UNITED NATIONS

ECONOMIC
AND
SOCIAL COUNCIL

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LIMITED

ST/ECLA/CONF.7/L.2.9
15 December 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

COMBINING HYDRO AND THERMAL CAPACITY RESULTS IN MAXIMUM ECONOMIC BENEFITS

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Note: This text is subject to editorial revision.

CONTENTS

1. Introduction

Technical literature contains many discussions of all phases of electric power system economics. Nevertheless, there appears to be little real understanding, except among engineers intimately engaged on such problems, of the benefits obtainable by properly combining hydro and thermal capacity in the development of power systems.

All too frequently articles appear in non-technical publications stating dogmatically that generation from hydro power plants is far cheaper than generation from thermal electric stations. Almost invariably the subject is treated as a problem of "hydro versus thermal". It is the purpose of this paper to emphasize that both hydro and thermal capacity usually have a function in the well planned power system.

2. System development planning

The purpose of System Development Planning from the engineer's standpoint is to assure the availability of adequate capacity to carry forecasted loads at minimum long range overall cost. Planning should aim also at maximum utilization of the natural resources of the area to the extent that such utilization is consistent with economy. These natural resources include hydro electric potential, coal and oil deposits, natural gas, manpower, manufacturing facilities, etc. However, the primary aim is to render the required service at minimum cost.

3. Comparative magnitude of hydro and thermal capacity

Non-technical articles discussing hydro versus thermal frequently emphasize the size of some of the recently built and currently planned hydroelectric projects and imply that in countries such as the United States and USSR hydro capacity is or soon will be predominant. Available statistics indicate just the opposite.

At the end of 1959 installed capacity in the United States was 157 million kW, of which 31 million kW or 20 per cent was hydro. According to estimates reported in Electrical World (19 September 1960), planned capacity additions in the United States during the six year period 1960-65 total about 75 million kW, of which 10 million kW (13 per cent) will be hydro.

/TVA is

TVA is properly considered an outstanding hydro system, yet two-thirds of its more than 10 million kW capacity consists of thermal generating units.

It might be thought that less developed countries would have a higher percentage of hydro capacity than the United States. Data available on power in the USSR shows that in 1958 only about 20 per cent of the installed capacity was hydro. Some very large hydro projects are being constructed or are planned in the USSR, but of an additional 60 million kW planned for installation by 1965 only about 18 per cent will be hydro.

Comparative comprehensive data for all of Latin America are not available; but the American and Foreign Power System with a total installed capacity in Latin America in 1958 of 1.5 million kW consisted of 36 per cent hydro and 64 per cent thermal.

It can thus be seen that although many large hydro projects are being developed throughout the world, there is no general trend toward predominance of hydro capacity. However, there is a tendency in many areas where large undeveloped hydro potential exists, to forget or ignore the fact, proven in the more highly developed areas of the world, that thermal capacity and hydro capacity combined almost always results in the maximum ultimate economic benefit for the area.

4. Need for thorough analysis of alternatives

The above data are not presented for the purpose of proving that thermal is better than hydro. There are areas completely lacking in hydro resources where themal capacity is the only present solution. There are other areas with exceptional hydro potential and where fuel supply is unusually remote and costly. In these areas installed capacity may be predominantly hydro for many years. However, for most of the world and particularly most of Latin America the choice between hydro and thermal is never obvious. There is no general rule, applicable to all times and places, that hydro is cheaper than thermal or that thermal is cheaper than hydro.

5. Possible alternatives

Each time it is proposed to add a step of capacity to a system, it is mandatory to consider all reasonable alternative, both hydro and thermal.

/Generally, there

Generally, there are numerous possible alternatives. There may be several hydro sites to be considered. Even if one hydro site is obviously superior, there will be alternative ways of developing it. Similarly, there will be alternative thermal possibilities, for example, steam electric, diesel electric, or nuclear fuel plants. Also it must be determined whether a base load or peaking station is preferable for immediate and future operating conditions.

It is not sufficient to determine which alternative is the best immediate next step. The economic analysis should take into account how the immediate choice will fit into the planned long range development of the System.

For example, if it is determined that the immediate capacity addition shall be a hydro development, the analysis should be extended far enough into the future to determine whether that layout of the hydro project which appears best or cheapest for the immediate step, is equally advantageous in combination with future capacity additions, either hydro or thermal. Obviously, the same principle applies and the same look into the future is required should the immediate choice be thermal capacity.

A system development programme generally consists of a tentative schedule of successive capacity additions, step by step, over a period of 5 to 10 years or even longer. The complete economic analysis must compare the costs of alternative sequences of capacity additions. In other words, it is an economic comparison not of one plant or unit versus another alternative plant or unit, but of one schedule of successive capacity additions versus one or more alternative schedules. More often than not, these alternative schedules include the same projects, arranged in varying sequences of installations. Recognition of the advantages of combining hydro and thermal capacity is important for realistic visualization of comparable alternative schedules.

6. Factors to be considered in the economic analysis

The most obvious factors that must be taken into account are costs, including both the cost of investment capital required for construction and the cost of operation and maintenance of the generating plant and related transmission and substation facilities. It is convenient to express these

/costs on

costs on an annual basis, the total comparative annual cost being the sum of the "fixed charges" on new investment capital required for the programme plus the annual operation and maintenance cost. If the comparisons extend over more than a few years and annual costs in the various years differ considerably, it is necessary to determine the "present worth" of the alternative schemes. This rather inappropriate terminology means that the estimated expenditures in future years must be discounted to a common date, most conveniently the initial year considered in the comparison, in order that the effective cost of the alternative schemes can be truly comparable.

Other important factors to be considered are the characteristics of the load, including annual rate of growth, system load factor, (daily, seasonal, annual as may be appropriate) and the shape of the load curve, that is, the hourly, daily and seasonal variations in relation to the annual maximum hour load.

The physical characteristics of the proposed alternative capacity additions must be evaluated. For hydrosites these include variability of streamflow, pondage and storage possibilities, and alternative project layout possibilities.

The most economic and advantageous method of providing thermal generating capacity depends upon the type and magnitude of the expected load and the delivered cost of fuel. The following types of thermal plants, singly or in combination with each other, or in combination with hydro, represent possible alternatives which must be thoroughly studied to substantiate the final choice.

(a) High pressure - temperature, high efficiency steam turbine generator equipment.

(b) Medium pressure - temperature, peaking steam turbine generator units.

(c) Gas turbines, regenerative or simple cycle.

(d) Low speed, heavy duty diesel engine.

(e) High speed diesel generating units, stationary or mobile.

It can be realized that a large amount of study is required to assure that all promising alternative programmes are given due consideration.

/Much tedious

Much tedious work is required to determine which of many practicable programmes is the most advantageous.

7. Effect of supplementary thermal capacity on maximum utilization of a hydro resource

The following examples illustrate how the potential of a somewhat marginal medium size hydro site can be utilized more completely and more economically by planning its development in combination with supplementary thermal capacity. It is not intended to imply that the same degree of economy can be realized for every hydro site. However, the economic advantage indicated by this particular example is sufficiently typical of the results of many similar studies to indicate that the effect of supplementary thermal is almost always worth investigation.

The capacity data and cost estimates used in the following examples have been adapted with only minor changes from a recently completed preliminary investigation of a medium size hydro project proposed for addition to an existing all-thermal power system.

This hydro project develops a head of about 185 m, the height of the diversion dam depending upon the amount of pondage to be provided. The river carries a considerable amount of sand and gravel during the flood season and a settling basin probably must be provided. Several alternative layouts have been studied. That used herein consists of an underground power house. A 2.75 metre I.D. vertical power shaft will lead from the intake to the power cavern. The discharge will return to the river through a 2.8 km long 4.5 metre I.D. free flow tailrace tunnel. Access to the power house will be by means of an inclined tunnel. Power cables will emerge through the access tunnel to a switchyard in the vicinity of the tunnel portal. The installation probably will consist of 4 - 12,500 kW generators driven by vertical Francis turbines. Transmission line distance to the load centre is 150 km.

Other layouts considered include an all surface layout and a combination surface and underground scheme. The ultimate choice between the three plans depends upon the results of further sub-surface exploration and more detailed cost analysis.

/For the

For the purpose of this paper the project has been analyzed without consideration of the characteristics of the actual system to which it will be interconnected. Figure I shows the capacity obtainable from the proposed project, for four alternative schemes of development, and assuming that the project is designed to operate independently of any other source of power supply - in other words a new source of power to serve a new load.

The graph in the upper left hand corner of figure I is a power duration curve for the critical low streamflow year. The critical minimum prime power which determines the project's load carrying capability is indicated on the graph for four schemes of project development, namely

A - Run-of-river project, no storage or pondage

B - Pondage daily scheme

C - Storage scheme - usable volume 80 million m^3

D - " " " " 180 " "

The remaining four graphs on figure I, one for each of the above schemes, are load curves for critical periods. For each load curve the maximum hour load is equal to the project capability, and it is assumed that installed capacity will be equal to the capability.

Figures I-A and I-B are daily load curves, with load factor 65 per cent. With the run-of-river project and the daily pondage scheme, firm capability is determined by the streamflow available on the day of minimum flow. With Scheme I-A, with no regulation, firm capability is equal to the minimum power, which for this project is 6,750 kW (5.0 cms at head of 168 m). With Scheme I-B, with daily regulation, firm capability is determined by the total energy available on the minimum streamflow day, utilized on the varying hourly loads of that day. The prime power is slightly greater than with Scheme I-A because of the higher head resulting from the higher dam required to obtain the pondage. Prime power is 7,200 kW and project capability is 7,200 ÷ .65 = 11,000 kW.

Both of these schemes result in very small projects, almost negligible utilization of the available resource, and high cost per kW of capacity. The more important data for the schemes are given in table 1.

Seasonal storage will increase the capability of the project very appreciably. The topography of the actual project from which these

/examples have

examples have been adapted is not favourable to substantial storage at the diversion dam. However, some 20 km upstream a good storage site exists, and for the purpose of this discussion it is assumed that storage can be made available at the upstream site. The additional capacity that can be installed at the storage dam is not taken into account in the following examples:

On the power duration graph of figure I there is shown the regulated seasonal prime power for two assumptions as to amount of usable storage provided - 80 milliom and 180 million m^3.

Figure I-C is a duration curve of seasonal load for the assumption of 80 million m^3 storage. The prime power is 28,800 kW and load capability, at a seasonal load factor of 52 per cent, is 55,000 kW.

Figure I-D is a smiliar load curve for the 180 million m^3 storage condition, resulting in a capability of 80,000 kW.

Capacity and cost data for these schemes also is given in the tabulation in table 1.

The principles illustrated by figure I are well understood and the four schemes are presented only for the purpose of providing a basis for the following illustration of the extent to which each of the schemes can be improved by combining the hydro project with complementary thermal capacity.

Figures II, III, IV and V show the results of combining 50,000 kW of thermal capacity with the hydro resource of each of the development schemes described in figure I. The comparative costs and capacities are given also in table 1. The amount of thermal capacity, 50,000 kW, has been selected arbitrarily. Obviously the most advantageous amount would be different for each of the four hydro schemes considered.

Figure II shows the run-of-river hydro scheme alone, as on figure I and also in combination with 50,000 kW of thermal. The only advantage for the hydro due to the combination with thermal is that more of the available hydro energy is usable on the larger load. Even if the hydro installed capacity is limited to 6,750 kW, the production cost per kWh of hydro output is reduced about 50 per cent. If the amount of installed capacity is doubled or tripled, the combined system capability under lowest water conditions will not be increased but the amount of usable hydro

/energy will

energy will be increased and the production cost per kWh further decreased. Analysis would determine the size of hydro installation that results in minimum production cost per kWh of combined hydro and thermal output.

Figure III shows a comparison of the pondage scheme of graph I-B with and without complementary thermal capacity. If enough pondage is provided the amount of hydro capacity that can be justified is increased from 11,000 kW without thermal to 28,000 kW with thermal. The unit cost of the hydro installation correspondingly decreases from $695 per kW for 11,000 kW to $411 per kW for 28,000 kW. The cost of 17,000 kW of incremental hydro capacity is $3,850,000, equal to $226 per kW. The total available engergy with the smaller project is 94 million kWh of which only 48 million would be usable on a load of 11,000 kW. The larger project could generate 225 million kWh, all of which would be usable on load in combination with the thermal output.

The production cost per kWh of hydro output without thermal is $0.0192 whereas in combination with thermal it is only $0.0063 and the production cost per kWh of combined hydro and thermal generation is $0.0109 per kWh.

Figure IV shows Scheme I-C with 80 million m^3 of storage for conditions with and without complementary thermal capacity. In this case, firm hydro capacity is increased from 55,000 to 80,000 kW because of the addition of thermal. Cost per kW of the hydro capacity is reduced from $429 to $377 per kW. The production cost of usable hydro output is reduced from $0.0119 to $0.0076 per kWh, and the production cost of combined hydro and thermal output is $0.0100 per kWh.

Figure V is similar to figure IV except that storage is increased from 80 million to 180 million m^3. Firm hydro capacity increases from 80,000 kW to 107,000 kW. Cost per kW installed decreases from $405 to $370 per kW. The production cost of hydro output decreases from $0.0112 to $0.0088 per kWh, and the production cost of combined hydro and thermal output is $0.0106 per kWh.

Summarizing, this particular hydro site is capable of much greater development at less cost per unit of output if it is developed in combination with thermal capacity. It will be noted that the gain is proportionately

/greater for

greater for the scheme without storage. This is because to some extent, the storage and thermal capacity serve the same function of firming up the low water hydro capacity.

Scheme	Firm hydro capacity and cost per kW installed.		Cost of incremental hydro capacity
	Hydro only	Hydro with thermal	($/kW)
Small pondage no storage	11 Mw at $695	28 Mw at $411	$226
Storage 80,000,000 m^3	55 Mw at $429	80 Mw at $377	$264
180,000,000 m^3	80 Mw at $405	107 Mw at $370	$266

Parenthetically, further analysis is required to determine the most economic amount of storage for each of the above schemes, based on more careful estimates of reservoir cost and taking into account the capacity and energy that can be obtained for a supplementary hydro plant utilizing the head available at the storage dam.

It is to be noted that these schemes cannot be considered as alternative proposals for meeting a specific capacity requirement since the capability of the various schemes are quite different. They are presented to show, by the comparisons shown on figures II, III, IV and V that each of the proposed schemes of hydro development can be greatly improved if provision is made for ultimate combination with thermal capacity.

In an actual case, where the alternatives being investigated for addition to a system are all-hydro versus hydro and thermal combined, the conclusion would depend to a large extent on five factors.

(a) The relative magnitude of the hydro project in relation to system load requirements.

(b) Whether the existing system is predominantly hydro or thermal.

(c) Magnitude of cost of initial construction of the hydro project in relation to its ultimate cost, assuming the total installation is carried out in steps.

/(d) Cost

(d) Cost of fuel for thermal plants.

(e) Magnitude of minimum year hydro firm capability in relation to average hydro output.

These are the principal arithmetic factors that direct the conclusion one way or the other. As pointed out later in section 8 below, there are other considerations, not all of which are subject to mathematic analysis, which can greatly influence the final conclusion.

The result of the above comparisons are valid only for the various costs used above for construction, fixed charges, operation and maintenance. The relative magnitude of the various cost elements will vary for different times, places, and types of job.

In a specific study it would be desirable to determine what combination of storage energy and thermal energy results in the most economic firming up of hydro capacity and the optimum proportioning of this supplementary energy between storage and thermal.

Another excellent example of the benefits resulting from combining hydro and thermal capacity is that of a 275 metre head project recently investigated. It is located remote from any substantial load area. The small stream on which the site is located has very little flow in the 3 to 4 month dry season. Probably once in 5 years minimum flows of 3.5 cms occur. It is possible to provide at considerable cost enough pondage for weekly regulations which would increase the usable minimum flow to 4.7 cms, equivalent to a minimum prime power of 10,300 kW. The terrain is such that seasonal storage is impossible except at exceedingly high cost. This project, if developed independently of other power sources to serve a load with a load factor of 68 per cent, would have a capability of 15,200 kW.

At a transmission distance of 130 km there is a load area which is served by an all-thermal system which in 1965 is expected to have a load of about 90,000 kW. There are no worth while hydro sites closer to the area than the one described above. It is proposed to develop this site to serve the large load area plus smaller loads nearer to the project.

In combination with the existing thermal capacity of the system the hydro project can operate on the peak of the load at a load factor of approximately 25 per cent with a firm capability in the driest year of

/38,000 kW.

38,000 kW. The estimated cost including transmission facilities is 13 million dollars or $342 per kW of firm capability. This compares with an estimated cost of $7,500,000 for a 15,000 kW plant ($500 per kW) which is the maximum installation that could be justified at present if the plant were developed independently of the existing large thermal load and capacity.

Of equal importance is the fact that the average water supply to the hydro plant is very much greater than the minimum dry season flow. The proposed 38,000 kW installation would have sufficient water to run continuously at maximum capacity for 6 months in the average year and its average year plant factor would be about 80 per cent. Because of the size of the thermal system to which it would be interconnected, the entire hydro output would be usable on load as soon as the plant goes into service.

Another example of how thermal capacity contributes to the maximum utilization of a hydro resource is that of a 36,000 kW hydro station which was originally a part of an all hydro system with a total installed capacity of about 45,000 kW. Because of sedimentation of the pond at this plant and diversion of flow from some of the other plants, the firm capability of this station had been reduced to about 53 per cent of the installed capacity. Successive additions of thermal capacity (and some base load purchase power) have firmed up its dry season capability to 100 per cent of its installed capacity. The increased load which can be carried as a result of these capacity increases now permits the utilization of a large block of wet season hydro energy which was previously not usable to replace thermal generation in the wet season.

Another example is that of a small originally all hydro system consisting of three plants with very limited pondage possibilities. The characteristics of the streamflow are such that under extreme dry conditions for several months of the year the reliable capability was about 60 per cent of installed capacity. Successive installation of diesel capacity has made it economical to reconstruct the smallest of the hydro plants (about obsolete) which originally had anninstallation of 1,200 kW and a firm capability of about 500 kW. When reconstruction is completed this plant will have a firm capability of 3,000 kW and the dry season system capacity will be equal to the total installed capacity.

/The development

The development of power systems throughout the world has generally followed a similar pattern. In the beginning, where the initial plants were hydro, they were small because the loads were small. They were, if possible, close to the load centres to reduce transmission costs and generally they used the best of the sites available, often only the best portion of potentially larger sites. As larger amounts of power became necessary, eventually the supply of cheap hydro sites near the load centres was exhausted. The alternatives were more expensive hydro sites, often much larger than the load required, or smaller thermal plants. The latter obviously had advantages in many cases at this stage of development, firming up the existing hydro capacity, permitting absorbtion of what was previously secondary hydro energy, and conserving the power system's financial resources which were often quite limited.

In some areas because of lack of favourable small hydro sites, the first step of the above pattern was eliminated. The earliest plants in such areas were thermal, often small isolated diesel engines.

Further load growth and expansion of service areas and gradual interconnection of systems made hydro sites attractive which previously were too large or too remote, or which required excessive financial resources. As the systems grew larger, the alternatives that could be considered for successive steps of expansion were multiplied. Greater economies became possible. At this stage the choice between hydro and thermal was dictated by the particular conditions applicable at the time for the specific case. Frequently a power company would have under construction both hydro and thermal capacity simultaneously, it having been determined that such a combination would be economically advantageous.

There are still many areas where power requirements are not yet large enough to justify the initial expenditures required for large ultimately low cost hydro projects. In such areas interim thermal capacity can yield great benefit in conservation of total natural resources, particularly if the thermal installation supplements existing hydro capacity.

8. <u>Other factors to be considered in system planning</u>

There are many other factors, some or all of which must be taken into account in a specific study, which have not been given consideration in the

/above simplified

above simplified examples. Some of these are:

(a) Provision of reserve capacity for accidental and scheduled equipment outage
(b) Market for secondary energy
(c) Non-coincidence of system peak load and minimum hydro capability. (Load - Streamflow diversity)
(d) Frequency of occurrence of critical low water years
(e) Thermal capacity as insurance against the probable occurrence of rare years with streamflow less than that used as basis of hydro project design
(f) Division of costs between National and Foreign expenditures.
(g) Probability of future interconnection of power systems
(h) Scheduling operation of thermal units for most efficient overall system production
(i) Schedules for use of stored water in years of greater than minimum flow
(j) Limited financial resources
(k) Availability of foreign exchange for importation of fuel supply - present and future
(l) Effect of inflation on cost comparison

Items (a) to (e) and (j) and (k) cannot be ignored in any comparison of hydro versus hydro plus thermal.

9. Conclusions

There are situations where the choice of the next major step in expansion of a system's capacity is obvious, or at most requires the comparison of only a few simple alternatives. More often the selection requires rather detailed analysis of numerous alternative programmes, each programme including a number of successive capacity additions over a period of 10 years or longer. Many factors must be given due consideration, including costs, load characteristics, types of plant, plant layout and design, problems of operation and maintenance, and financial consideration which the engineer cannot ignore.

Planning of system development should aim for ultimate maximum utilization of the natural resources of an area, but only to the extent that

/such utilization

such utilization is consistent with overall economy. Money required for the development of power may be equally important for the development of other natural resources. For any specific hydro project there is a definite amount of capacity that can be installed which will result in minimum cost per unit of output. As indicated by the examples discussed in this paper, when a specific hydro project is developed for operation in combination with supplementary thermal capacity, the amount of installed hydro capacity which will result in maximum overall economy will be greater than if the hydro development is planned independently, and the cost per unit of hydro output and system output will be reduced.

Even when analysis indicates that successive steps of capacity addition well into the future should be hydro, it is still desirable to determine to what extent present project design should provide for future realization of the advantages derivable from probable ultimate supplementary thermal capacity.

The history of power development throughout the world and the foreseeable development of improved thermal power sources and thermal operating efficiency permit of no other conclusion, than that the ultimate capacity of most systems will be predominantly thermal.

Therefore, it is recommended first that hydro and thermal should never be considered mutually exclusive alternatives, and secondly, that the planning of hydro development should include investigation of the additional benefits derivable from the hydro project due to addition of supplementary thermal capacity.

/SUMMARY

SUMMARY

The object of this paper is to stress the advantages to be obtained by combining thermal with hydro in the development of a power system.

Statistics available on highly developed countries indicate that both thermal generation and hydro capacity have functions in a well planned system.

As the paper indicates, in a system development programme it is important to consider the schedule of successive capacity additions for the alternative schemes for a period of 10 years or longer in order that a true economic comparison be made.

Some other factors to be considered in an economic analysis are the required investment capital, rate of interest, operating and maintenance cost of the generating plant and related facilities as well as the characteristics of the load to be met.

The physical characteristics of the various alternatives must also be evaluated, i.e., for hydro there are various streamflow, pondage and storage possibilities whereas for thermal, the alternatives should include location, capacity, and type of prime mover.

The paper illustrates how a hydro site can be more fully utilized when planned in combination with thermal capacity. For this illustration a recently completed hydro investigation has been adapted to demonstrate the hydro variations mentioned above.

Figure I in the paper shows the capacity obtainable for each of the type hydro projects operating independently, while figures II to V show the increased capacity obtainable when combined with 50 mW of thermal capacity.

Although tabulations showing the cost comparison of various alternatives based on a year by year expenditure have not been presented, this method is discussed in the text of the paper.

The points mentioned above will be dealt with much more fully in the paper, and include sufficient cost data to substantiate the argument for considering thermal generating facilities in combination with hydro capacity in an overall development programme.

/KEY TO

KEY TO SYMBOLS IN FIGURES I TO V

(A) Run-of-river hydro plant
(B) Hydro pondage plant
(C) Hydro storage plant
(D) Storage in millions of cubic metres
(E) Run-of-river prime power
(F) Regulated prime power
(G) Prime power
(H) Power duration curves
(I) Water rate in kW/cubic metres/second
(J-1) Period in months
(J-2) Period in hours
(J-3) Period as a percentage of time
(K) Load
(K-1) Load curve - daily
(K-2) Load curve - seasonal
(K-3) Load curve - annual
(L) Peak load = maximum hourly load in period
(M) Total generation in period
(N) Energy not usable on load
(O) Flow from pondage
(P) Flow to pondage
(Q) Load carrying capacity
(R) Scheme or plan of development
(S) "Seasonal load curves
Alternative schemes of development
Single hydro plant
Power duration and load curves"
(T) Projects with seasonal storage
(U) Thermal capacity installed
(V) Critical load factors
(V-1) Critical load factor - daily
(V-2) Critical load factor - seasonal

Table 1

COMPARISON OR ALTERNATIVE HYDRO SCHEMES: EFFECT OF COMBINING WITH THERMAL CAPACITY COMPARATIVE COSTS PER UNIT OUTPUT

	Unit	Hydro only				Hydro and thermal (Thermal capacity 50 Mw peaking, 40 Mw continuous)			
		Run-of river scheme	Pondage scheme	Storage schemes		Run-of river scheme	Pondage scheme	Storage schemes	
		1-A	1-B	1-C	1-D	2-A	2-B	2-C	2-D
Scheme									
Pondage capacity	million m^3	0	0.06	0.30	0.44	0	0.24	0.69	0.86
Storage capacity	" "	0	0	80.0	180.0	0	0	80.0	180.0
Height of dam	m	10	22	22	22	10	22	22	22
Average net head	m	169	180	180	180	169	180	180	180
Water rate (8 x 4)	kW/cms	1 350	1 440	1 440	1 440	1 350	1 440	1 440	1 440
Minimum regulated flow	cms	5.0	5.0	20.0	29.0	5.0	5.0	20.0	29.0
Regulated hydro prime power (5 x 6)	kW	6 750	7 200	28 800	41 700	6 750	7 200	28 800	41 700
Critical load factor for capacity determination	%	-	65.0	52.0	52.0	-	65.0	52.0	52.0
Firm peaking capability - hydro and thermal	kW	6 750	11 000	55 000	80 000	56 750	78 000	130 000	157 000
Required hydro installed capacity	kW	6 750	11 000	55 000	80 000	6 750	28 000	80 000	107 000
Average year available hydro energy	million kWh	59.2	94.0	376.0	488.0	59.2	225.0	488.0	555.0
Annual generation in year with maximum hour load equal to system capability - usable hydro	" "	29.6	48.2	242.0	352.0	59.2	225.0	488.0	555.0
Thermal	" "	-	-	-	-	189.3	117.0	82.0	133.0
(at L.F. = 50%) Total	" "	29.6	48.2	242.0	352.0	248.5	342.0	570.0	688.0
Estimated project cost and cost per kW									
Hydro plant (incl. transmission and storage)	1 000 dollars	6 700	7 650	23 600	32 400	6 700	11 500	30 200	39 600
cost per kW installed	dollars/kW	992	695	429	405	992	411	377	370
Thermal plant (dollars 220/kW)	1 000 dollars	-	-	-	-	11 000	11 000	11 000	11 000
Total hydro and thermal	1 000 dollars	-	-	-	-	17 700	22 500	41 200	50 600
Cost per kW (hydro and thermal)	dollars/kW	-	-	-	-	312	288	317	322
Average year cost of generation									
Hydro-annual fixed charges (11.2%)	1 000 dollars	755	860	2 650	3 640	755	1 295	3 400	4 450
-Operation and maintenance	1 000 dollars	50	65	225	310	50	120	310	410
Total	1 000 dollars	805	925	2 875	3 950	805	1 415	3 710	4 860
Production cost per kWh	dollars/kWh	0.0272	0.0192	0.0119	0.0112	0.0136	0.0063	0.0076	0.0088
Thermal - Annual fixed charges (11.4%)	1 000 dollars	-	-	-	-	1 255	1 255	1 255	1 255
- Operation and maintenance (dollar 0.0090 kWh)	1 000 dollars	-	-	-	-	1 700	1 050	735	1 195
Total	1 000 dollars	-	-	-	-	2 955	2 305	1 990	2 450
Production cost per kWh	dollars/kWh	-	-	-	-	0.0156	0.0197	0.0243	0.0184
Total hydro and thermal	1 000 dollars	-	-	-	-	3 760	3 720	5 700	7 310
Production cost per kWh	dollars/kWh	-	-	-	-	0.0151	0.0109	0.0100	0.0106