS AB Y CD

the project. Various techniques are available for this purpose, which will not be described here in view of the lengthy exposition that this would require. The process involved may become very complex and laborious when a large number of sources of supply are included and a number of alternatives must be investigated. Further complication results if consideration should be given to variation of operating heads, due to drawdown on storage located at the site of the generating plants, or to fluctuation of tailrace water level.

As it is well known, some of the tools used for the above purpose are the flow hydrograph, the flow mass diagram, the flow and load duration curves, and the power-energy curve (also called "peak percentage curve" or "integrated load curve"). The latter, which shows the relation between power and energy in any horizontal segment of the load curve, is particularly useful to compare different arrangements of sources of supply in the system load curve.

It has been said above that the determination of the project LCC, and of the overall additional system LCC resulting from the addition of the project, should be based on the lowest streamflow liable to occur at the time of the system peak load. This may be misunderstood as meaning that a hydro project should never be developed beyond the capacity provided by its lowest streamflow. But what we mean here is that this minimum streamflow capacity should always be sufficient to cover the project LCC required from the project. As discussed in section 5, an installed capacity higher than that corresponding to lowest streamflow conditions may be economically justified in terms of project's energy production over a period of year, to save fuel or to replace more expensive purchased power.

It may also be argued that the above criterion of basing the project LCC on lowest streamflow is too conservative because the construction of the project is considered to meet the system load in some future year, and there will be little chance of the lowest streamflow occurring in that particular year. As the writer sees it, this argument does not exactly apply because the project should be able to maintain its LCC in any future year beyond that used as a target.

/5. Project economics

5. Project economics

The new hydro project being evaluated will be considered as the most economical source of additional capacity if, through its addition to the system, the overall cost of the energy delivered to the customers over a period of years will be lower than with any alternative source of additional supply.

As a result of system load growth, the economical arrangement of the various sources of supply in the system load curve, and thus the annual usable output from each source, may vary from year to year.

Furthermore, over the period of years used for the economic analysis, other additions must be made to system capacity, from other new sources or from extensions of either the new project under consideration or some of the existing plants, whereby additional elements of cost will have to be included in the computation of total cost of energy over the period.

For these reasons, the economics of the proposed project can not be determined correctly by any short cut method considering it as the only addition to the system, but must instead be worked out by a laborious year by year analysis, in which the overall system production cost (capital and operating) is computed in each year and added up at the end of the period. This must be done for various alternative schemes of development, each assuming different new sources of supply added to the system when they become needed to provide the necessary system LCC, including an "all thermal" scheme in which all the additional capacity needed over the period will be obtained only from thermal plants. Among these alternate schemes, different assumed installed capacities at the same hydro project, exceeding that required for system LCC, should also be included, to determine whether overdevelopment of these projects is economically justifiable in terms of usable generation during high water periods. The scheme to be finally adopted should be that which will present the lowest total production cost at the end of the period.

In the above analysis, the components of production cost in each year should comprise the capital cost (annual fixed charges) of each addition to the system, including that of related transmission and stepdown substations,

/and the

and the operating costs of all sources of supply in operation in the year, including those existing prior to the period of analysis. The capital cost of the latter, although being a component of the total cost of energy, does not need to be included in the analysis, because it will be a constant in all schemes under comparison. The operating cost of hydro plants and projects may often be also neglected in view of its insignificant amount in relation to the total production cost.

The number of years that should be included in the analysis is limited by the difficulties in forecasting system load too far ahead, and by unpredictable inflationary trends, or other economic factors, which may affect differently the costs of hydro and thermal power. As a rule the period adopted covers from 5 to 10 years, although tentative analysis covering a longer period, even up to 20 years, may be undertaken.

Such a study involves the following main steps:

(a) Preparation of the system load forecast for the period of study, including annual peak loads (maximum hour), annual system input and annual load factor.

(b) Construction of the annual system load curve with percentual ordinates. More than one curve will be required if the load forecast shows an appreciable change of annual load factor over the period.

(c) Selection of the projects to be added to the system during the period of study, and determination of the years in which they should be in operation, by calculating their LCC, and the resulting system LCC, and matching the latter to the forecast system annual peaks.

(d) Preparation of construction cost estimates for each system addition.

(e) Construction of "total-period" flow duration curves for each existing hydro plant or new hydro project added to the system, and translation of their flow ordinates, through the respective project heads, into kilowatts of prime power. These duration curves cover the whole period of streamflow record (10 to 30 years, actual or estimated record), and are assumed to represent a virtual "average" year, which thus includes all the flow occurrences, from minimum to maximum.

/(f) Determination of

(f) Determination of the total potential energy available yearly in each hydro plant or project, by drawing horizontal lines on the above duration curves at the ordinates corresponding to the respective installed capacities, and measuring the areas under these lines. By adding up the potential energies thus obtained for each source, the total system potential hydro energy will be obtained.

(g) By applying the above total system potential hydro energy to the system annual load curve (with the help of its "power-energy" form), the total hydro energy usable per year will be determined. The total amount of thermal net generation required per year will be then determined by subtracting this total usable hydro energy from the forecast total system input, due consideration being given to difference in transmission losses.

After determining, as per above, the system additions to be made in different years, and the annual generation required from the hydro and thermal plants, the capital and operating costs in each year can be calculated.

In calculating the thermal operating cost, consideration must be given to the relative efficiency of the various generating units involved, so as to obtain the most economical distribution of the thermal load between these units. This calculation, which may be intricate, generally requires the cooperation of the mechanical engineer.

An important element of cost in the above analysis are the rates of annual fixed charges on capital investment made respectively in hydro plants, transmission facilities and thermal plants. Perhaps the proper and realistic determination of these charges is not given the attention it deserves when comparative studies are made for the evaluation of a proposed project. There seems to be a tendency to use figures established by tradition or habit, without a thorough determination, in each specific case, of the correct coefficients to use for the real cost of money and rates of depreciation and obsolescence of the installations involved.

Another very important item in these economic studies is of course the cost of fuel. In countries where oil production, refining and distribution activities are going through the process of nationalization it becomes difficult to estimate oil prices over the period of future years required for the comparative analysis of power project economic.

/Under conditions

Under conditions as existing in Brazil the fuels that can be generally relied upon for central station power production are residual and Diesel oils, since coal deposits are insufficient, besides being all located in the southern section of the country, far from the areas where the most important power systems are located. The exploitation of oil reserves, practically all the refining and the importation of crude and refined products constitute the monopoly of PETROBRAS, a mixed company fully controlled and managed by the Federal Government. Oil production from local reserves is still insufficient to cover the country's consumption. Most of the oil is thus still imported. The prices of oil, which depend on the country's foreign exchange balance, changes in special exchange rates allocated to oil imports, other inflationary pressures, and PETROBRAS' operating costs, suffer periodical and frequent changes as established by Federal directives for different regions of the country. Their variations become thus difficult to predict.

The curves presented in figure II show for comparison the variation from 1940 to date of cost indexes respectively of building construction and fuel oil in the city of Rio de Janeiro. They show that although both indexes have grown at an average cumulative rate of 11 to 12 per cent per year, the cost of fuel has suffered enormous short term oscillations.

Although the economics of a proposed hydro project should be determined by the detailed calculation previously described, the curves in figure III are presented to show, in a rough and preliminary way, the range of "capacity factors" at which a hydro project may compete with thermal power. The "capacity factor" is defined as the ratio between the average output over a period of years and the rated installed capacity of the plant. In order to make the plotting of these curves as simple as possible, it was thought convenient to show them in terms of the difference between the capital costs, per unit of installed capacity, of respectively hydro (including transmission) and thermal plants. They can be used with any unit of currency, as long as the same unit is adopted for the values of "D" (difference in capital costs) and "c" (total operating cost of thermal plant).

/6. Final remarks

6. Final remarks

Except for the few obviously good hydro sites, the conception of economical water power developments requires on the part of the engineer initiative, patience and creative ability, besides the indispensable technical competence. He should not wait for an order from management to produce a hydro scheme, whenever this becomes required due to urgent need of system expansion. By doing so he will never have sufficient time to properly evaluate a project and convincingly propose it for development. He should, instead, be continually investigating hydro possibilities, without necessarily being committed to arrive at a favorable recommendation for construction.

As a result of the evolution of system load, as well as of fuel and construction costs, a hydro project that proved to be uneconomical today may become economical in the future. Therefore, the study of a site as a rule should not be definitely abandoned, but should instead be constantly reviewed for possible future reconsideration. Exceptions to this would be when from present investigation it becomes obvious that the site will be always inadequate, or when its license is granted to another party. However, even in the latter case there may be instances when the continuation of the site investigation will be justified, because the other party may end up by not developing it due to financial or other reasons, whereby its license will eventually expire.

A hydro project, although of insignificant LCC in relation to system peak load, may prove to be justifiable in terms of fuel savings, incidentally giving the utility the opportunity of participating in the development of the hydraulic resources of the region. Therefore, opportunity for hydro development, although in a relatively small scale, may be found even in areas allegedly unprovided with water power due to the absence of outstanding sites. Water power is really inexistent only in arid regions.

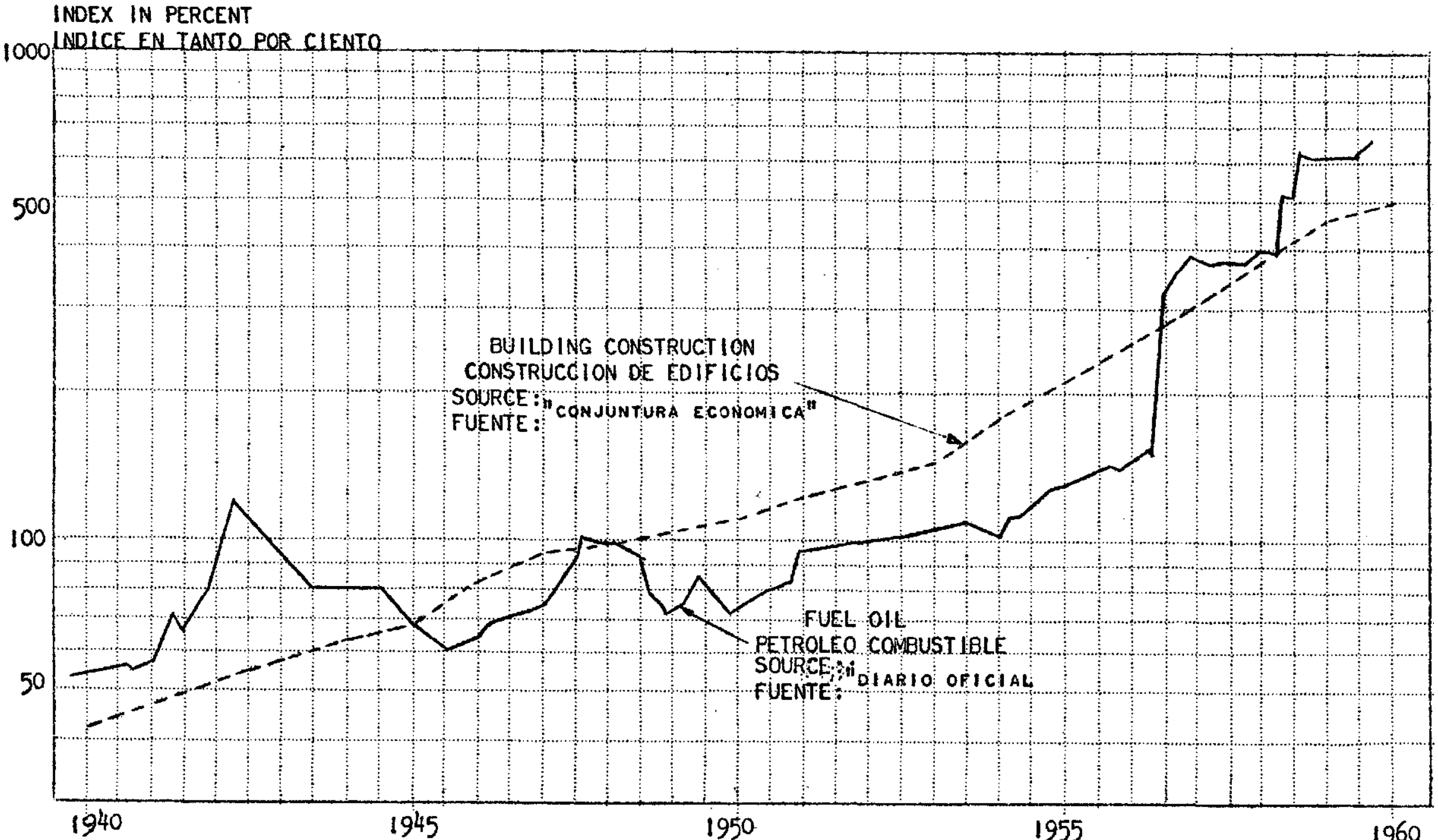
There may be cases in which Government stepped into water power development and controls, by means of concessions, all the outstanding hydro sites available in the area. Consonant with the above, this should not prevent private utilities from considering the development of minor sites, discarded

/by Government

FIGURE II - GRAFICO II

COST INDEXES: FUEL OIL AND BUILDING CONSTRUCTION - RIO DE JANEIRO - BRAZIL

INDICES DE COSTO: PETROLEO COMBUSTIBLE Y CONSTRUCCION DE EDIFICIOS - RIO DE JANEIRO - BRASIL



AVERAGE COST OF FUEL OIL IN 1948 = CR$ 596 PER METRIC TON

COSTO MEDIO DEL PETROLEO COMBUSTIBLE EN 1948 = CR$ 596 POR TONELADA METRICA

by Government, as long as they prove to be economical, i.e., as long as they can deliver energy to the system at a cost lower than that which would be obtained from thermal plants, thus fitting in as complement to thermal, although in a relatively small scale.

Besides depending on favorable topography, seasonal storage as a rule is expensive, even if a cheap damsite can be found. This results from the cost of land, rights and relocation of roads, structures and utilities. It might be expected that in underdeveloped countries the cost of these items should be low. But it happens that most of these countries are now subject to severe inflation, and in an inflationary economy real estate costs are first and most intensively affected. Consequently, seasonal storage can generally be justified only when the stored water can be used through a relatively high head.

On the other hand, daily or weekly pondage usually can be provided at reasonable cost, and considerable benefits can be derived from pondage plants combined with thermal power or other sources of base capacity. Therefore, a hydro site should never be discarded because of its low run-of-river capacity and of the impracticability of developing economical seasonal storage, before thorough attention has been given to the possibility of developing pondage and to the use of the latter in coordination with other sources of system supply.

The pumped storage plant constitutes a special type of the pondage project, which requires for its justification adequate topography downstream of the tailrace and the availability of very cheap off-peak system surplus capacity. Since, under favorable conditions, this type of development will provide low cost peaking capacity, it should always be examined when evaluating a hydro site.

Since the LCC of a hydro project will generally increase with system load growth, it is essential that, in laying out a project, adequate provision be made for future additions to installed capacity. Since this will usually increase the initial cost of the project, and since it is difficult to foresee exactly how much additional installed capacity may become justifiable in the future, the engineer must use very good judgement to decide how far he should go in making this provision.

Derivation of curves in figure III

T = Capital cost of thermal plant and related transmission, in units of currency per kilowatt installed.

H_o = Capital cost of hydro plant and related transmission, in units of currency per kilowatt installed.

f = Capital fixed charges as a percentage. Assumed to be the same for hydro, transmission and thermal installation.

i = Hydro operating cost, in units of currency per kW per year.

H = $H_o + 100i/f$ = Total capital cost of hydro, in units of currency per kilowatt installed. In preliminary calculations $i = 0$ and thus $H = H_o$

D = $H - T$ = Differential capital cost, hydro and thermal.

K = Capacity factor, in average streamflow year (total-period year), in per cent.

c = Thermal operating cost (fuel + labor + maintenance), in units of currency per net kW.

Break-even equation:

$$fT + 8760Kc = fH$$

$$K = \frac{fH - ft}{8760c}$$

$$K = \frac{H - T}{8760c/f} = \frac{D}{8760c/f}$$

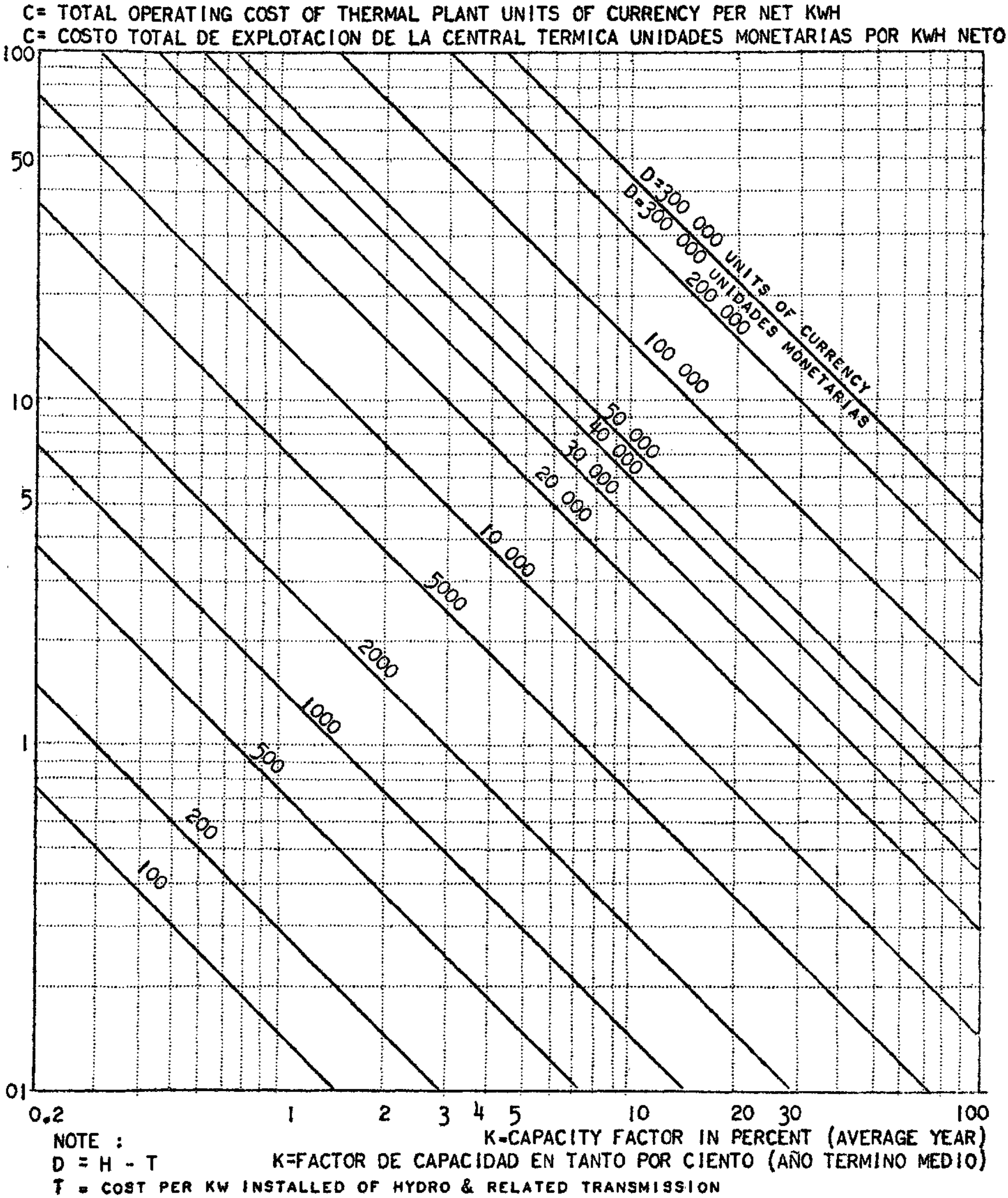
Assuming $f = 13\%$

$$K \doteq \frac{D}{673.85c}$$

The above equation, plotted in figure III, is only approximate, aiming only at a rough and preliminary evaluation. It neglects hydro operating costs and the difference between energy losses in transmission from respectively hydro and thermal sources, and it assumes the rate of capital fixed charges to be the same for hydro, transmission and thermal installations.

FIGURE III
GRAFICO III

BREAK-EVEN OF HYDRO & THERMAL COSTS (APPROXIMATE)
IGUALACION DE COSTOS HIDRAULICOS Y TERMICOS (APROXIMADAMENTE)



NOTE :
D = H - T
T = COST PER KW INSTALLED OF HYDRO & RELATED TRANSMISSION
T = COSTO POR KW INSTALADO DE POTENCIA TERMICA Y TRASMISION ANEXA
H = COST PER KW INSTALLED OF HYDRO & RELATED TRANSMISSION
H = COSTO POR KW INSTALADO DE POTENCIA HIDRAULICA Y TRASMISION ANEXA
CAPITAL FIXED CHARGES = 13% FOR ALL INSTALLATIONS
CARGOS FIJOS DE CAPITAL = 13% PARA TODAS LAS INSTALACIONES