PAPER No. 297.

PLANNING

HYDRO ELECTRIC DEVELOPMENT

IN PAKISTAN

BY

S. S. KIRMANI, B. E., (HONS.) P. S. E. I.,

Director Central Designs,

Punjab Irrigation Secretariat,

Lahore.

PAPER No. 297

PLANNING HYDRO ELECTRIC DEVELOPMENT IN PAKISTAN

1. INTRODUCTION.

The industrial and agricultural development in Pakistan mainly depends on cheap and abundant power supplies, cheap and adequate transport and a sufficiency of water supplies for irrigation, reclamation as well as for power. Apart from the needs of ordinary services and industries, power is urgently required for the reclamation of vast areas of lands in the Punjab which are rapidly turning into desolation on account of salinity in the soil. With the partition of the country, Pakistan has lost all the developed resources as well as most of the potential power sites. Unfortunately the resources of coal and other natural fuels in this country are so insignificant that the solution for developing power entirely lies in harnessing the water power resources.

Under these circumstances, it is only natural that Pakistan should assign special priority to the development of its hydro electric resources and favour plans which may even seem ambitious to some extent, in order to attain sufficiency in power in the shortest time. At the same time, it is important not to forget that the economy of the young state is still in the making and the available resources are not unlimited. There are other fields of development besides power, which require immediate attention. The resources should be so utilized as to give the maximum benefit and to stabilize the economic structure of the country in the shortest time. The need for a sound and economic power development plan which is commensurate with the basic needs and the available resources of the country, is therefore, apparent. The main object of this paper is to discuss the chief considerations in the formulation of hydro-electric projects with particular reference to some of the proposed projects in Pakistan; to suggest the lines on which hydro electric development should be planned and to point out the hazards of uneconomical development.

2. NEED FOR ADVANCE ORDERLY PLANNING.

The orderly planning of development projects in advance of the country's requirements both as to their engineering and economic feasibility is at all times a sound policy. This is so fundamental as to require no argument. Failure to do so will result in the sanctioning of projects based on inadequate investigations and hastily conceived plans in a desperate effort to meet the urgent needs leading to waste of valuable time and resources.

Advance planning necessary for the success of the Plan :—

On the engineering side, lack of sensible foresight and thorough preliminary investigations and planning well in advance of starting a project, will mean uneconomical expenditure and serious delays due to modifications of plans necessary to meet unforseen conditions arising during construction. The Rasul Project is one example in which the capital expenditure on civil works alone has increased to Rs. 186.0 lacs according to the 1949 revised estimate as against the original estimate of Rs. 68.0 lacs prepared in 1946 - an increase of over 117 %. The final estimate may still be higher. This project was scheduled to be completed in 1949 but actually it could not be commissioned untill the middle of 1952 - a serious delay which had its repercussions on the progress of economic development of the country. Both these defects are to a large extent, due to Partition of the country but one of the main reasons is defective planning.

Advance Planning necessary for wise selection :

On the economic side, insistence on immediate action, either due to political pressure or in a desperate effort to meet the country's immediate needs, leaves no time for careful investigations of the economic worth of the Projects, nor a wise selection could be made between projects according to their comparative merits. The Hirakud Dam Project in India and the Mianwali and Warsak Projects in Pakistan are instances at point. The Hirakud Dam Project was started under political pressure without thorough preliminary investigations in a desperate effort to meet the urgent need for power, irrigation and flood control in the Province of Orissa. It was not until sufficient capital expenditure was incurred and actual construction had gone underway when it was realized that the conditions arising during construction would necessitate a total expenditure of Rs. 92 crores on the scheme as against the original estimate of Rs. 47 crores which would make the very feasibility of the project questionable. The inevitable result was hold up of the progress and waste of valuable capital. As the expenditure already incurred on this project was quite heavy, there could be no question of going back which besides other things would result in political repercussions. Thus in the absence of advance orderly planning, a major project was started on hastily conceived plans without careful investigations of its engineering feasibility and economic worth leading to waste of valuable resources which otherwise could have been utilized to give results of far-reaching economic value to the country.

The Mianwali and the Warsak Projects are instances where, in the absence of advance planning, the need for immediate action has left no time for a wise selection between projects according to their comparative merits. In spite of the huge clamour for power, how many projects have been planned and investigated during the last five years since Partition so that a selection could be made according to their comparative merits. The only two projects of importance which are under investigation since 1948 are the Mianwali and the Warsak. The demand for power is so keen that both these projects have to be taken

up and in the absence other investigated projects, the question of wise selection does not arise. There may be several other potential power sites the development of which might have had a more important effect on the economic progress of the country, but they have to be left out because sufficient investigations have not been carried out. The nation may feel gratified that its potential power resources are being developed but surely it is not correct to say that they are being developed in the best way.

Advance Financial Planning - an important factor :

Advance financial planning or long term budgeting of development programme is of equal importance with advance physical planning. This will ensure greater economy, efficiency, and uniformity in capital expenditure. The programme should be consistant with the available resources. If it is too large in relation to the resources then it has to be either left unfinished or its scope cut down, its progress retarded, or the nation has to face inflation. All these will lead to waste and inefficiency. An example of this will be found in the development programme of India after partition. A number of ambitious large scale projects were started to attain self sufficiency in food by 1951 without any regard to the available resources. Later on capital expenditure on these projects had to be cut down in order to avoid the danger of inflation. The programme failed in its objective of attaining self-sufficiency in food. Had the programme in the first instance been prepared in relation to the available resources, then India would have had a few completed projects instead of a number incomplete projects.

Now let us consider the development programme of Pakistan. The total rasources of this country are Rs. 1720 crores which is equal to a national income per capita of Rs. 224 annually. The proposed expenditure on Development projects for the period 1951-57 according to the Columbo Plan is as follows :—

Agriculture	Rs.	82.0	crores.
Transport and communication.		53.0	,,
Fuel and Power		47.0	,,
Industry and Mining		49 0	,,
Social Service.		29.0	,,
	Total	260.0	crores.

This is equal to an expenditure of Rs. 43.33 crores annually i.e. 2½ % of the national income. In view of the extreme urgency for development the above percentage may appear very small at first sight. But it should be noted that Pakistan would still need Rs. 125 crores (48% of the total cost) of external finances to complete the programme which shows that its resources are being fully utilized. The expenditure on development can only be increased further by either cutting down the expenditure on

not have taken more than six months for each project and in a period of six years the installed capacity of hydro-plants would have increased by 58,000 K. W. As most of the civil works; namely the canals, the regulators, roads, housing etc., already exist the capital cost of development would have been minimum. The proximity of these sites to the existing grid and their situation in the load centres would have resulted in the minimum cost of transmission and distribution lines. These projects would have filled up the gaps between the demand and supply and would have provided power in the shortest time and at a most economical cost. When the large developments like the Mianwali and Warsak come into operation, there would have been an already developed system. This factor is very important as the development of full load after a major power station is constructed, takes a very long time. Unfortunately these power sites have been neglected in the desire to draw up large spectacular projects without realizing that failure to solve pressing current problems would endanger the long term objectives aimed at by such projects.

The defective timing of the projects as discussed above, had serious repercussions on the economic development of the country. The power supply in this period had been so short that even the demand of the existing industries could not be fully met and the development of new industries had to be retarded. Power from the Rasul Project which was primarily meant for tubewell pumping had to be earmarked for essential industries with the result that the large number of Tubewells already constructed had to keep idle. Consequently the reclamation programme recieved a serious set back and the large capital spent on it remained unproductive while interest and depreciation charges kept mounting. In a desperate effort to save the situation, a programme for increasing the capacity of fuel plants in the Punjab by 42,000 K.W. during the period 1951-54 had to be formulated inspite of the fact that the operation of these plants would mean increased imports of fuel which would be a burden on the foreign exchange.

The above analysis leads to the conclusion that failure to start the power projects at the proper time, will not only retard the power development programme but will also set back the progress on the industrial and agricultural development of the country. There is yet another case when too much development of power in relation to the needs may also prove harmful particularly to the economic progress of an underdeveloped country like Pakistan. This factor is very important in view of the present tendency among planners to over-empahsize investments on gigantic hydro-electric projects costing several crores of rupees which are neither consistent with the needs nor with the developments in other spheres of progress.

For instance, the proposed Darband Dam Project aims at constructing a 900 feet high dam, the highest in the world and will cost over 220 crores of rupees according to the preliminary estimates. The final estimates may not be less than Rs. 250.0 crores. The project, besides

not have taken more than six months for each project and in a period of six years the installed capacity of hydro-plants would have increased by 58,000 K. W. As most of the civil works; namely the canals, the regulators, roads, housing etc., already exist the capital cost of development would have been minimum. The proximity of these sites to the existing grid and their situation in the load centres would have resulted in the minimum cost of transmission and distribution lines. These projects would have filled up the gaps between the demand and supply and would have provided power in the shortest time and at a most economical cost. When the large developments like the Mianwali and Warsak come into operation, there would have been an already developed system. This factor is very important as the development of full load after a major power station is constructed, takes a very long time. Unfortunately these power sites have been neglected in the desire to draw up large spectacular projects without realizing that failure to solve pressing current problems would endanger the long term objectives aimed at by such projects.

The defective timing of the projects as discussed above, had serious repercussions on the economic development of the country. The power supply in this period had been so short that even the demand of the existing industries could not be fully met and the development of new industries had to be retarded. Power from the Rasul Project which was primarily meant for tubewell pumping had to be earmarked for essential industries with the result that the large number of Tubewells already constructed had to keep idle. Consequently the reclamation programme recieved a serious set back and the large capital spent on it remained unproductive while interest and depreciation charges kept mounting. In a desperate effort to save the situation, a programme for increasing the capacity of fuel plants in the Punjab by 42,000 K.W. during the period 1951-54 had to be formulated inspite of the fact that the operation of these plants would mean increased imports of fuel which would be a burden on the foreign exchange.

The above analysis leads to the conclusion that failure to start the power projects at the proper time, will not only retard the power development programme but will also set back the progress on the industrial and agricultural development of the country. There is yet another case when too much development of power in relation to the needs may also prove harmful particularly to the economic progress of an underdeveloped country like Pakistan. This factor is very important in view of the present tendency among planners to over-empahsize investments on gigantic hydro-electric projects costing several crores of rupees which are neither consistent with the needs nor with the developments in other spheres of progress.

For instance, the proposed Darband Dam Project aims at constructing a 900 feet high dam, the highest in the world and will cost over 220 crores of rupees according to the preliminary estimates. The final estimates may not be less than Rs. 250.0 crores. The project, besides

other things, aims at producing 24.0 lakhs K.W. of power and will take at least 15 years to complete. Suppose the construction on this project is started in 1956 after the Colombo Plan. In order to fully utilize the power, the industries should develop too and the capital cost on these will be at least Rs. 1440 crores at a conservative rate of Rs. 6000/- per K. W. The total capital investment required for power and industry in West Pakistan will be Rs. 1690 crores and if provision is made for as much development in East Pakistan also, the total investments will be Rs. 3380 crores for the whole country in a period of 15 years. This works out to Rs. 225.2 crores on the average per year as against Rs. 16-0 crores provided in the Colombo plan i.e , more than 14 times. Besides at least as much capital is required for the development of agriculture communications and transport, social services etc., for a balanced advancement in all spheres of development of the country. Is such planning consistent with the resources of Pakistan? If it is not, will it not be necessary to cut down the expenditure on other spheres of development such as agriculture, transport, social services etc., in order to successfully complete the development programme of power and industries which will leave an unbalanced set of measures harmful to the economic structure of the country? And if unfortunately the country has to face any calamity during this long period, either on account of war, floods, famine etc., requiring mobilization of all the available resources to avert it, the expenditure on the whole development plan will have to be cut down which will result in serious delays in its completion and waste of valuable resources. Even suppose the country's resources are adequate to take up the development of all phases, will it still be wise to concentrate on a single gigantic multi-purpose project costing 250 crores of rupees instead of 3 or 4 multi-purpose projects on a smaller scale which come into operation one after the other in the same period. In the former case the capital will be locked up for a long period, the power will not be available during the period as the demand increases while at the end of the period there will be a sudden jump. In the latter case power will be available as the demand increases, the benefits from the scheme will be realized even during the period and we will have projects which "pay as we go" and which will co-ordinate the development on other spheres.

Sometimes the power phase of a large project is so arranged as to operate in successive stages as the demand increases. For instance suppose in the Darband Dam Project the development of power is so planned that a part of the power house goes into operation in the 10th year, another in the 12th year and so on and the full development in the 19th or 20th year after commencement of construction. There is again a fallacy in such a programme. The very fact that it is not fully developed in the 10th or 12th year itself shows that there is no suffiicient demand at that time, whereas we will be obliged to spend a large part of the total cost on the dam, the housing, the communications, the transmission lines and the substructure of the power house, because these works must be completed at any rate before the first phase of the power can come into operation. On the other hand the full benefits

from the investments cannot be realized until the 19th or 20th year when the whole power house will be working. During all this long period interest and depreciation charges keep mounting and the project remain unproductive for quite a long time. Thus even in such cases it will always pay to completely develope a few independent projects on a smaller scale rather than to concentrate on a single large project operating in successive stages.

3. FACTORS AFFECTING ECONOMIC DESIGN.

In the preceding analysis the broad principles of planning hydro-electric development in relation to the country's resources and needs and co-ordinating it with the development in other fields have been discussed and the hazards of unsound planning have been pointed out. It is now proposed to discuss the main factors affecting economic design of hydro-electric projects. In order to examine the relative merits of projects it is necessary to define a standard of comparison and some suggestions in this respect are also given :

The main elements of cost of electrial power are

(*a*) Capital cost.

(*b*) Fixed Annual charges.

(*c*) Operating charges or working expenses.

(a) *Capital Cost :*

The capital cost depends on the type of the development. The usual types of hydro plants are

(1) Run-of-river plants without pondage like Rasul, Malakand and Dargahi which use water just as it comes,

(2) Run-of-river plants with pondage like the Mianwali which has storage sufficient only to take care of the diurnal fluctuations in the load,

(3) Storage or reservoir plants like the Warsak, in which the surplus flow is partially or fully stored for use in the dry months. The essential features of hydro-electric plants and the factors effecting their capital costs are given below :

Essential features.	*Main factors effecting cost.*
Generation :	
1. Dam	
(*a*) Non-overflow section	Topography, Geological conditions and type of the dam - solid concrete

	hollow concrete, earth, rockfill etc., - availability of materials.
(*b*) Spillway	Type of spillway - solid concrete, hollow concrete, tunnel type, by-pass channel type etc.
2. Waterway	
(*a*) Head race and tail race canals,	Topography of the country - canal lined or unlined.
(*b*) Penstocks.	Steel, concrete or woodstave.
(*c*) Surge Tank.	Simple or differential.
3. Power House and Equipment.	
(*a*) Building	Open or underground, type and size of turbines.
(*b*) Equipment.	
(*i*) Hydraulic equipment Turbines, governors and relief valves.	Type and size of the turbines.
(*ii*) Electrical equipment Generators, switching equipment, conduits etc.	-do-
(*iii*) Mechanical equipment cranes.	-do-
4. Reservoir :	Value of the land and property to be submerged cost of shifting existing roads and railway lines etc.
5. Communications	Location of the site with respect to the existing communications.
Transmission and Distribution.	
6. Transmission lines system.	Location of the site with respect to the load-topography of the country-voltage and capacity.
7. Distribution system.	Relative position of loads.

Each power plant has its own special features and the selection of a particular feature depends upon its engineering and economic feasibility.

Detailed discussion on all the features is beyond the scope of this paper.

Capital Cost of Generation.

Generally the cost of generation varies inversely with the head. Power Plants with high heads give a lower capital cost per kilowatt and vice versa. But this does not necessarily mean that high head power plants are always cheaper. A low head development like the Mianwali situated close to the load centre may still be more economical than a high head development in the remote Himalayas inspite of a lower cost of generation in the latter because the extra cost on long transmission, roads, railways etc., and the heavy losses in transmission may increase the unit cost of power at the consumers' end. Hence it is not correct to judge the comparative worth of projects by the capital cost of generation alone.

The method of determining the merits of power projects by comparing the cost of production per K.W. of installed capacity is often misleading. For instance the capital cost per K.W. of a power plant in which a part of the intalled capacity serves only as a standby will be very much lower than in the case of a power plant without any standby capacity. In such cases, therefore, it is necessary to compare the capital cost of power plants on the basis of the maximum power that can be generated.

The merit of a power plant can be judged by its Firm Power Capacity. The firm capacity of a power plant can be defined as "that portion of its total installed capacity which can perform the same function on that portion of the load curve assigned to it as alternative steam capacity could perform." It depends on the minimum stream flow at time of peak load, on the pondage available on the installation provided, on the shape and size of the connected load curve and on the interrelation of existing plants. Thus power plants in which the firm capacity is a small percentage of the total installed capacity, appear more economical than they really are if the basis of comparison is the capital cost per K.W. of the installed capacity. The following table gives a comparison of the various projects in Pakistan on the above basis.

Particular	Rasul	Dargahi	Mianwali	Warsak
1. Total installed capacity (K. W.) ...	22,000	20,000	125,000	150,000
2. Maximum power ..	22,000	15,000	103,000	120,000
3. Standby capacity ...	...	5,000	25,000	30,000
4. Firm capacity ...	11,800	15,000	103,000	120,000
5. Capital cost of Production (Civil works & generation) lacs of Rs. ...	282.0	132.0	1256	1373
6. Capital cost of production per K. W. of installed capacity (Rs.) ...	1281	660	1005	918
7. Capital cost of production per K. W. of maximum power generated (Rs.) ..	1281	880	1218	1144
8. Capital cost of production per K. W. of firm power demand that can be met (Rs.) (as an isolated unit) ...	2370	880	1218	1144
9. Capital cost of Transmission. (Lacs of Rs.) ...	431.0	54	336	642
10. Capital cost of transmission per K. W. of generating capacity. (Rs.) ...	1957	360	326	504

Note :—(1) The heavy cost of transmission in Rasul is due to the fact that an extensive grid far in excess of the requirements of Rasul was provided in order to facilitate interconnections with Uhl river grid, Lyallpur, Dargahi, Malakand and Mianwali.

(2) The cost of the Warsak Project is Rs. 15.6 crores and by allocating a large part of the cost to irrigation, Navigation and Flood control the capital cost for power was worked out as Rs. 1076 lacs in the Project. The cost that should be correctly allocated to power works out to Rs. 1373 lacs.

Fixed charges and operating expenses :

Fixed annual charges include interest and amortization, depreciation, taxes and insurance. They depend primarily upon the investment costs of the various components of the power system and represent a very large cost of water power. In steam plants, however the fixed charges form a much smaller part of the total cost of power.

The rate of interest on the money invested in a power project varies from year to year, depending upon the conditions of the money market. Government usually finances its undertakings by the sale of bonds and provision must be made for the retirement of the bonds *i.e.*, for amortization, as well as for payment of interest. The usual practice in Pakistan is to provide interest charges at 4 per cent while preparing the project reports. This provision is adequate if the project is to be considered only as a self supporting project. On the other hand if it is to be a self liquidating project, amortization charges should also be provided and the total fixed charges in such a case would increase to 6 to 7% depending upon the period of amortization.

Depreciation depends upon the useful life expectancy of the various features of the power development. The useful life of dams and other civil works in a hydro-electric development may vary from 50 to 100 years or even more, while that of the mechanical and electrical equipment may vary from 25 to 30 years. The usual practice is to provide depreciation charges at 3 % for mechanical and electrical equipment and 0·5 to 1 % for the civil works. If amortization is also provided, then it may not be necessary to provide full depreciation during the period of amortization as this would in effect constitute double repayment. It is necessary however, to include sufficient depreciation to provide for replacement of those items which will have to be replaced during the amortization period. Operating expenses include the cost of operation, maintenance and repairs, wages of staff, administrative and legal charges etc. In hydro plants they form a small part of the total cost of power generation. The usual practice is to provide operating charges at the rate of $\frac{1}{2}$ to 1 % for civil works and $\frac{3}{4}$ % for mechanical and electrical equipment.

Effect of Load Factor on the cost of power.

The load factor of any system may be defined as the ratio of the average load over a specified period to the peak load occuring in that period. It is an index of the load characteristics. The energy output of a power plant will vary directly with the load factor at which the plant is operated. In other words in order to produce a given quantity of energy, the installed generating capacity must be increased as the load factor decreases. The effect of load factor on the cost of power is very material in the case of hydro plants because the annual cost of these plants is practically indepen-

dent of the plant output. Suppose the cost of energy generated at a hydro plant is 2 pies per k. w. h, if it is operated at 80 % load factor. If the same plant is operated at 40 % load factor, it will produce only one half as much energy and the cost will increase to 4 pies per k. w h. In the case of steam plants the effect of load factor is not so marked because if they operate at a lower load factor the cost of fuel will be saved which represents a large part of the operating expenses.

Cost of Transmission.

The cost of transmission is an important item in the total cost of power at load centres. In the case of hydro-electric development situated remote from the load centre, the cost of transmission may be as great as nor greater than, the cost of generation. The cost of transmission depends upon the length, voltage and capacity of the line. In the selection of alternative projects it is not sufficient to compare the capital cost of generation. A development in itself may give an exceptionally low cost per K. W., of capacity but it may require so large an investment in transmission lines to reach the market that the power cannot be delivered in competition with power from other sources.

The annual cost of transmission includes interest at 4%, depreciation at 3% and operating expenses at ¼ %. The annual cost of distribution will be higher on account of heavy depreciation and maintenance and is calculated at 10¼ % of the capital cost of distribution including interest at 4 %.

Effect of interconnections on the economics of development.

If a hydro plant is to be considered as an independent source of supply the economics of development becomes a simple matter. The plant will operate at load factor of the connected load and its capacity will be fixed by the available stream flow and the extent to which it can be regulated by storage. Any water which is not passed through the turbines has to be wasted and the utilization factor will be low. On the other hand, when a large number of generating plants, both hydro and steam, are interconnected and feed into a large transmission system or grid, it is possible to take advantage of the diversity between the different loads on the system, minimize the standby capacity and secure high plant capacity factor and high fuel economy. Interconnections will make it economically feasible to develop large capacity hydro-electric projects and to utilize large amounts of low cost secondary and seasonal power which otherwise would be wasted.

Suppose in 1958, the monthly load duration curves relating to the Punjab and N.-W. F. P., interconnected grid system are as shown in Exhibit No. 2, with an aggregate peak load of 300,000 K. W. and a total energy output of 2,400 million k. w. h., the system annual load factor being 60 %. Suppose we want to develope the Soan Dam Scheme, in

which the annual average stream flow is 5,80,000 acre feet and there is a large storage capacity in the reservoir which will enable regulation of seasonal flow. If this site is fully developed, it will produce 65 million k. w. h., annually.

Now if the Soan Dam Scheme is to be built as the sole source of supply to an independant system, the load factor will be that of the connected load, in this case 60 per cent say. Since the annual output is 65 million k. w. h., the effective capacity of installation will be 12,400 K. W. If on the other hand, the hydro-plant were built as a part of the large system indicated in Exhibit No. 2, the installed capacity can be independent of the load. It could, if desired be built as a base load plant operating at an annual load foctor of 100 per cent. In such a case the effective installed capacity would be 7400 K. W. and the station would occupy the position shown at A on the load curve. If the power plant is designed to operate at the average system load factor of 60 per cent the capacity would, as already shown, increase to 12,400 K. W. and the plant would then move up the load curve to position B. Under these conditions the quantity of energy which the plant would have to produce during the months of November to February and June to August is much in excess of that required during the other months.

As a third alternative the Soan power station can be developed as a peak load plant to operate during the months of greatest demand. From the peak utilization curve shown in Exhibit No. 3, it may be calculated that the upper 23.3 per cent of the system load contains 65 million k. w. h. It would therefore be possible to build a peak load plant having an installed generating capacity of 70,000 K. W. and to operate it at an annual load factor of 10.6 per cent. Under such conditions most of the summer flow would be held in the storage reservoir and the plant would operate at its maximum capacity in the winter months.

In all the above three cases full utilization of the stream flow has been made but the generating capacities of the plant would be different. In such a case if the cost per K. W. of installed capacity were to be used as the criterion for selection, then the third alternative with plant capacity equal to 70,000 K. W. would be the most economical as the cost of the dam, the reservoir, housing etc., remain the same in all cases. On the hand if the basis for comparison is to be the cost per unit of power then the first alternative with plant capacity equal to 7,400 K. W. would be the most economical as in this case the total capital cost would be minimum while the annual energy-out put remains the same in all cases.

The above example shows the wide latitude in planning conferred upon the engineer as a result of interconnections of hydro plants with large electrical systems and how misleading it would be to judge the merits of a project on the cost per K. W. or the cost per unit power alone.

which the annual average stream flow is 5,80,000 acre feet and there is a large storage capacity in the reservoir which will enable regulation of seasonal flow. If this site is fully developed, it will produce 65 million k. w. h., annually.

Now if the Soan Dam Scheme is to be built as the sole source of supply to an independant system, the load factor will be that of the connected load, in this case 60 per cent say. Since the annual output is 65 million k. w. h., the effective capacity of installation will be 12,400 K. W. If on the other hand, the hydro-plant were built as a part of the large system indicated in Exhibit No. 2, the installed capacity can be independent of the load. It could, if desired be built as a base load plant operating at an annual load foctor of 100 per cent. In such a case the effective installed capacity would be 7400 K. W. and the station would occupy the position shown at A on the load curve. If the power plant is designed to operate at the average system load factor of 60 per cent the capacity would, as already shown, increase to 12,400 K. W. and the plant would then move up the load curve to position B. Under these conditions the quantity of energy which the plant would have to produce during the months of November to February and June to August is much in excess of that required during the other months.

As a third alternative the Soan power station can be developed as a peak load plant to operate during the months of greatest demand. From the peak utilization curve shown in Exhibit No. 3, it may be calculated that the upper 23.3 per cent of the system load contains 65 million k. w. h. It would therefore be possible to build a peak load plant having an installed generating capacity of 70,000 K. W. and to operate it at an annual load factor of 10.6 per cent. Under such conditions most of the summer flow would be held in the storage reservoir and the plant would operate at its maximum capacity in the winter months.

In all the above three cases full utilization of the stream flow has been made but the generating capacities of the plant would be different. In such a case if the cost per K. W. of installed capacity were to be used as the criterion for selection, then the third alternative with plant capacity equal to 70,000 K. W. would be the most economical as the cost of the dam, the reservoir, housing etc., remain the same in all cases. On the hand if the basis for comparison is to be the cost per unit of power then the first alternative with plant capacity equal to 7,400 K. W. would be the most economical as in this case the total capital cost would be minimum while the annual energy-out put remains the same in all cases.

The above example shows the wide latitude in planning conferred upon the engineer as a result of interconnections of hydro plants with large electrical systems and how misleading it would be to judge the merits of a project on the cost per K. W. or the cost per unit power alone.

As a further example consider the Mianwali Power Station situated on a large river the flow of which can only be regulated partially. The effective generating capacity of this plant is 100,000 K. W. and it feeds into the large interconnected grid system of Punjab and N.W.F.P. Suppose the maximum peak demand of the system in 1958 is 300,000 K. W. and the typical daily load curve in December which is assumed to be month of heaviest demand, is as shown in Exhibit No, 4, the daily load factor being 72 per cent.

The dependable stream flow for Mianwali Power Station in December is epuivalent to 80,200 K. W. or 19,20,000 Killowatt-hours per day. Similar particulars of other stations connected to the grid are as given below :—

	Generating Capacity K. W.	Power equivalent to stream flow in December (K. W.)	Daily output in 1000 K. W. H.
1. Mjanwali ...	100,000	80,200	1.920
2. Warsak ...	120,000	60,000	1,440
3. Rasul ...	22,000	11,500	276
4. Malakand ...	15,000	10,000*	240
5. Dargahi ...	15,000	10,000*	240
6, Thermal Stations ...	70,000	70,000	1,680
Total ...	342,000	241,700	5,796

*FIGURES ASSUMED.

The reservoir at Warsak has sufficient capacity to take care of daily fluctuations of load while at Mianwali, the regulation can only be partial, sufficient only to take care of the hourly fluctuations. The other power stations namely Rasul, Malakand and Dargahi where the stream flow cannot be regulated naturally take the base load position as shown in Exhibit No. 4. If the Mianwali, Warsak and the thermal plants are assigned the position shown on the load curve then the load factors at which each power station will be operared are as given below :—

	Units utilized in 1000 K. W. H.	Load Factor.
Rasul ...	276	100%
Malakand ...	240	100%
Dargahi ...	240	100%
Mianwali ...	1920	100%
Thermal Plants ...	1120	66.7%
Warsak ...	1374	48.2%
Total ...	5170	

In this way the full utilization of the output from Mianwali, Rasul, Malakand and Dargahi power stations would be made while the Warsak station would take up the peaks, thereby conserving the water in the low flow period. As the plants operate at a high load factor the cost of energy output will be minimum. If on the other hand each power plant were to operate independently at the system daily load factor of 72 per cent, full utilization of the output would not be possible and the cost of energy output would be very high

When considering the economic value of hydro power sites, therefore, it is not sufficient to make a simple camparison with the cost per K. W. of installed capacity, or cost per unit power. The power site should be considered as a link in a co-ordinated system of power supply where the hydro and steam stations perform those functions for which they are best suited. The effect of the development of the power site upon the economy of the whole system should be studied. A scheme which might be economically unfavourable as an independent source of supply, might prove feasible, and even attractive as a unit in the grid system.

4. CONCLUSIONS

From the considerations set out in this paper, the following general conclusions can be drawn :—

1. The need for power in Pakistan is urgent. The available resources are limited and should be so utilized as to give the maximum benefit. Advance planning is necessary to establish the engineering and economic feasibility of projects and for wise selection between them.

2. At present there is a tendency to over-emphasize investment in concentrated large scale projects which are more spectacular rather than basic, Such programmes are not generally consistent with the available resources of the country and will result in either starting more than what is required or in a cutting down process which will leave an unbalanced set of measures.

3. Emphasis should be laid on projects which do not involve heavy capital cost and which can mature in the shortest time.

4. The development of power should be consistent with the development in the other fields of progress such as agriculture, industry, transport etc.

5. Development of power sites should not be considered as isolated units but as interconnected units of a large transmission sytem. It is essential to study the effect which the construction of the projects would have upon the economics of the whole system.

6. The capital cost of power plants varies a great deal depending upon many factors the most important of which is the location of the site and the nature of service to be rendered. Both the capital cost and the unit cost of power should be considered while comparing the relative merits of projects.

7. The other important requirements to be satisfied before a project can be finally selected are

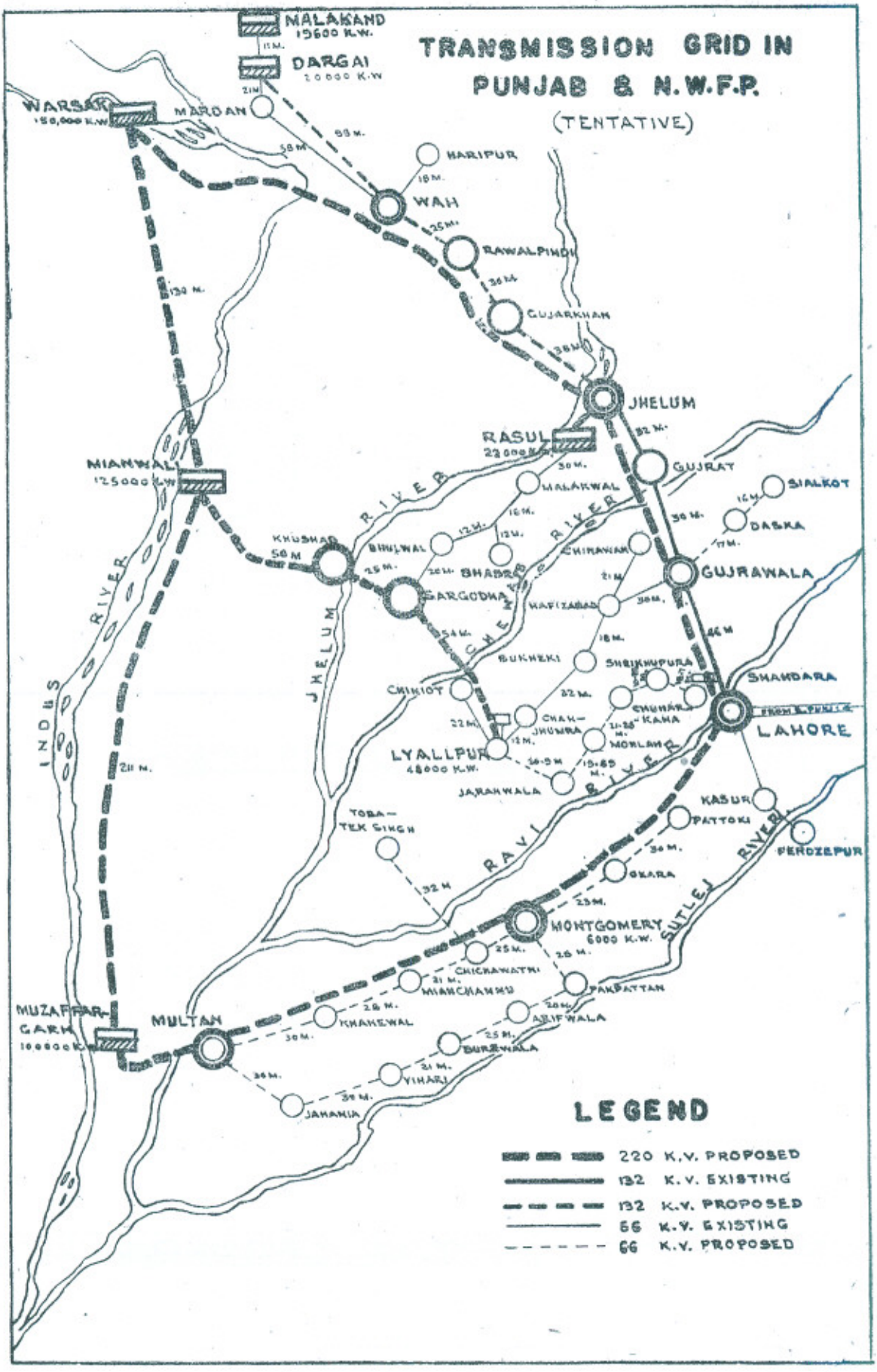
   (*a*) There should be a demand for the power produced.

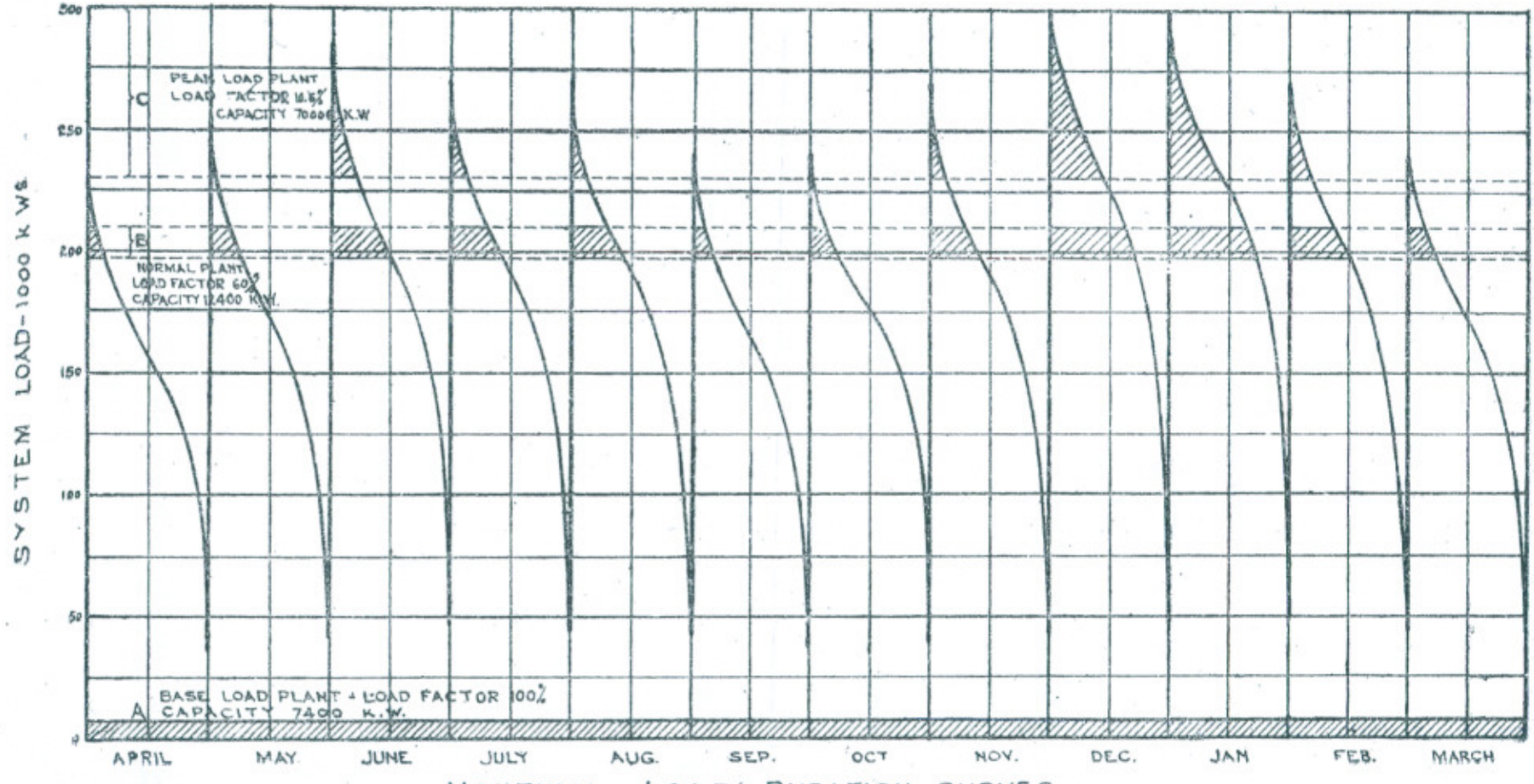
   (*b*) The benefits should exceed the costs.

   (*c*) The size of the project should be fixed at the point at which the excess of benefits over costs is maximum.

   (*d*) The cost of the project should be less than any other potential valuable means of securing the same results.

Printed at the
Business Printing Press,
166, Anaakali, Lahore

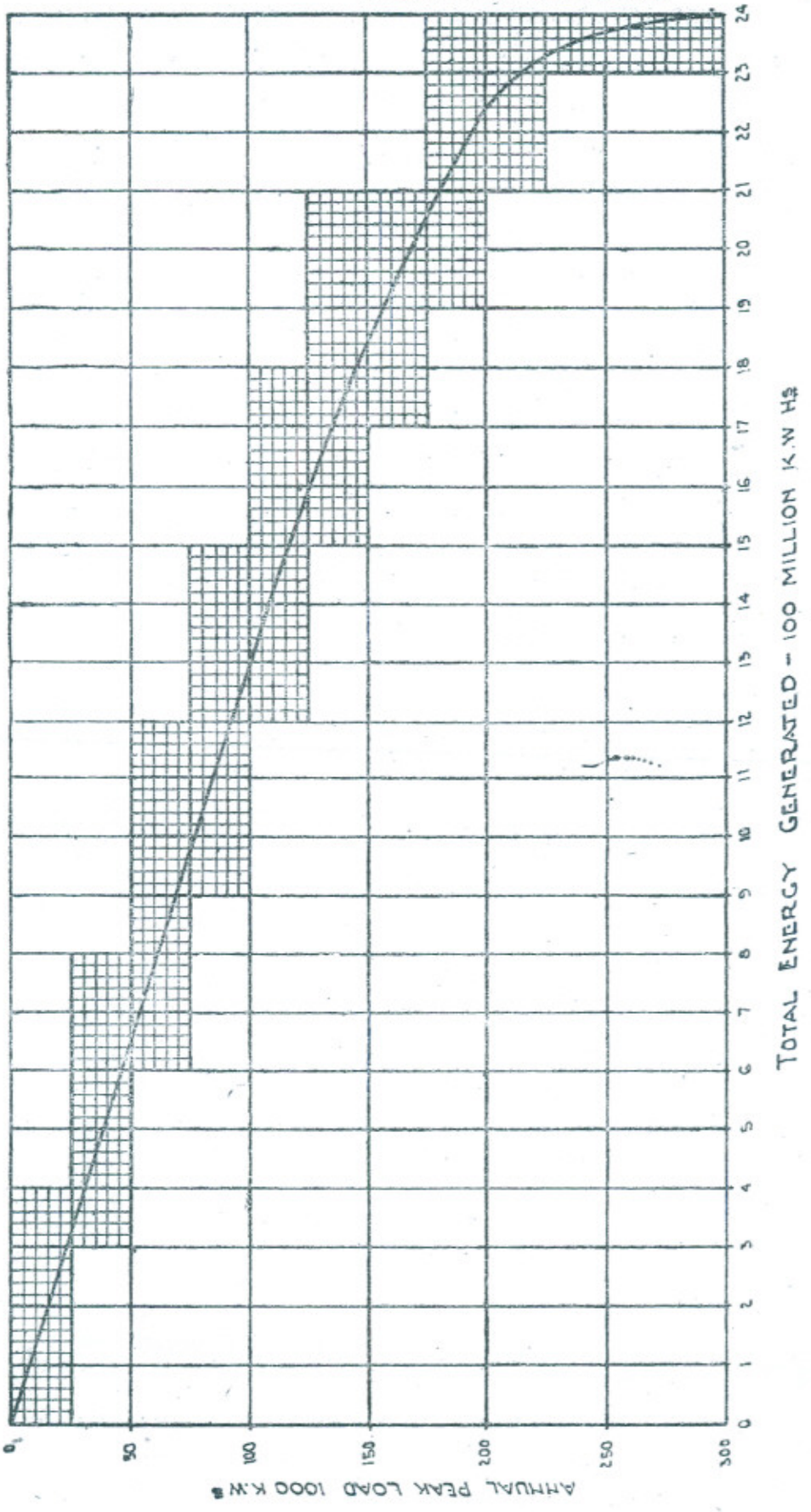

TRANSMISSION GRID IN
PUNJAB & N.W.F.P.
(TENTATIVE)
MALAKAND
15600 K.W.
DARGAI
20000 K.W.
WARSAK
150,000 K.W.
MARDAN
HARIPUR
WAH
RAWALPINDI
GUJARKHAN
JHELUM
RASUL
22000 K.W.
MIANWALI
125000 K.W.
GUJRAT
SIALKOT
DASKA
MALAKWAL
KHUSHAB
50 M
BHALWAL
BHADER
SARGODHA
CHIRAWAN
GUJRANWALA
HAFIZABAD
BUKHEKI
SHEIKHUPURA
SHAHDARA
CHINIOT
CHAK-JHUMRA
KHUNARIANA
MORIANWALA
LYALLPUR
48000 K.W.
LAHORE
JARANWALA
KASUR
PATTOKI
FEROZEPUR
TOBA-TEK SINGH
OKARA
MONTGOMERY
6000 K.W.
CHICHAWATNI
MIANCHANNU
PAKPATTAN
MUZAFFAR-GARH
100000 K.
MULTAN
KHANEWAL
ARIFWALA
BUREWALA
VIHARI
JAHANIA
INDUS RIVER
JHELUM RIVER
CHENAB RIVER
RAVI RIVER
SUTLEJ RIVER
LEGEND
220 K.V. PROPOSED
132 K.V. EXISTING
132 K.V. PROPOSED
66 K.V. EXISTING
66 K.V. PROPOSED

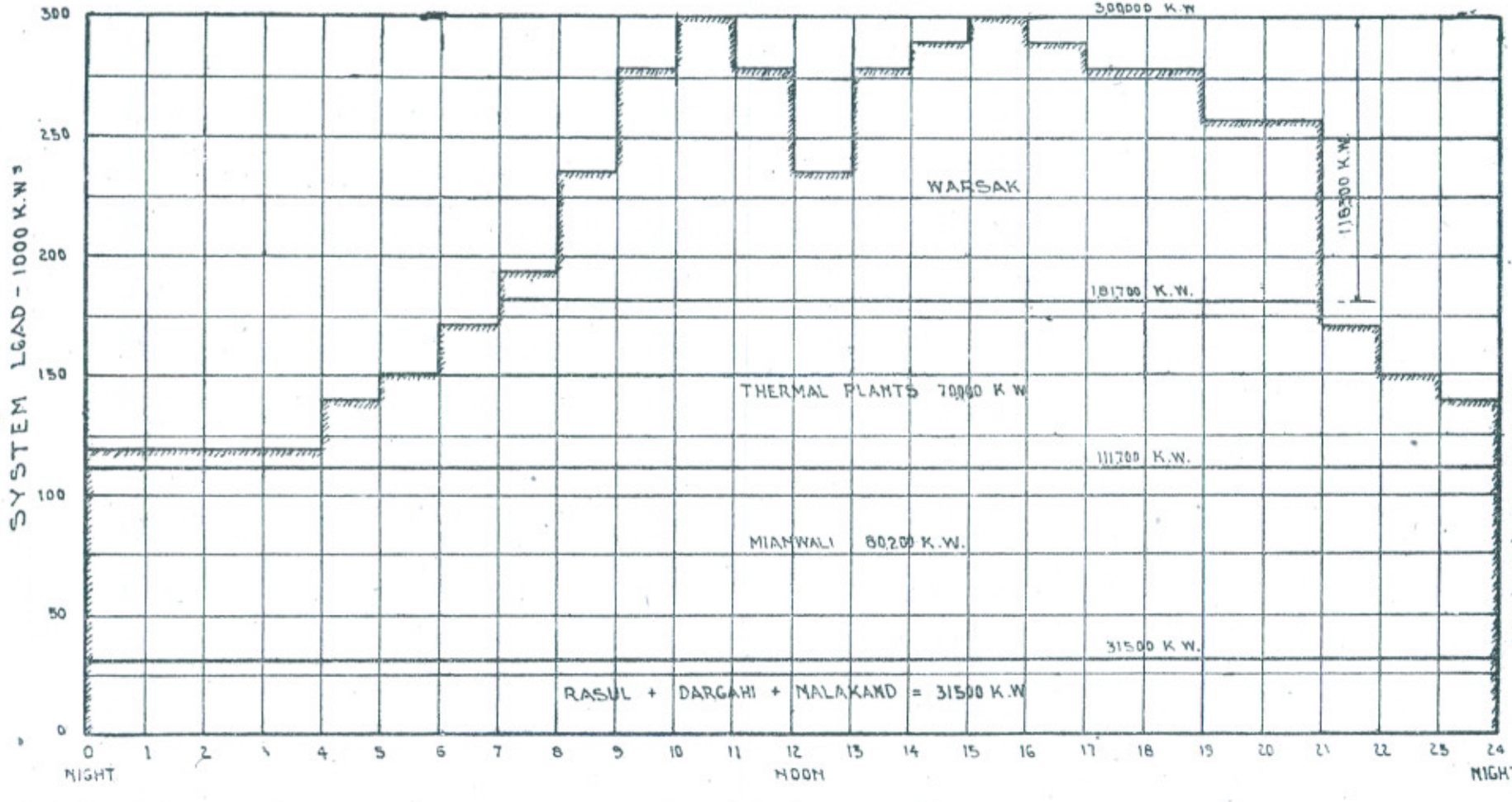


MONTHLY -- LOAD DURATION CURVES

PAPER NO 297-EXHIBIT-Z

PAPER NO. 297 - EXHIBIT - 3





TYPICAL DAILY LOAD CURVE IN DECEMBER

PAPER NO. 297 - EXHIBIT 4