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Village Electrification Through Micro-Power Plants on Canal Falls

By

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INTRODUCTION

The achievements of WAPDA in the field of power generation in West Pakistan have been phenomenal. The rate of development of power in West Pakistan is one of the highest in the developing countries of the world. The serious shortage of power faced by us has been met to some extent and a nuclear power station at Karachi—130,000 KW has also been sanctioned, thus bringing Pakistan on the International map of nuclear power generation. "Vis Alit Successus" (Power fosters progress). West Pakistan has rightly followed this motto and has gone ahead with the development of hydro-electric power, thermal power through Sui Gas, coal and diesel generating stations.

An important part of our development consists of electrifying the villages where 80% of the population live and for which Government has given due recognition. Unfortunately due to the non-availability of foreign exchange, this sector could not so far be developed to the desired extent. This paper is an attempt to suggest an improvised method of electrifying at least those villages and rural areas where irrigation channels with falls exist (not only for agricultural purposes such as lift irrigation and tubewell for drainage and reclamation, but also for industries). With the modern methods of mass communication such as radio and television etc., electricity in the rural areas is likely to play a still greater part in the social and economic progress of rural population.

A break through has been achieved in the design of hydraulic turbines and micro power plants in the last decade. This advance can usher in a revolution in generation of power from low head falls such as our canal falls. Our experience with generation of power from canal falls by the existing design of turbines and civil works has proved expensive, and could not, in general, compete with thermal power. Excerpts from articles on the subject given below are relevant in this connection :

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HYDRAULIC TURBINE DEVELOPMENT DURING THE LAST FEW YEARS

The technique of hydraulic turbines originated many years ago, but it has nevertheless been possible to make amazing progress in the course of the last fifteen years.

In conjunction with the progress made by generator manufactures as well as on the civil engineering side, the future prospects for hydraulic power are extremely promising despite the competition from other sources of energy. Progress has been made principally with regard to improved economy, greater ease of operation and longer equipment life. This has led, on the one hand, to spectacular results such as increased unit outputs and rotational speeds and a reduction in the weight of the equipment; and, on the other hand, to less obvious improvements, mainly in the technological field, the incidence of which is none the less remarkable with regard to machine performances.

Furthermore we have seen the creation and the development of new types of machines, such as vertical shaft impulse turbines, bulb units and pump-turbines. These new solutions will, without doubt, contribute towards making hydraulic power more competitive in the course of the coming years.

'Bulb' units, which are the latest addition to the turbine family, have undergone tremendous development during recent years. They are horizontal-shaft propeller turbines with fixed or adjustable guide vanes and runner blades. They are most appropriately considered as 'axial turbines' as their centre line coincides with that of the flow (Fig. I).

A complete review of their origin and development would be outside the scope of this discussion, but it is worth noting that the idea is a fairly old one which has been the subject of considerable research both in the United States and Europe and especially by the France.

Conventional propeller or Kaplan turbines with spiral casings and draught elbows have been found to be a very costly form of equipment for very low head sites. New techniques have therefore had to be developed in order to reduce structural and electro-mechanical equipment costs and to arrive at a more profitable type of plant. Any substantial reduction in the directional changes of the flow through the turbine increases its specific output (*i.e.* a smaller runner produces the same output under a given head), reduces the excavation and concreting requirements for a given runner size, and simplifies the basic turbine components. This tendency was already most noticeable in the Kaplan turbines with control vane assemblies.

The work done in France on the problem of harnessing tidal energy has produced some really remarkable results in this respect. A French company has been studying this problem since 1942, especially in connection with the

Rance project, and considerable progress has been achieved. The Rance tidal project is now actually under construction and is to feature 24 units producing 11,000 kw each.

1. Advantages of bulb units over Kaplan turbines

The axial layout and converging inflow of the bulb turbine enables it to be run at high specific rates of flow, which are conducive to high efficiencies. The intake layout of an axial turbine reduces swirl at the runner entry and thus enables high efficiencies and specific outputs to be achieved. Low-swirl inflows to the runner are essential for high efficiencies, and excessive swirl at the runner intake is one of the factors which prevents any very high specific speeds from being achieved in conventional machines with spiral casings.

The straight draught tube of an axial unit is also much more efficient than the draught elbows of conventional turbines.

For these various reasons, bulb unit runner diameters are generally some 7% or 8% less than those of Kaplan turbines of the same output running under the same head, which results in an appreciable saving on electro-mechanical equipment costs (Fig. II). Furthermore, specific outputs are 20% higher than with equivalent Kaplans, and the power unit length to runner diameter ratio of a bulb unit is only 1.8, against 2.5 to 3 for low-head Kaplan units.

As we have already seen, the characteristic specific power (*i.e.* the power produced by a 1 m. diameter runner under a 1 m. head) of a Kaplan unit is at most 27 HP, whereas figures of up to 36 HP have been achieved with bulb units. At this condition, the kinetic energy below the runner is very nearly equal to the head; in other words, as the draught tube has to achieve practically 100% energy recovery, it must be very simple in shape and have a near perfect working efficiency.

A further attractive feature of bulb units—which is their main advantage from the economic point of view—is that they require much less structural work. Excavation and concreting requirements are much lower than for a Kaplan turbine mainly because of their straight draught tube and the absence of a spiral casing. The simpler structures they require also cost less to build, and the power units can be installed closer together than other turbines; for instance twelve bulb units only take up the same amount of room as eight Kaplans of the same output. Furthermore, as most of a bulb unit power house is under water, it only requires very little in the way of superstructure. A number of important firms, as well as "Electricite de France" and "Compagine Nationale du Rhone", have made some comprehensive comparisons for power sites on the Rhine and the Rhone, as a result of which it has been found that the saving achieved with bulb units works out at about 30% to 35% of the cost of a power plant equipped with conventional vertical -shaft Kaplan units. In terms of electricity output, this means a 15% lower cost 'per installed kilowatt, than with conventional power equipment.

The advantages of bulb units over Kaplans are less marked at high heads. Their present range of application extends from very low heads (*i.e.* as at certain times of the day at tidal power stations) up to about 15 m. or 16 m.

Accessibility to the inside of the bulb still remains a problem, however, especially as regards the seal, which is one of the most delicate parts of the machine.

Even the most successful designs are bound to have some disadvantages, however, and bulb turbines are no exception. With their small runner and alternator diameters, they suffer from low inertia, with the result that they have a regulation constant of between 1.5 and 2 seconds. This makes them unsuitable for use in isolated networks having a low self-regulation coefficient; they should, therefore, rather be installed in a system in which other power stations can deal with frequency variations. Recent research on this subject has shown, however, that this disadvantage may not be as serious, as it was first thought.

2. Present bulb unit development trends

The present trend towards higher individual machine outputs is limited almost solely by the possibilities of cooling the alternator, which is smaller in diameter than that of a conventional power unit.

As far as the turbines are concerned, this limit depends on the weight of the runner overhanging the downstream bearing in the unit. To give an example, the bearing in the Saint Malo turbine worked under a load of 110 tons, for a 6 meter runner diameter. As things are at the moment, the upper limit occurs for a runner diameter of about 7 m.

The problem of cooling the alternator has been investigated extensively by electrical engineers, and especially by those of the Alsthom Company. None of the usual cooling methods is suitable for the small-diameter alternator rotors fitted to these units, so that a number of new methods had to be devised for the various alternator sizes involved.

In the case of the 1 m. to 1.5 m. diameter alternators used in 'micro' power stations, the problem has been solved by running the alternators in oil, which very efficiently conducts the heat away to the submerged bulb casing.

For higher powered units, the idea has been adopted of keeping the bulb casing filled with air under pressure, as the power required to keep the coolant circulating decreases with the square of the pressure. This use of compressed air as a cooling medium was first tried on the Argentat units for Pierre-Benite on the Rhone, which will be produced 25,000 HP under a head of 12.5 m. and for the units in the Rance Scheme. As this type of cooling also slightly increases the efficiency of the unit, it will be possible to extrapolate the outputs obtainable from bulb units to a figure of about 40,000 HP.

3. Bulb unit categories

Bulb units fall within three distinct categories, each of which will now be described.

1. "Micro" power station bulb units which are confined to low outputs and heads (*i.e.* up to 1,500 HP and 10 m. respectively). Their runner diameters do not exceed 2-2.5 m.

These units are a single assembly consisting of a propeller turbine with a directly driven generator in a streamlined watertight casing. The guide vanes are either fixed or adjustable, frequently the former. The alternator is of the caged asynchronous type without slip rings. Oil in the casing simultaneously cools the machine, lubricates the bearings, insulates the stator assembly and, as it is at a slightly higher pressure than the water outside, seals the unit.

Some 'micro' power station bulb units have also been provided with alternators running in air at atmospheric pressure, so as to enable synchronous generators to be used.

The delicate problem with small bulb units—which has now been solved —was to design a shaft seal that could be relied upon to prevent water from seeping into the oil in the casing.

An interesting arrangement is one used for every low head applications, in which the bulb units are installed in a siphon (Fig. III). This is a very economical layout, as the unit is shut down by making the siphon break by letting air into it a via a vent valve, which does away with any need for the usual turbine shut-off valves.

2. *River bulb units*. These are fairly big turbines with runner diameters varying between 3 and 4.5 m. They were developed from prototypes which were first put into service in about 1957 and 1958. One of them, near Grenoble has a 3.8 m. diameter runner and is designed to produce 12,400 HP under a 12.5 m head.

Units incorporating step up gearing can also be built, with the turbine driving a conventional-type alternator which, as it is running at high speed, has a smaller diameter than usual. It should be noted, however, that though the alternator is less expensive in this case, the cost of the step up gearing also has to be taken into account, which is a fairly delicate assembly either requiring a planetary gear system or, alternatively, single or two-stage spur gearing.

Units of this type have already been installed at certain power sites, especially in Germany. The limit of their output is determined by the maximum power the gearing can take, which is no more than 7,000—8,000 HP. Though it is quite true that gear trains transmitting 30,000 HP are in service—especially in thermal power stations—these are reduction gear systems which are transmitting comparatively low torque values, and, therefore, only involve light gear tooth loadings. They work under very different conditions from those associated with hydraulic turbine step-up gearing.

3. *Direct-drive bulb units for big rivers or tidal power stations.*—These seem to be the bulb units with the most promising future before them. Their alternators are cooled with air at atmospheric pressure or at 2-3 kg/sq. cm.

The tidal units are now under manufacture in collaboration with the Alsthom Company and other French manufactures include, among others, the 24 units for the Rance Project (Fig. IV) and experimental unit for Russia, which latter is to feature step up gearing. River units under construction include the four units for Pierre-Benite on the Rhone.

An advantage of bulb units is that they can also be run as pumps. They are reversible machines which, as in the Rance project, can be run either as turbines or as pumps without changing the runner bladings, depending on the difference between the sea level and the water levels in the basins, which vary several times during the day. They can also quite easily be used for relief purposes, in which cases the unit is shut down and merely acts as an orifice; this type of operation occurs at tidal power stations whenever the head is practically nil.

It is well known that East Pakistan has a number of tidal estuaries and it is the delta of some of the biggest rivers of the world, namely: the Ganges, the Brahamputra, and the Megnna. Tidal power in this area has great future with the recent advances in the design of direct drive bulb units. The hydro-electric power resources of East Pakistan are limited as it is a flat country. A big hydro-electric scheme on the old Brahamputra is under consideration, where modern design of turbines could be of great use, as the fall even on this scheme is low.

PUMP TURBINES

Review shall be completed with a few words about the pump turbine, which is quite a new type of machine. Though pumps shall not be discussed, as they are outside the scope of this subject; the fact that pumping problems are steadily gaining in importance should nevertheless be borne in mind.

As regards power production, the increasing difficulty of regulating distribution networks as greater individual thermal power station unit outputs are achieved (250,000 kw) in Europe, (400,000 kw) in America and the existence of atomic power stations both add to the importance of pumping. Big thermal power units lack operational flexibility because they depend on their boiler operating conditions, which as it happens, make it impossible for the units to take on loads very rapidly. The position is even worse in the case of atomic power plant, where major governing difficulties also arise. Thermal, atomic and run-of the river power stations are the producers of basic electricity, whereas peak demand energy is supplied by hydraulic power stations receiving their supplies of water from reservoirs. The usefulness of pumped storage as a means of absorbing surplus energy and delivering it at peak demand periods is obvious.

Until now, pumped storage plants have featured units comprising a turbine, a pump, and an electric machine running alternately as a generator and as a motor (Fig. V). Such layouts are both very expensive and fairly complicated.

A much more functional solution is to combine the turbine and the pump as a single machine. Even though such a design is still quite expensive, it is obviously less so than an installation with a separate pump and turbine.

A combined design based on present knowledge of centrifugal pumps and Francis turbines is by no means revolutionary from the technical point of view. The only difficulty is that the respective pump and turbine operating points do not occur at the same pressure on the flow *vs.* pressure characteristic. The turbine requires a higher pressure, and if the design values for the installation depend on the turbine, the pump will be at a disadvantage, and *vice-versa.* In addition since the turbine operates under the static head with the duct losses subtracted, and the pump runs under the static head plus the duct losses, the delivery head of the pump will obviously be greater than the net head driving the turbine. As this is the opposite of what is really required, a compromise has to be sought.

Several different pump turbine designs have been developed. One is based on a Francis turbine with adjustable guide vanes and, in addition, adjustable runner blades providing the same type of double control as on a Kaplan turbine. This layout has been used in a number of very interesting constructions.

An alternative is to use a Francis turbine similar to a conventional machine, but with different dimensions.

A third possibility is the layout for four 31,700 HP pump turbines designed for a 32 m. head for the Torrejon power plant in Spain (Fig. VI). The design of the runners in these machines is a compromise between a turbine runner and a pump impeller; the guide vane assembly is of the conical type.

There is little doubt that pump turbines have a brilliant future before them.

Pump turbines have application in some of the major projects under consideration in West Pakistan. A scheme for off-channel storage from Indus by pumping water from the future Kalabagh reservoir into the Soan Basin at Dhok Pathan is under examination. Similarly there is another possibility of a off-channel storage at Ghariala on Haro river by pumping water from Indus. Pumped storage are also possible from the future Tarbela-Soan Link.

As we have seen in this brief review of recent hydraulic turbine design trends, some really remarkable results have been achieved. Progress has mainly been directed towards three distinct aims, which are the following :—

(*i*) Improved economy, by increasing individual machine outputs and speeds and a general redesigning of power unit structures; all these have combined in reducing the dimensions, and therefore also the weight and cost of the equipment supplies to power sites, as well as indirectly resulting in smaller civil engineering structures. None of all this has affected the reliability of the machines, despite the fact that the interests of economy and maximum reliability are sometimes in direct opposition ;

(*ii*) *Easier operation.*—Here, the accent has been one more convenient power dismantling of whole power units or their components, and much attention has been given to more convenient maintenance work. A point to note in this connection is, however, that these attempts have fairly often resulted in more complicated equipment which has occasionally tended to offset the savings achieved by building smaller machines;

(*iii*) *Longer turbine working life.*—Most of the efforts made in this connection have been aimed at finding more suitable metals, which are, however, also more expensive.

The development of such new machine types as the vertical-shaft Pelton turbine, the high head Francis turbine, the bulb turbine and the turbine pump has made hydraulic power more competitive with respect to other current forms of power production.

Has this development reached its limit? The answer is very certainly in the negative. Further progress in hydraulic machine design may still be expected to keep hydro-electric power in a leading position among the various means of harnessing the natural forces at Man's disposal.

MICRO-POWER PLANTS

Microplants are small hydro-electric schemes designed for lowest head.

Their advantage lies in the feasibility of fitting out inexpensively small local falls with plain and sturdy equipment which does not involve any high transport, erection and operating costs.

Electricite de France have applied themselves to the development of schemes fulfilling the above requirements in the case of heads between 1 m.

(3.28 feet) and 3 m. (9.44 feet) the capacity of which varies between few tens and several hundreds of kw.

Experience has shown that the principles taken for this type of schemes also apply—under different form of application to higher heads.

PRINCIPLES OF DESIGN OF MICROPLANTS

Fully automatic operation provides an attractive solution which should lead to eliminate operating labour. Yet, its careless use would mean adding the main plant complicated weak auxiliary control and protection equipment liable to fail. The operating labour thus eliminated would be replaced by personnel for plant supervision and maintenance.

With this consideration in mind, microplants have been designed so as to reduce the quantity of components and to simplify operation to the greatest possible extent. These components have been designed in order to provide them with a great strudiness and in a particular, designers strained their ingenuity in order to eliminate weak spots like for instance some mobile parts of the machine and apparatus. These arrangements added upto the quality of the protection and safety equipment provide utmost safety of operation.

Since, in spite of all this care, some maintenance and repair works are still to be expected, the equipment has been designed in order to allow easy and fast dismounting and re-erection with a view to quick "standard exchange" of failing components which may be reconditioned at the shop.

These principles have been applied to 2 D. F. experimental scheme on the Essone River at Echarcon.

EXPERIMENTAL BULB TYPE UNIT OF ECHARCON

The entire experimental unit of Echarcon, with a 120 KW max. capacity for a 3 m. (10 feet) head, has been prefabricated and divided into components, each of which does not exceed 1200 kg. (2,645 lb.) as regards the unit proper and 750 kg. (1,155 lb.) as regards platework. The largest components are easy to handle, are reassembled on the site and may be fastened with few anchorages inside a waterway including two sidewalls and an invert. The electrical instruments being housed inside ventilated outdoor type cabinets, no operating building is required.

The hydro-electric set (Fig. III) includes a metal pipe providing a convergent-divergent, the entry of which is bent so as to constitute a syphon.

The turbine including a fixed distributor and a propeller, drives directly on immersed bulb-type generator fastened upstream the distributor.

The casing plunges into the forebay through the entry of the syphon and into the tailbay through the draft tube outlet of varying slope according to the head of the harnessed site. The inside space only gets into contact with atmosphere through an electro-valve and a ventilator with a check valve.

The unit works by open and shut action priming or un-priming the syphon according to the upstream water level. Thus, the mean turbine capacity is adjusted to the flow by control of its working time instead of continuous variation of the instantaneous output of the machine (Fig. III*a*).

The machine is put to work by closing the electro-valve and starting the ventilator which extracts air from the casting and primes the syphon.

It is worth mentioning that the air remaining inside the casing is washed away when the height of the water overflowing into the syphon reaches a definite level sand that priming may then proceed without any help of the ventilator. Advantage may be taken of this phenomenon for priming purposes when there is no source of current available.

Stopping is secured by opening the electro-valve which lets air flow into the syphon and unprimes it.

From the electrical point of view, the operation of a microplant varies according to its capacity and purposes.

In the case of an interconnected system, one may either have a synchronous or an asynchronous generator which is coupled with the major system as it reaches the synchronous speed. Afterwards, the generator keeps the speed corresponding to the system frequency so that the power furnished only depends the head.

In the case of a separate system, regulation is secured keeping steady the power furnished by the unit: with this aim, the balance between generation and system demand is absorbed by a specially designed circuit (Fig. III*b*) the balance between power being obtained by means of a magnetic amplifier which regulates the current flowing in absorptive resistors in order to keep the frequency at a constant value or to have it flowing a pre-determined law.

This system, based on a loss of energy at partial loads, merely reproduces—in a different way—what is done in all run-of river plants which "spill" when the load is reduced since power storage is but little possible in the case of lowest heads.

From upstream to downstream, three main elements assembled in order to build a continuous tubular beam may be seen, namely :

(1) the syphon;

(2) the unit proper ;

(3) the draft tube ;

1. The syphon

The syphon aimed to ensure a satisfactory feeding of the unit, also constitutes the element which cuts the liquid vein.

Its shape has been designed in order to :

1—avoid vortex air entires and secure a flow with a minimum of losses;

2—make the construction easy and diminish the weight;

3—simplify maintenance.

Among others, it includes a wide circular port closed by a convex vacuum cover of laminated material. The cover weighs a few kilograms. Its opening is instantaneous and it allows fast and easy access to the inside parts of the unit as well as a way for the generator in the case of dismantling.

The stresses applied to the syphon upstream nosing dipping into the water are minor. At Echarcon the nosing is of metal plate construction, but for a standard fabrication, it could be of laminated plastic which has a remarkable low weight and a high resistance to corrosion.

The syphon top has an opening connected with both an electro-valve and the ventilator through a check-valve.

The diameter of the electro-valve is the smallest consistent with the syphon unpriming in 1/2 a minute.

The ventilator is of sufficient capacity to prime the syphon within one or two minutes. Its suction head does not suffice to draw water once priming is completed.

At the bottom, the syphon is provided with adjustable screw-type shoes which constitute the bearing parts of the machine upstream the turbine.

2. The Unit

The unit includes a taper distributor, a throat ring forming convergent-divergent nozzle, a drip-proof generator and its driving propeller.

The generator is of the synchronous type with permanent magnet field, thus avoiding the use of slip rings and brushes, which are not much consistent with generator immersion. The unit looks like a taper-cylinder shaped flow meter with a removable propeller of the fixed blade type.

The body, the flanges and the propeller are of aluminium alloy.

The taper part fits into the central ring of the distributor so that the water thrust applied on the runner increases the stability of the generator, which is held over its bed-plate by means of six bolts pulling it downstream and is fastened to the distributor central ring, through a taper shaped washer.

The distributor is made of two concentric taper shaped rings connected by the fixed guide vanes. It guides the liquid flow, holds the generator and ensures the continuity of the unit casing.

Like the syphon, the distributor is provided with bearing shoes completing the bed-plate of the upstream part of the installation.

Tightness is ensured with stuffing boxes on outlets of cables and pipes.

The throat ring is of aluminium alloy in order to facilitate its handling and only weighs 120 kg.

3. The draft tube

The draft tube derives from the straight taper type. Its shape is favourable both to the water flow and construction economy as well as consistent with the reduction of river earth-works.

It is suspended downstream to a transverse beam and braced with tie-rods. This arrangement allows its swivelling for the disassembling of the unit so that its coupling flange parts without gripping from the throat ring. This is a very important feature which allowed securing the continuity of the tubular beam made by the casing and by way of consequence to diminish its weight while keeping a satisfactory mechanical strength. In Echarcon the draft tube is of metal plate construction but like in the case of the syphon upstream nosing, series fabrication is molded laminated material is also possible.

Connection with masonries.—The dimensions of waterway to micro-plant must provide a water speed less than 0.75 m/s (2.5 feet) at turbine rated flow. The channel includes two side-walls and an invert. The upstream part of the microplant before the turbine runner rests upon the invert through seats, the height of which is such that the normal forebay level is some 20 cm inches under the spill of the syphon. A sufficient freeboard is thus provided to protect the unit in the case of dismantling.

These seats designed to withstand equipment and water flow weight are placed on the invert, bolted down and braced at the top with transverse sectional irons fastened with anchor lugs into the side-walls.

They are provided with supporting pieces for the syphon shoes.

Other supports placed against the distributor provide it with a bearing of the same type.

Horizontal thrust stresses are compensated by a screen crossing the waterway, fastened to the bottom of the syphon and to its lateral beam extensions to the side-walls as well as to the invert.

This screen is designed with a sufficient sag to make the tensile stresses applied by upstream water pressure consistent with the system equilibrium. The screen thickness is such that the unit stress consists with utilized material features.

Juxtaposed but not joined metal plates have been chosen in Echarcon. Tightness is secured with rubber strip seals placed between plates as well as between screen and side-walls.

The draft tube is suspended through adjustable threaded rods to a floor connecting the side-walls together.

The entire microplant is thus connected with the masonry either with adjustable or flexible connections, which makes erection easier and independent of the civil engineering works.

Low head power generation from canal falls in West Pakistan

I can recall our frustrating experience of designing an economical water wheel for power generation from canal falls, for which some experiments were also carried out in the Irrigation Research Institute soon after Independence. The cost of conventional turbines and the civil works such as power house, etc. also proved so expensive that we were quite dis-illusioned after completion of some of our low head canal fall hydel stations. It is gratifying that a break through has been achieved in this field and we can re-appraise the whole question of power from canal falls.

A look at the irrigation map of West Pakistan in the Indus Plain would show that our canals extend to every remote corner of the Province like the life giving arteries of a human system. We have converted the vast desert of the Indus Plain into a fertile agricultural field by these channels, but we can now use this very system for village electrification and rural industrialization, reclamation by tubewells, and other needs with this new break through in the design of bulb turbines and micro power plants. It gives great satisfaction to know the large quantities of water which are wasting their energy at hundreds of falls could be harnessed for the benefit of the rural population.

In World Power Conference of 1957 held at Belgrade, a paper was presented by the author on the Economic Importance of Water-Power for Under-Developed Countries. There can be no two opinions that hydro--electric power in West Pakistan can play a major part in meeting the future demands, particularly in the Northern areas. It is interesting to note that it is the under-developed countries of Africa and Asia that have the maximum hydro-electric power potential as can be seen from Table No. I of the above paper—Appendix I. Even in the southern areas of West Pakistan, there are possibilities of hydel power generation on canal falls. In this connection a paper was presented by the author on "Superiority of Hydro-Electric Power Stations over Thermal Stations for the Southern Areas of West Pakistan" for the symposium held under the auspices of CENTO Scientific Council, Lahore on the role of science in the development of natural resources with particular reference to Pakistan, Iran and Turkey.

Recently the last of the series of power stations on low head canal falls at Nandipur on Upper Chenab Canal was completed by WAPDA. As stated in the paper for CENTO Symposium though there are large possibilities of power general from canal falls on D. G. Khan Canal, Rohri Canal, Nara Canal and Kalri Lake in the Southern Areas of West Pakistan, no development has been made. With the advances in the design of bulb turbine and micro power plants, it is possible to affect considerable economy and the question needs to be re-examined particularly for the isolated and far flung areas, where power cannot be easily made available due to the very long transmission lines required from the main grid.

Major schemes for rural electrification would cost large amounts of money and foreign exchange which are difficult to obtain. It may be desirable to have power generation from canal falls to make hydro-electric power available to isolated areas where chances of future extension of electric transmission lines are remote. The transmission lines existing, under construction and proposed, even in the most developed areas of the former Punjab run generally at distances of about 25 miles, which is a considerable distance for transmission of power for agricultural or industrial centres whereas irrigation channels exist throughout the area at closer intervals and falls thereon could be conveniently harnessed for power generation.

A look at the map of proposed Electric System in 1975 (Fig. VI) shows the thin coverage of power lines in the southern areas South of Multan. The areas North of Multan have highly developed transmission lines as cheap power is available from hydroelectric stations in the northern areas, and there is great demand of power for industries. The southern areas of Sukkur and Hyderabad have to depend on thermal power from Sui Gas. The future power at Moro or Mari would certainly connect the various gaps along the Indus river but still some isolated areas are left out. A reference to this may show that big gaps exist in the eastern Nara and Rohri Canal areas. These areas have excellent possibilities of power generation from falls on Nara and Rohri Canals. Similarly a gap exists between Kashmore and Rajanpur. Power here could be made available from D. G. Khan Canal. Please refer to table at Appendix II. It is seen from this table that the cost of hydro-electric power from these canal falls is cheaper than Sui Gas power even if conventional civil works are provided for the Power House with conventional turbines. With modern advances in the design of turbines and economical civil works, this cost could be reduced by about 30%. For small power stations on perennial channels in Bahawalpur and Multan areas, falls exist on Lower Bari Doab Canal system, Pakpattan Canal, and Bahawal Canal, which could be harnessed for power generation by installing micro power plants for all future tubewell projects. These power stations could be used for areas which are not served by the existing or proposed transmission lines.

SELF HELP FOR VILLAGE ELECTRIFICATION

In the Third Five-Year Plan, emphasis has been laid on making the country less dependent on foreign aid. It has also been decided to go in for a heavy industry complex. In this connection, it is to be noted that our electrical industry is also very backward as we import most of the equipment and materials required for our electrical industry, though a start has been made to manufacture small sized transformers etc. As the industry has to be brought on a proper footing, it is very necessary to give a serious thought to mass produce bulb turbines and equipment for micro power plants within the country, so that these could be installed on many of the smaller channels spread over throughout West Pakistan. This equipment could play a great role in the advancement of rural economy. Village Co-operatives, Co-operative Department and Basic Democracies could join hands in making this a reality. At present villagers are largely depending on diesel power for tubewell pumping and other agricultural and industrial needs, which is proving quite expensive. Power from micro-power plants would fill the gap, particularly in the areas where there is no possibility of extending the grid in the near future. Consumer societies exist in advance countries comprising of consumers of electricity. Similar societies could also be formed in Pakistan.

An important feature of micro power plants should be their economy. As far as possible improvised material should be used.

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APPENDIX I

Potential Hydro-Electric Resources

		Percent of World's total hydro-electric energy supply by regions	Percentage of regional total now being utilized
North America	..	9.2	19.7
Central America	..	2.4	1.9
South America	..	11.3	0.7
Europe	..	9.2	17.7
U.S.S.R.	..	11.8	1.5
Africa	..	41.0	Negligible
Asia	..	14.2	4.1
Australia	..	0.9	4.6

APPENDIX II

Comparative Economics of some Proposed Hydro-Electric and Thermal in the Southern Areas of West Pakistan

Item		Sui Gas Installation in Hyderabad already executed by WAPDA (Extension Scheme).	Jamroa Weir Hydro-Electric Project (Nara Canal).	Sukkur Hydro-Electric Scheme (Rohri Canal).	Sui Gas Installation near Sukkur proposed by WAPDA.	Kashmore Hydro Electric Project (D.G. Khan Canal).
1. Discharge available	Max.	.. ..	4725 c/s	11,725 c/s	..	5200 c/s
	Min.	.. ..	1007 c/s	6,694 c/s	..	2700 c/s
2. Drop	Max.	.. ..	18.29 ft.	21.5 ft.	..	100 ft.
	Min.	.. ..	14.87 ft.	19.9 ft.	..	average
3. Total installed capacity	..	15,000 KW	5,600 KW	15,000 KW	30,000 KW	37,800 KW
4. Annual output (in million units)	..	131.20	35.7	114.71	262.5	233.8
5. Capital cost in lakhs of rupees	..	130.00	205.70	460.50	360.00	1039.00
6. Cost per installed KW in rupees	..	866.00	3620.00	3070.00	1200.00	2770.00
7. Total annual charges in lakhs of rupees.	..	55.17	16.78	39.52	127.00	78.38
8. Cost per unit at bus Bars in paisa	..	4.2	4.8	3.45	4.84	3.36

N.B.—For the sake of comparison the same Load Factors (*i.e.* 100%) have been assumed for all the schemes.

This is a copy of the Appendix of the Paper "Superiority of Hydro-Electric Power Stations over Thermal Stations for the Southern Areas of West Pakistan", presented in the Symposium held under the CENTO Symposium, Lahore—January, 1962.

AXIAL TURBINE

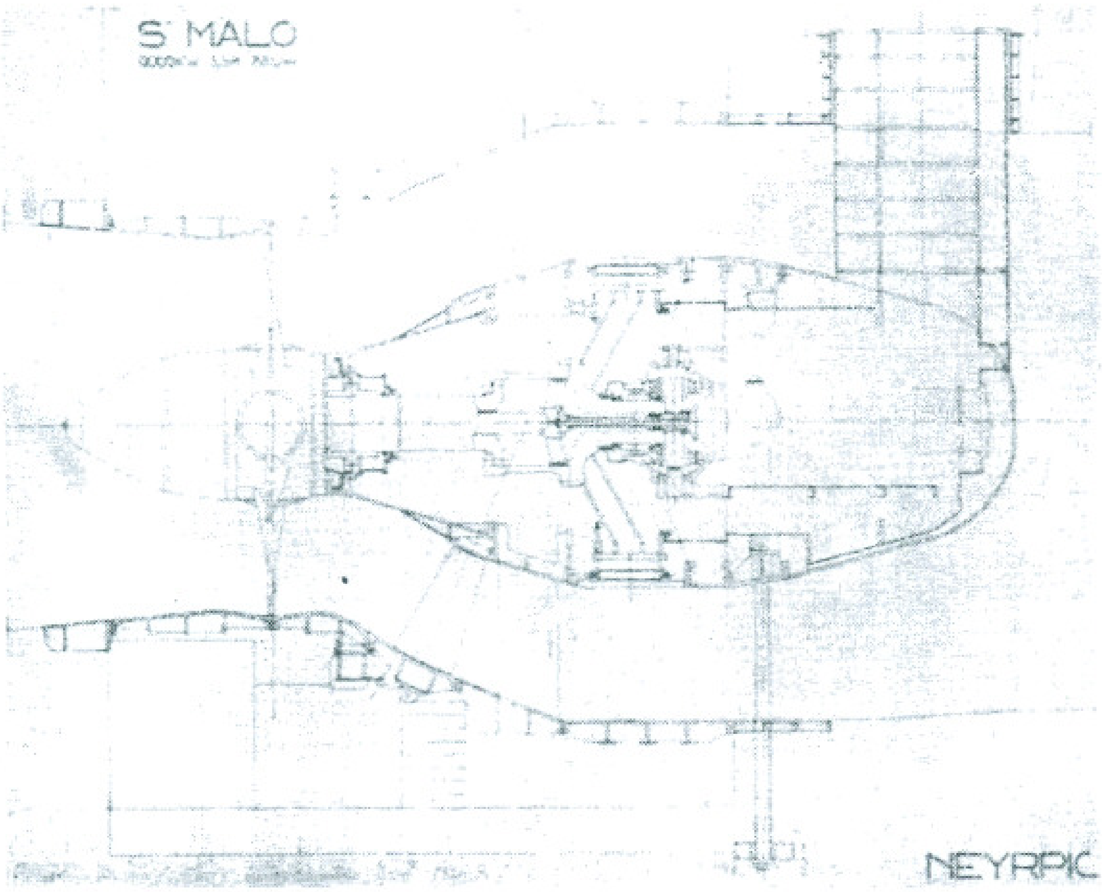


Fig. I

COMPARATIVE STRUCTURAL REQUIREMENTS FOR 3 KAPLAN UNITS AND 3 BULBS TURBINES OF EQUAL CAPACITY

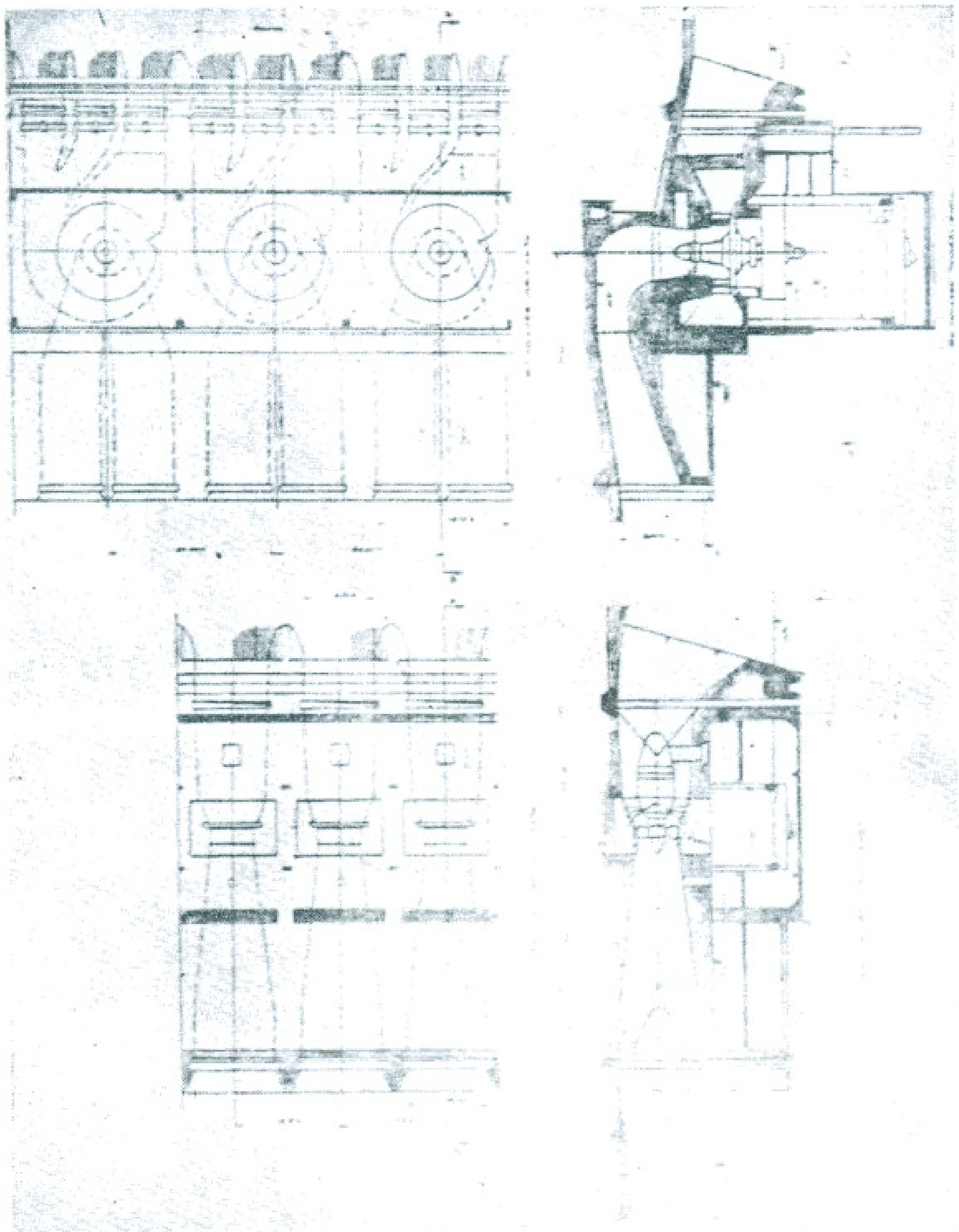


Fig. II

MICRO PLANT BASIC OPERATION SCHEME

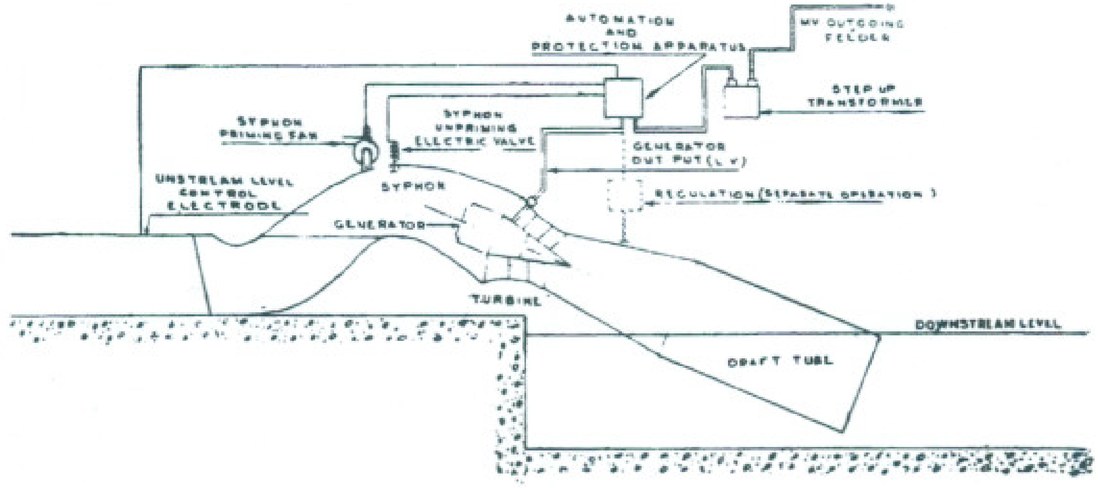


Fig. III

Fig. III (*a*)

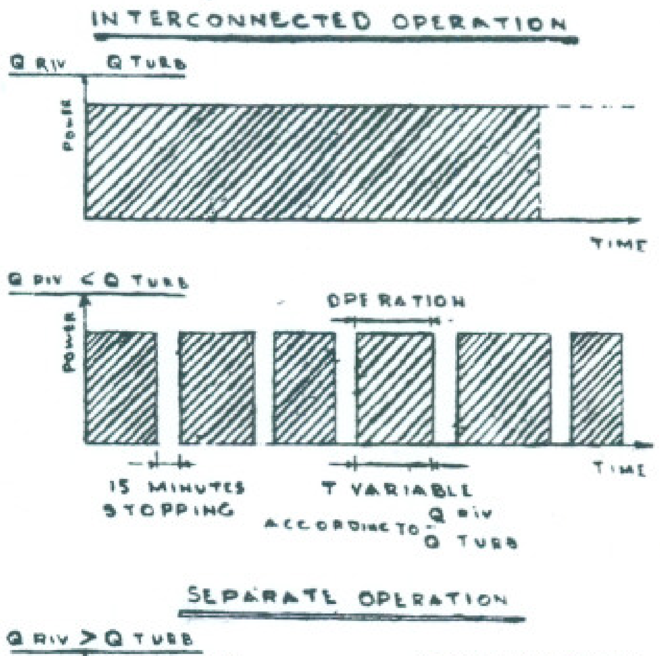
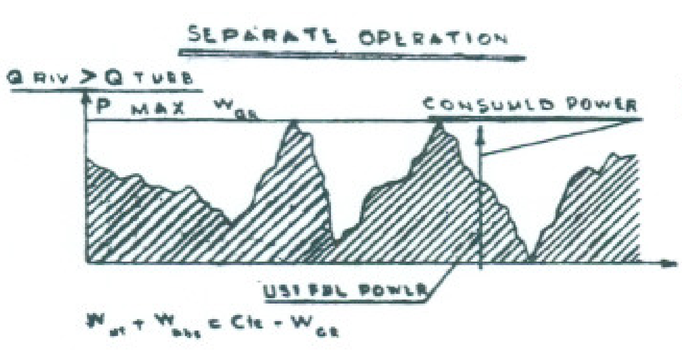


Fig. III (*b*)



LARANCE TIDAL POWER PLANT

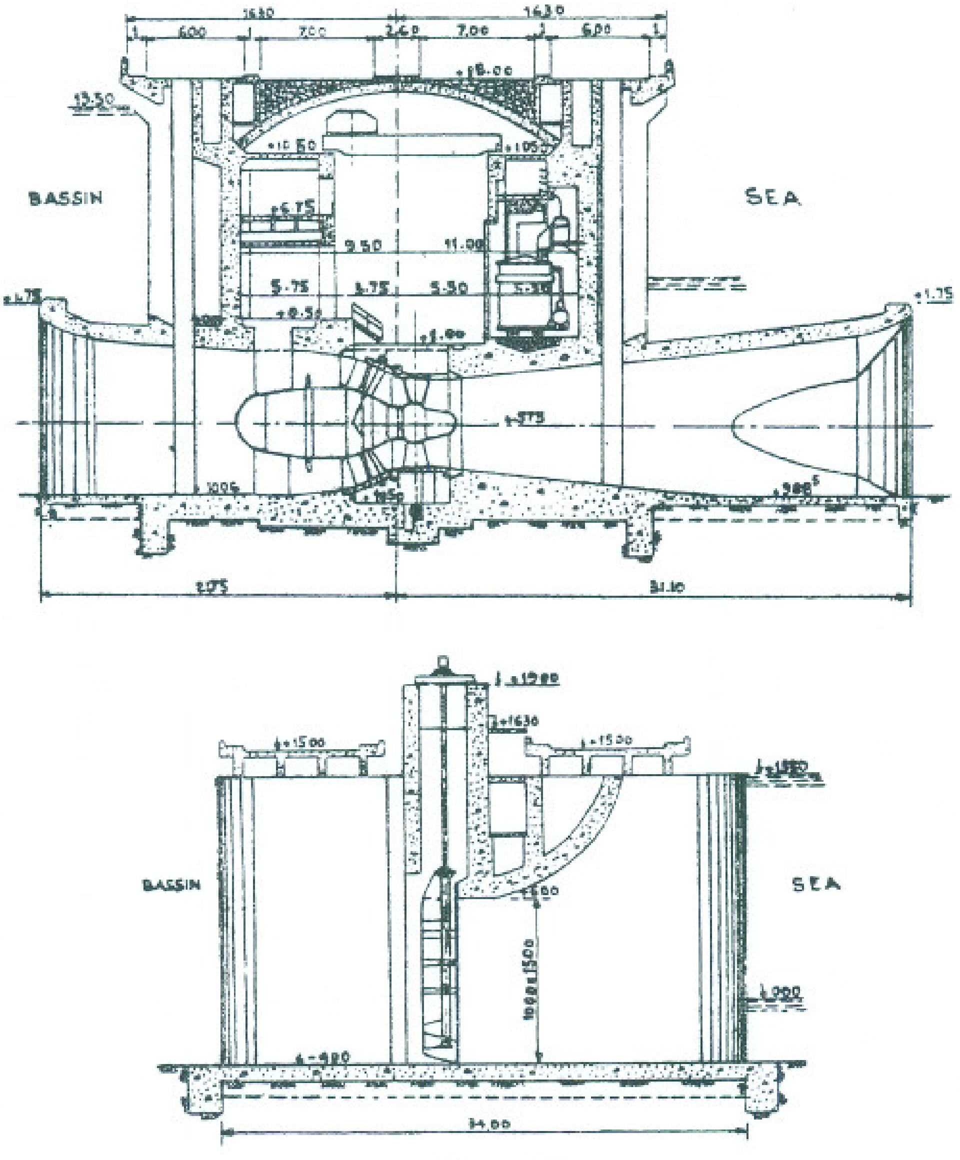


Fig. IV

TURBINE PUMP UNIT

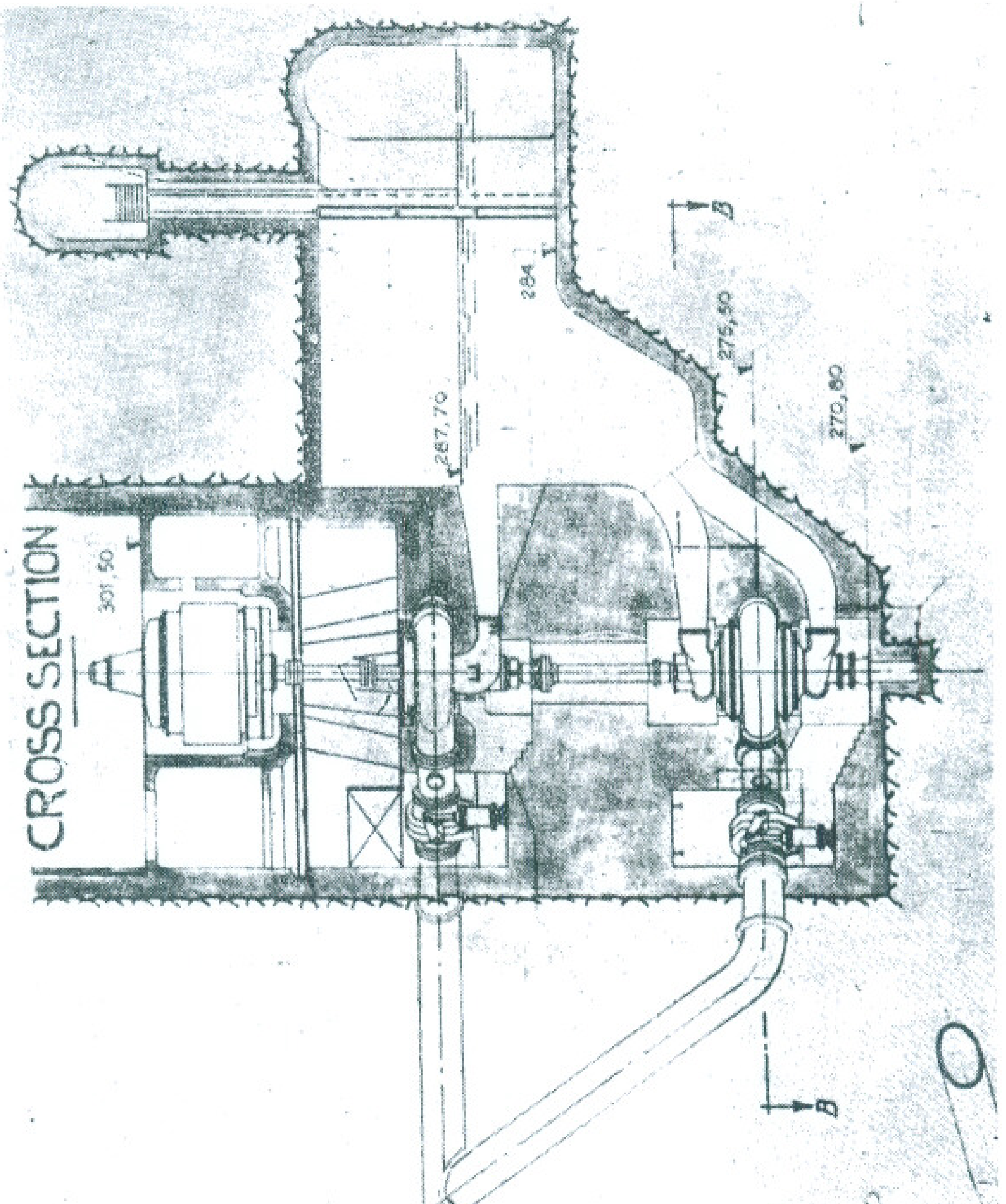


Fig. V

FOUR VERTICAL SHAFT FRANCES TURBINE OUTPUT 33100 K.W.

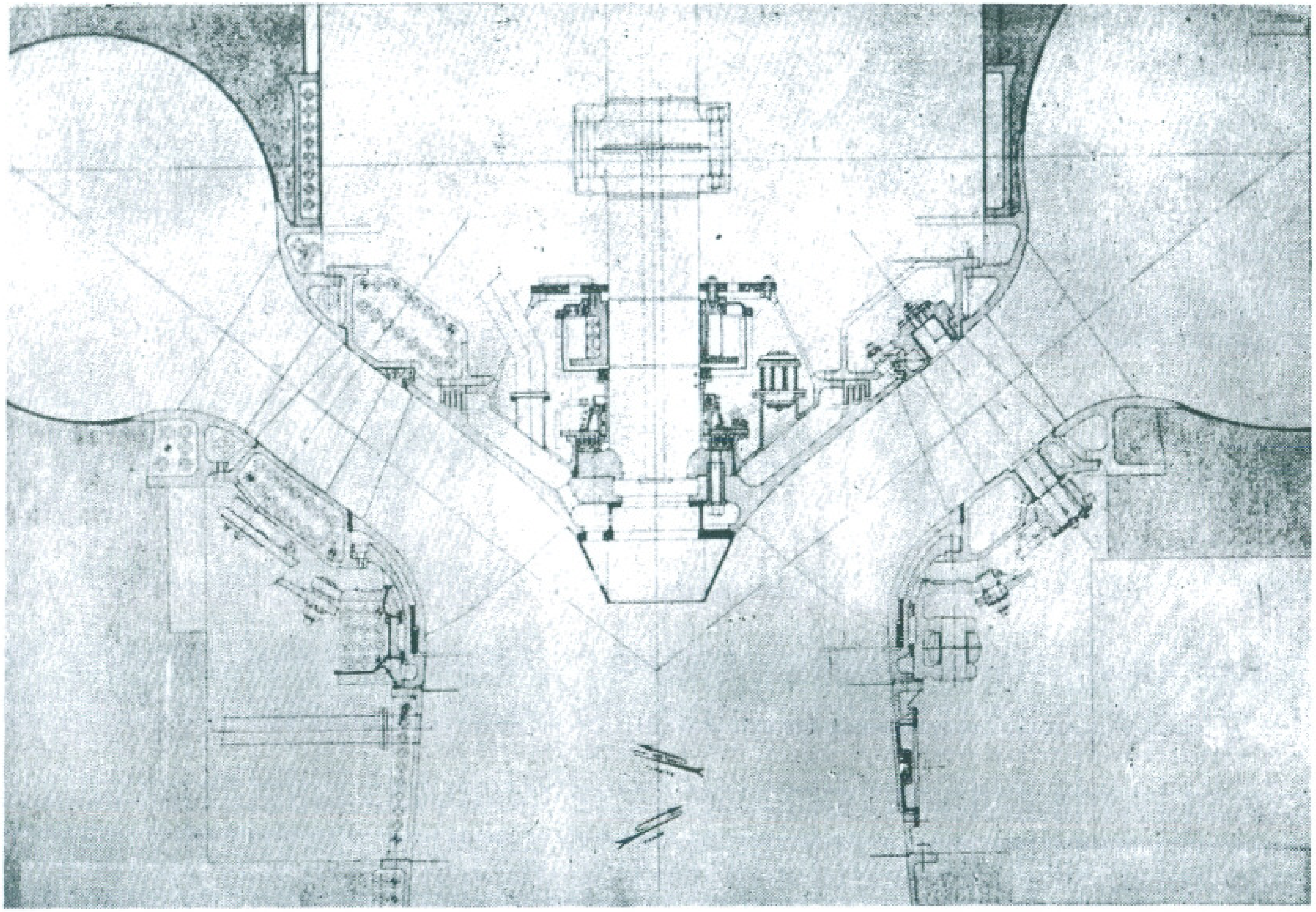
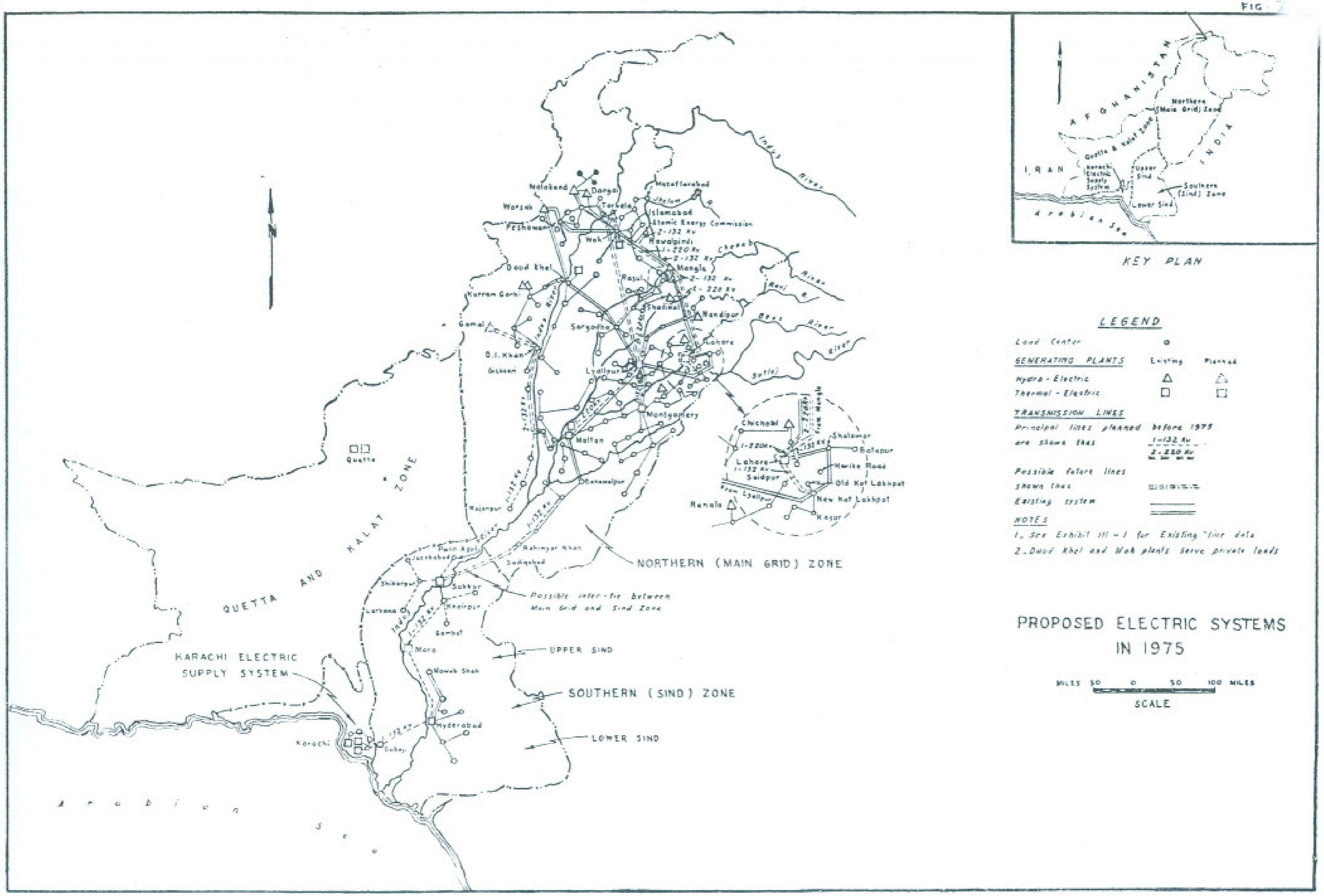


Fig. VI

FIG.



PROPOSED ELECTRIC SYSTEMS IN 1975