CHAPTER 10

CONSTRUCTION SCHEDULE AND WORK EXECUTION PLAN

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CHAPTER 10. CONSTRUCTION SCHEDULE AND WORK EXECUTION PLAN

10.1 Construction Schedule

10.1.1 General

Construction schedule for the Pilaya Hydro Power Project was studied on the condition that start of operation of the Project would be at the end of 1990 as described in Chapter 4, "Load Forecast."

Taking into consideration the present situation it is estimated that one and half (1.5) years for preparatory works and five and half (5.5) years for main works and installation of equipment and machinary are required, respectively. Therefore, the work must be started on access roads no later than January 1984, while it is planned for the main work to be commenced in May 1985.

In regard to various preparatory works and installation of facilities such as those for electric power for construction needed to start on the main works, they must all be completed by the beginning of 1985.

The construction schedule for this Project was set up as shown in Table 10-1.

10.1.2 Outlines of Annual Schedule of Works

(1) First Year of Construction (1984)

Work is to be started simultaneously on access roads to the dam site and the powerhouse site. Taking into consideration the period required for delivery of machinery needed to start the main works in May 1985, these access roads are to be opened to traffic by April, 1985.

(2) Second Year of Construction (1985)

The remainder of work on the access roads is to be performed, and after the rainy season has ended, diversion tunnel-related surface excavation work and installation of the tunnel boring machine (T. B. M. hereinafter called), and excavation by conventional method of the upstream portal of the headrace tunnel, the part downstream of the starting point of T. B. M., the tunnel at the base of the surge tank and the penstock tunnel portion is to be started.

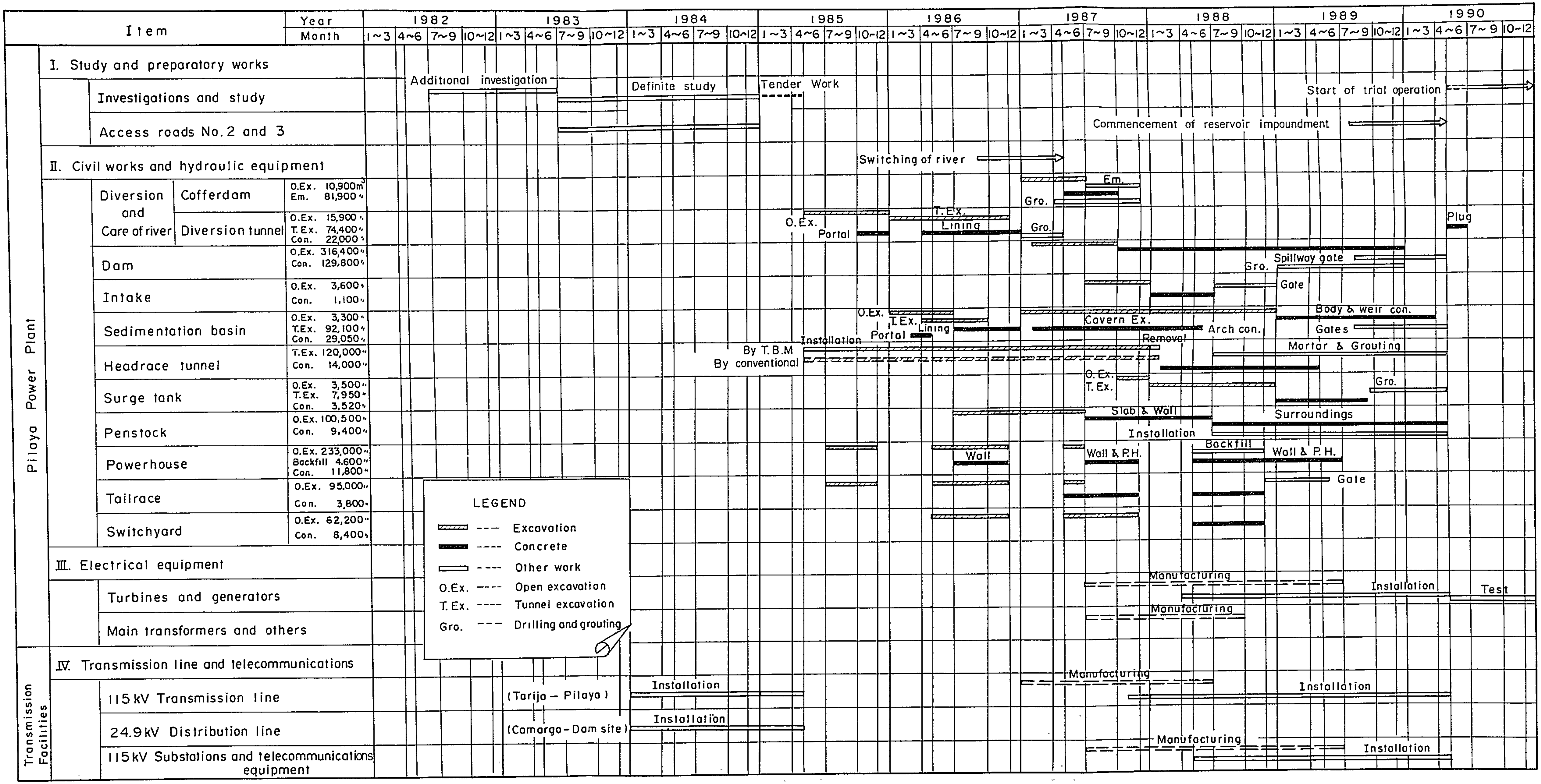
Excavation works for the powerhouse and the tailrace are to be carried out simultaneously.

All preparatory works accompanying the abovementioned works are to be completed by the end of April.

(3) Third Year of Construction (1986)

Diversion tunnel excavation and placing of lining concrete are to be carried

Table 10-1 Construction Schedule



out. Excavation of the sedimentation basin access tunnel, and placement of portal concrete and lining concrete are to be completed within the year to prepare for the underground cavern excavation.

Meanwhile, regarding the headrace tunnel work, conventional-type excavation from the upstream portal and excavation by T. B. M. from the downstream part will be continued, but since this work will be on the critical path, special care will be required with respect to construction schedule management.

During the dry season of this year, excavation works for the powerhouse and the tailrace are to be continued, besides which open excavation of the penstock route, placement of retaining wall concrete for the powerhouse, and open excavation of the switchyard are to be executed.

(4) Fourth Year of Construction (1987)

Diversion-tunnel grouting is to be performed, and river diversion is to be done at the beginning of May. Excavation of cofferdam river-bed portions is to be immediately started. Then, embankment and water cut-off grouting is to be performed. The cofferdam is to be completed at the end of November when the dry season ends. With regard to the dam work, excavation of the river bed is to be started in earnest after river diversion, and placement of dam concrete is to be commenced from October.

Open excavation for the intake work is to be started in the latter half of the year.

With respect to the sedimentation basin work, excavation of the arch portion of the river-side sedimentation basin and lining concrete, and part of similar work for the mountain-side sedimentation basin are to be carried out.

In headrace tunnel work, excavation of the T. B. M. section is to be completed, while the plan is for the stage of rough completion of excavation to be reached for sections by the conventional method.

The open excavation part of surge tank work is to be completed within the year. In penstock work, concrete is to be placed for retaining walls and slabs after completion of excavation.

Otherwise, work on the powerhouse, tailrace and switchyard are to be continued during the dry season.

(5) Fifth Year of Construction (1988)

In addition to dam concrete being placed, it is planned for intake concrete to be placed and the intake gate to be installed, while the remainder of the arch portion of the mountain-side sedimentation basin and excavation of the basin body part is to be completed.

In headrace tunnel work, from the end of January when removal of the T.B.M. and excavation of the section by the conventional method are to be completed, lining concrete placement at parts judged necessary are to be completed by the end of the year.

In surge tank work, excavation of the vertical shaft portion is to be completed within the year.

In penstock work, installation of steel pipes is to be started from the end of June when concreting work is to be completed.

Other than the above, it is scheduled for building construction and concrete work to be mainly done out of the works for the powerhouse, tailrace and switchyard.

(6) Sixth Year of Construction (1989)

All of the dam concrete is to be placed by the end of the year, and installation of spillway gates is to be started from August. The whole year is to be taken as a period for carrying out curtain grouting.

In sedimentation basin work, it is scheduled for concrete placement and installation of gates and the like to be started.

In headrace tunnel work, mortar injection and grouting are to be performed at parts where necessary, while in surge tank work lining concrete placement and grouting are to be carried out.

At the powerhouse, all civil engineering and architectural works are to be completed by the end of June, while in tailrace works gate installation is to be done.

(7) Seventh Year of Construction (1990)

All civil works and installation of gates and the like are to be completed by the end of April, and diversion-tunnel plugging is to be done.

As for installation of power generating equipment which was started in April 1988, the first unit is to be completed at the end of April when other works are to be finished and trial operation is to be started after water impoundment, while for the two units following, installation and trial operation are planned to be done one after another by the end of 1990.

Equipment such as transformers, transmission lines, telecommunication facilities, etc. must all be installed by the end of April also to be in time for the trial operation.

It will be possible for commercial operation to be started from the end of 1990 through the above schedule.

10.1.3 Critical Path and Construction Method

The critical path of this Project is the work of the headrace tunnel which will be as much as 10.4 km in length. The comparison of a conventional method and a method using T.B.M. is as follows:

	Velocity	Period
By conventional method	80 m/month	130 months
By T.B.M.	300 m/month	35 months

Consequently, for early start of operation the use of T. B. M. will be indispensable.

In order to excavate the headrace tunnel in a short period of time, and economically as well, it is desirable for approximately 8 km from the downstream portal to be driven by T. B. M. and approximately 2 km from the upstream portal by a conventional method, and thereby, it will be possible to complete the works simultaneously in 33 months, including time for installation and removal of the T. B. M.

10.2 Work Execution Plan

10.2.1 Temporary Facilities for Construction

With regard to temporary facilities for construction, types, sizes, etc. would be determined by siting conditions, the scales of structures, the construction schedule, topographic and geologic conditions, etc. The outlines of the principal facilities were set forth as shown in Fig. 10-1-(1) and Fig. 10-1-(2).

(1) Electricity Supplement for Construction

It is estimated that electric power required in construction of Pilaya Power Plant will be approximately 2,700 kW. The breakdown is as follows:

- Dam site side (including sedimentation basis, headrace tunnel upstream section) 1,200 kW
- Headrace (T. B. M. section only, supplied from powerhouse site side) 800 kW
- Powerhouse site side (excluding above but including penstocks) 700 kW

For the purpose of supplying this electric power a 115 kV transmission line is to be constructed by the end of April, 1985 from Tarija to the powerhouse site in advance of the main works, and electric power is to be received from the existing Villa Abaroa Diesel Power Plant (5,500 kW) and San Jacinto Hydro Power Plant (7,000 kW) now under construction. For supply of electric power to the dam site, a 24.9 kV distribution line is to be constructed from Camargo to the dam site via Culpina, and electric power is to be received from Camargo Diesel Power Plant presently planned by ENDE for construction as a link in its rural electrification program.

The above-mentioned 115 kV transmission line and 24.9 kV distribution line are to be respectively utilized upon completion of Pilaya Power Plant as a transmission line for supplying electric power to Tarija and as a power supply line for dam gates, illumination, etc.

Provision of diesel power generating facilities at the dam and powerhouse sites for securing the electricity supplement for construction was made the object of a comparison study, but because there is no suitable location at the dam site for installing diesel facilities, and there would be considerable difficulty in transportation of diesel fuel oil in view of road conditions, it was decided that the 29.4 kV distribution line should be provided. Meanwhile,

Fig. 10-1 (1) Temporary Facilities

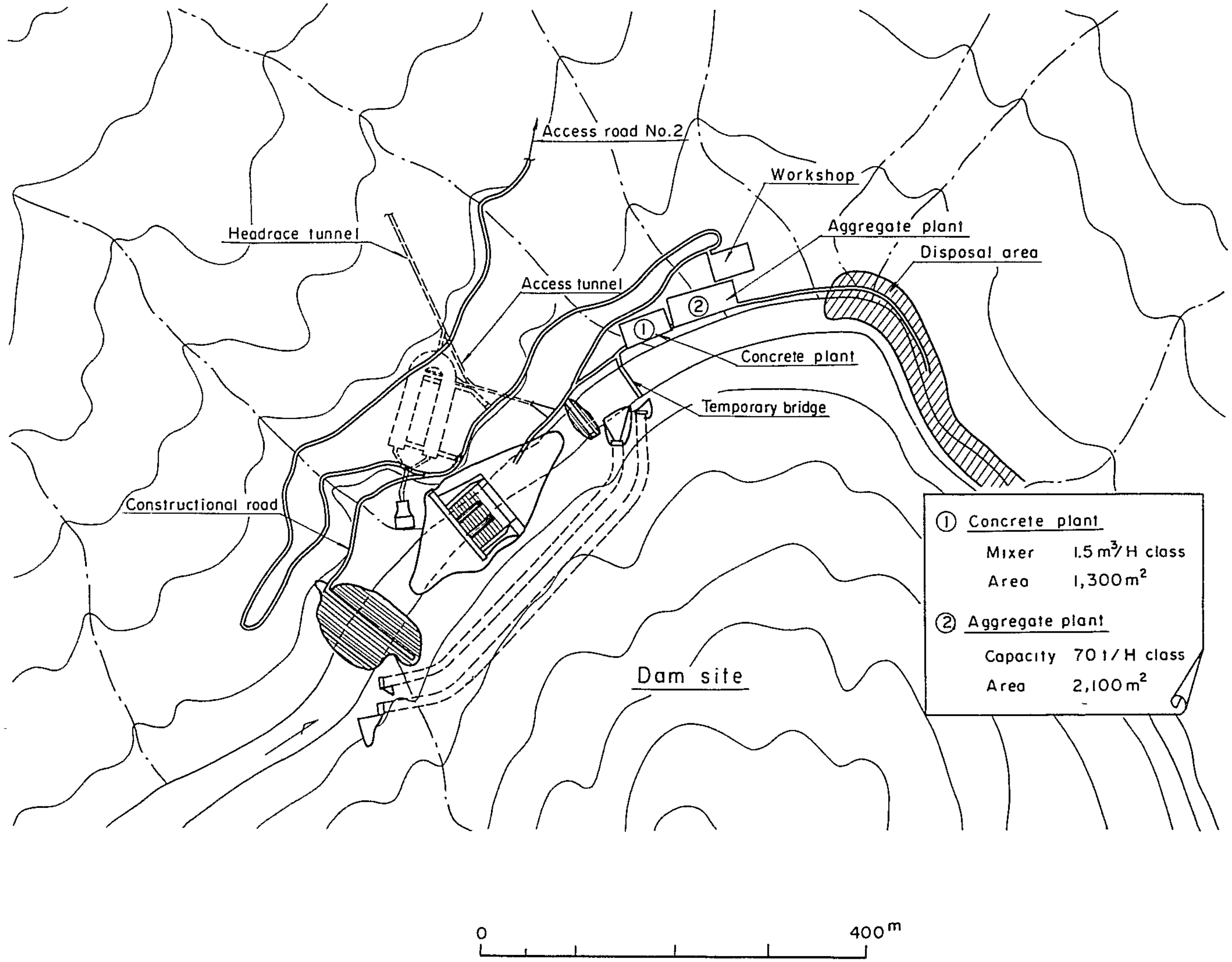
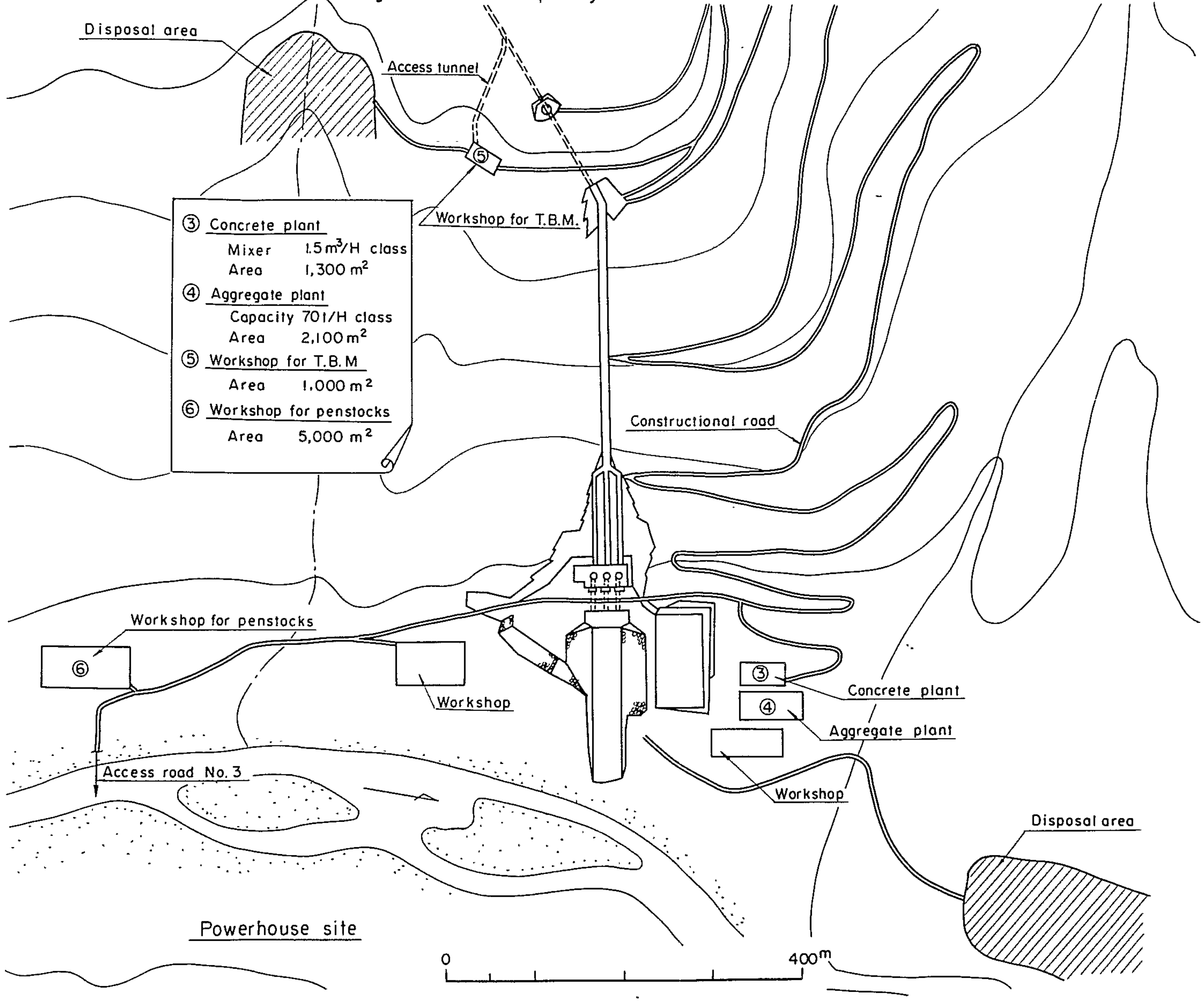


Fig. 10-1(2) Temporary Facilities



with regard to supply of electric power to the powerhouse site, there will be a fair amount of surplus capacity at the power plant in Tarija, and since the T. B. M. method demanding reliability in power supply is to be adopted, it was decided that the 115 kV transmission line should be constructed.

(2) Concrete Facilities

Concrete aggregates are planned to be manufactured and supplied by aggregate plants to be provided at the left bank downstream of the dam and the vicinity of the switchyard. The raw materials for aggregates are to be obtained chiefly utilizing excavation muck from the river bed, sedimentation basin sites and powerhouse site, and by collection from the river bed.

It is planned for concrete to be supplied to the various work sites using truck mixers and dump trucks, providing one concrete plant at the dam site and at the powerhouse site respectively.

(3) Compressed Air Supply Facilities

Stationary and portable air compressors are to be used in combination for supply of compressed air needed for construction. Stationary types of the necessary capacities are to be installed at the portal of each tunnel, while portable types are to be used at other work sites.

(4) Water Supply Facilities

For the dam site the plan is to be for all of the work sites to be supplied with water pumped from the gully (Quebrada Pura Loma) at the left bank 400 m downstream from the dam site. On the powerhouse side, water is to be drawn from a check dam to be constructed on the Rio Agua Caliente and sent to the various work sites.

(5) Temporary Buildings

The construction office of ENDE, and besides, the contractor's office, staff quarters, laborer's quarters, etc. are to be provided at the upstream village of El Monte in connection with the dam site, while for the powerhouse side, such buildings are to be provided in the vicinity of a community situated approximately 10 km from the powerhouse site along the access road.

(6) Disposal Areas

Excavation muck from various work sites except that for aggregate material for concrete is to be disposed as follows:

i) Dam Site

Disposal area for excavation muck cannot be secured sufficiently around the dam site for the topographic aspect of steep valley.

Consequently, it is assumed that excavation muck should be disposed in riverside or steam bed downstream of dam site, but stream of river must not be obstructed by the disposal.

ii) Powerhouse Site

Excavation muck out of the headrace tunnel (the part of driven by T.B.M.), surge tank and other part should be mainly disposed in disposal areas shown on Fig. 10-1-(1),(2).

(7) Others

Lots can be easily developed for the steel pipe and other workshops and there will be no problems in particular.

10.2.2 Construction of Principal Structures

(1) Construction of Dam

i) Excavation for Dam

Firstly, diversion tunnels are to be provided at the right bank of the Rio Pilaya and the flow of the river is to be diverted. Although water cut-off grouting is to be performed in order to alleviate seepage through the river-bed sand-gravel below the cofferdam, since the soil property is of high permeability, it is thought necessary for arrangements making it possible for pumps to be operated at any time at the excavation site for the dam.

Since topography of the dam excavation site is cramped for space, and moreover, foundation rock is deep, excavation and transportation of muck, down to the level that could be reached by dump trucks will be done with heavy equipment such as 30 to 40 ton class bulldozers, 4.5 m^3 level-load wheel loaders, and 32 ton dump trucks, while below this level a crane system or an incline system is to be used for hauling muck up after which the muck is to be re-loaded on to dump trucks.

ii) Dam Concrete

Dam concrete is to be supplied at the mixing and butching plant (concrete plant) installed at the left bank downstream of the dam with the buckets loaded on dumptrucks, then transported and placed at the specified locations hoisting the buckets by a climbing crane to be within the limits of the swivelling radius of the crane, and placement outside this area is to be by concrete pump.

The outline of the climbing crane and the approximate area to be placed with it are as shown in Fig. 10-2 and Fig. 10-3.

It will be possible for 129,800 m^3 of concrete placement to be done in 27 months by means of the method described above. (Average, 250 m^3/day; maximum, 500 m^3/day).

Fig.10-2 CLIMBING CRANE

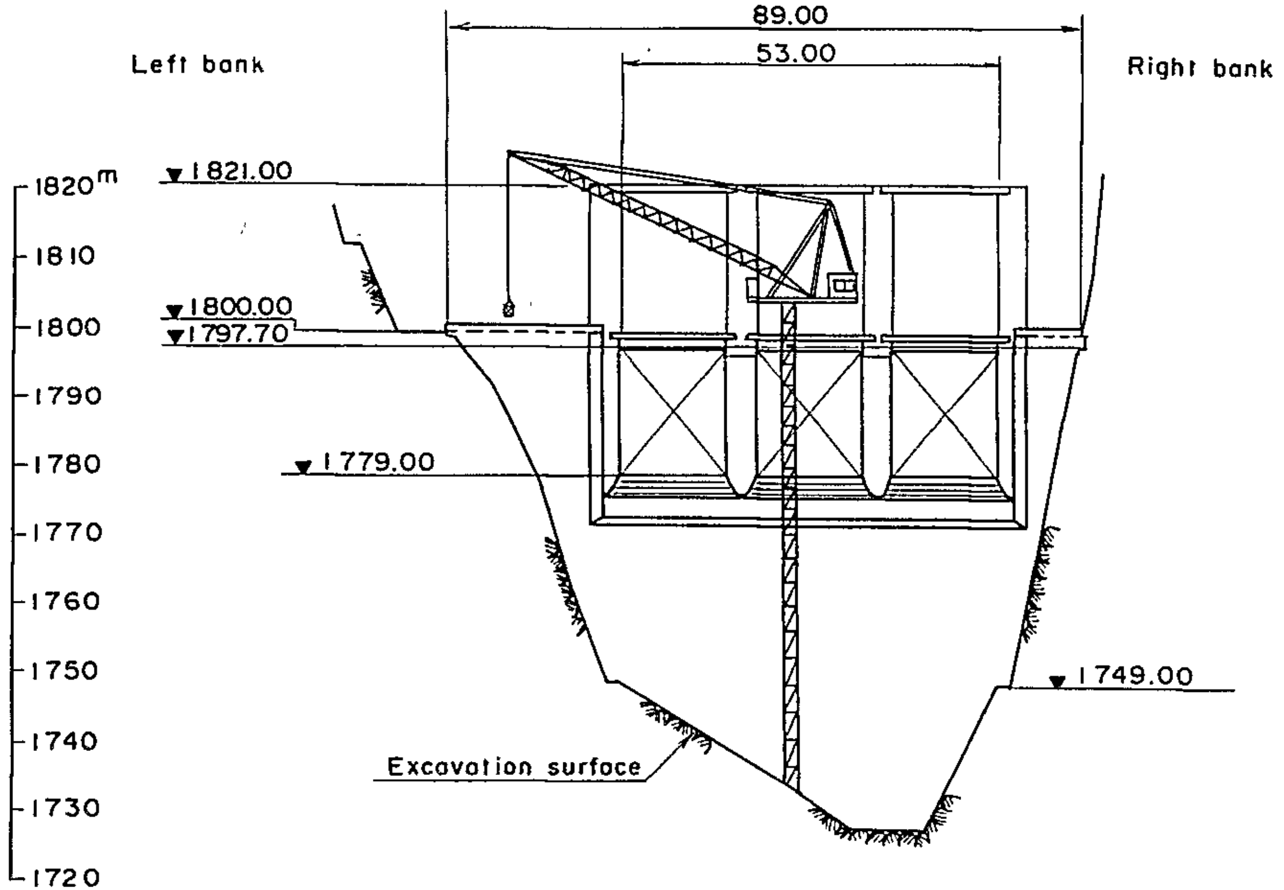
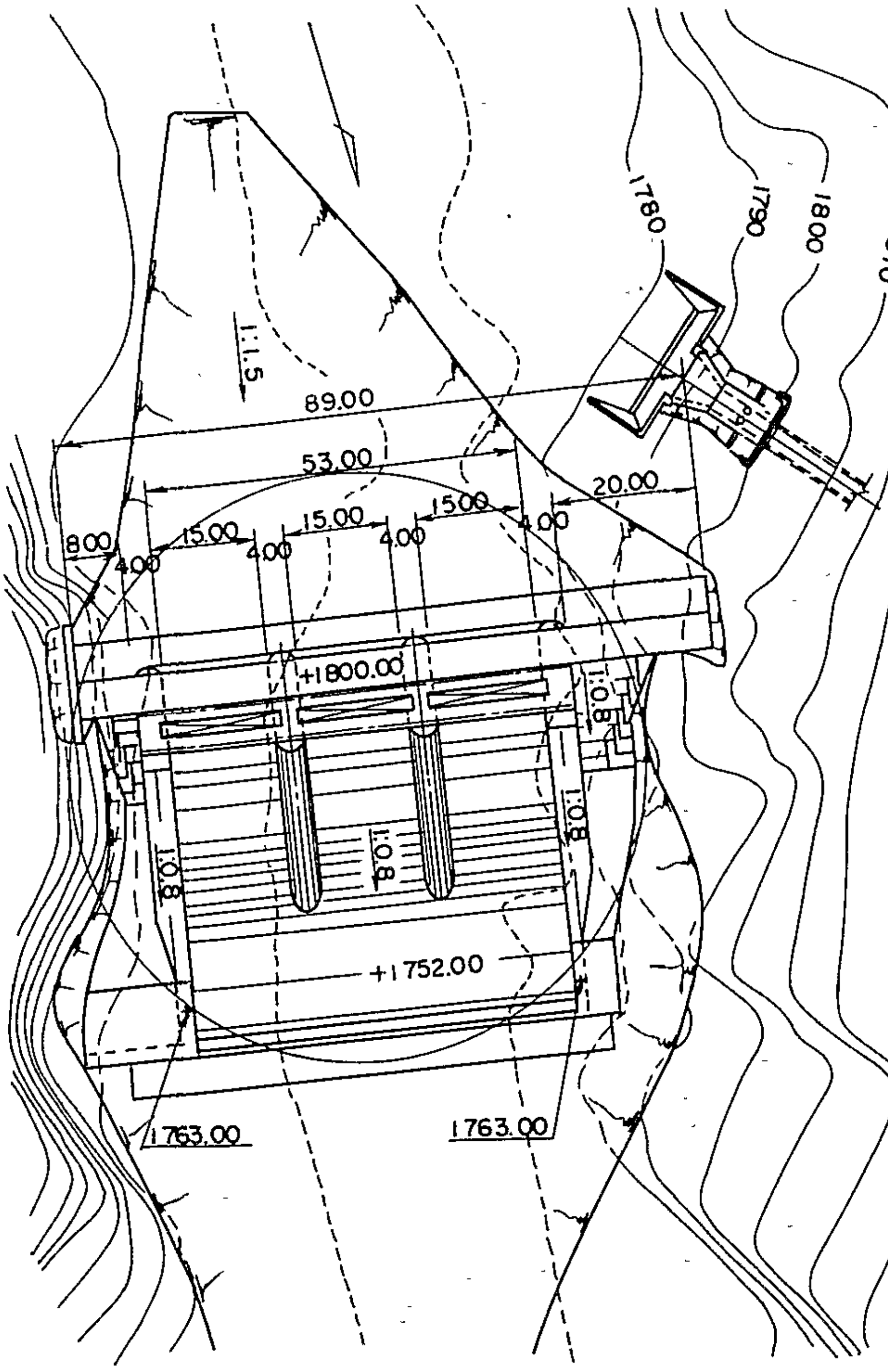
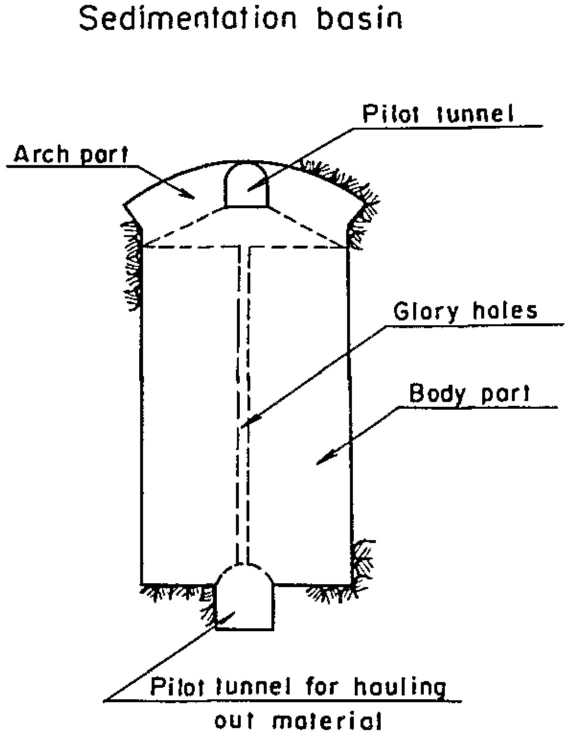


Fig. 10-3 CONCRETE PLACEMENT AREA BY CLIMBING CRANE



(2) Construction of Sedimentation Basins

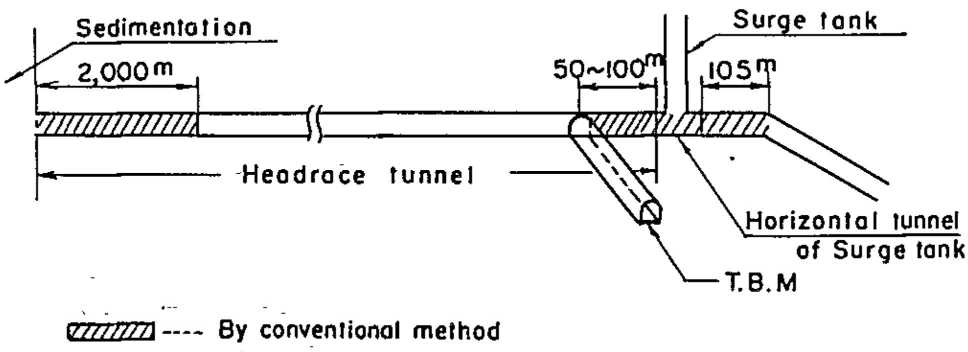
As shown in the drawing at the right, a pilot tunnel is first driven through and arch lining concrete is placed while successively enlarging the pilot tunnel. The above procedure is to be taken in order from the sedimentation basin on the river side to the sedimentation basin on the mountain side.



Next, in order to maintain stable stress conditions of the surrounding bedrock of the cavern during excavation, the cutting down of the bed is to be simultaneous for the riverside and mountain-side sedimentation basins. Excavation muck produced in cutting down is to be dropped into glory holes provided in advance, and this muck is to be transported utilizing the pilot tunnels for hauling out material.

After completion of excavation, placement of concrete of side walls, etc. is to be performed.

(3) Construction of Headrace Tunnel



The drawing above explains the methods of excavation for the headrace tunnel, surge tank and the tunnel section of penstocks.

The approximately 2 km from the upstream portal of the headrace tunnel mentioned in 10.1.3, "Critical Path and Construction Method," and the section from the T.B.M. delivery tunnel to the surge tank are to be constructed by a conventional method, and the approximately 8 km in between by T.B.M. In addition, the horizontal tunnel of the surge tank and the tunnel section of penstocks are also to be constructed by the conventional method in succession to the bottom end of the headrace tunnel.

i) Conventional Method

Excavation is planned to be entirely mechanized, with mucking done by the rail method. It is expected that full-face excavation can be adopted for all sections.

ii) Excavation by T. B. M.

Prior to excavation, a lot as workshop must be prepared outside the delivery tunnel for temporary facilities required in assembly of the T. B. M. which will have been transported to the site split into sections, as well as a start-out tunnel ($\angle \doteqdot 10$ m) at the delivery tunnel connection for installation of the T. B. M. proper.

Excavation by T.B.M. is performed supporting the machine by grippers and causing the cutterhead to advance by oil hydraulic pressure cylinders. After excavation of 1.1 m corresponding to a standard stroke, the grippers are moved to the cutterhead sides and the posture is controlled by laser beams, and this pattern is repeated for excavation while supports are provided the excavated bore. Mucking is done by rail with a train conveyor provided at the rear of the T. B.M. The muck from one stroke is hauled outside by one train consisting of four 6 m^3 steel cars pulled by a 10 ton battery locomotive. Extensions of rail tracks, piping, air supply, water supply, drainage, ventilation and illumination facilities, and communication lines are made after approximately every five strokes. After an advance has been made to a point approximately 200 m distant, the power transformer cable is taken up by a cable drum loaded on the transformer platform car and a separate transformer cable is laid.

Supports are to be provided by shotcrete, rock bolts, laths, etc. as necessary.

The excavation capacity will be greatly affected by the characteristics of the rock, with the principal factors being the unconfined compressive strength and tensile strength of the rock, the densities and directions of cracks and joints in the rock, substances contained, and concentrations of materials aggravating wear such as quartz. Therefore, in setting the cutting capacity, it is necessary to thoroughly investigate and analyze these factors, and appropriately determine the capacity through experiments and so on. Here, it can be estimated that an advance in excavation of 300 m per month can be achieved.

An outline drawing of a tunnel boring machine is shown in Fig. 10-4.

Fig. 10-4 Outline of

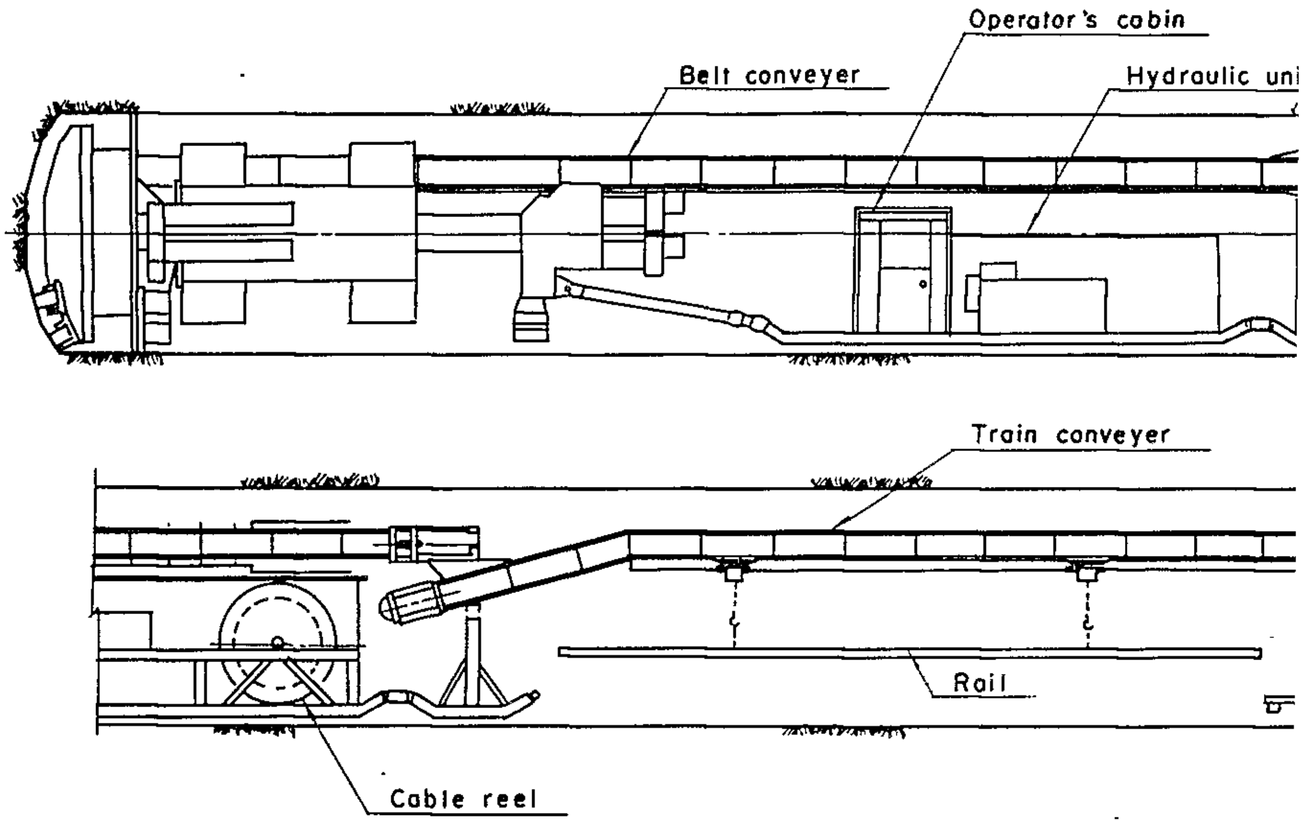
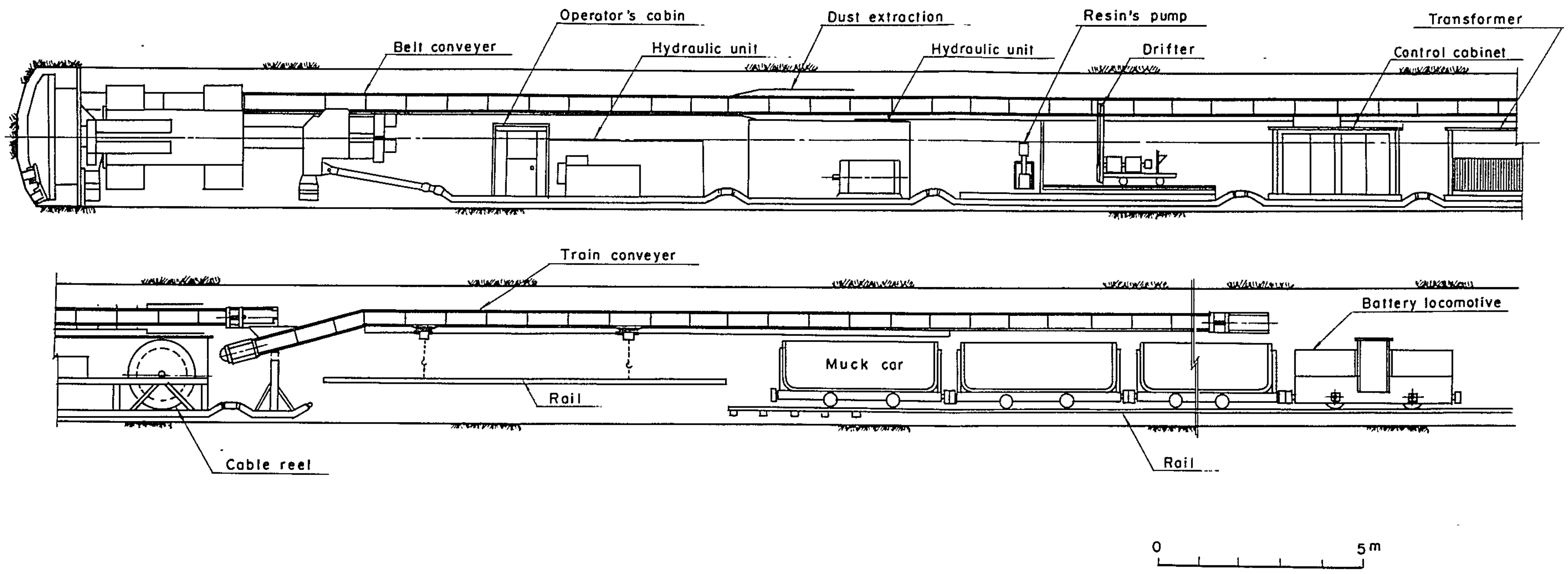


Fig. 10-4 Outline of T. B.M. (Tunnel Boring Machine)



CHAPTER 11

CONSTRUCTION COST

CHAPTER 11 CONSTRUCTION COST

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CHAPTER 11. CONSTRUCTION COST

11.1 Basic Conditions

11.1.1 General

In estimating the construction cost of this Project, the natural conditions of the project site, the regional conditions, the project scale and the present engineering level which can be expected were taken into consideration, and computations were made based on commodity prices as of December 1981.

In the construction cost, the expenses required for items which can be procured domestically in Bolivia were calculated under domestic currency requirements and all other items under foreign currency requirements.

11.1.2 Scope of Construction Cost Estimation and Electric Power Facilities

The scope of construction cost calculation covers access roads, Pilaya Power Station, related substations and a 115 kV transmission line. These power generating, transmitting and transforming facilities comprise the following:

a) Pilaya Power Generating Facilities
Dam and intake
Sedimentation basins, headrace tunnel and penstocks
Powerhouse and switchyard
Access roads and temporary facilities

b) 115 kV Transmission Line and 24.9 kV Distribution Line

115 kV Transmission Line	
Pilaya-Camargo	65 km
Camargo-Potosi	170 km
Camargo-Telamayu	115 km
Pilaya-Tarija	60 km
Potosi-Camargo	187 km (allocated part)
24.9 kV Distribution Line	
Camargo-Culpina-Dam Site	85 km

c) Transformation Facilities

Camargo Substation	
115 kV circuits	4
Main transformer capacity	5,000 kVA, 1 unit
Tarija Substation	
115 kV circuit	1
Main transformer capacity	10,000 kVA, 1 unit

d) Telecommunication Facilities

Pilaya Terminal Station	PLC and VHF
Camargo Terminal Station	Ditto
Tarija Terminal Station	Ditto
Telamayu Terminal Station	Ditto
ENDE Head Office	MHF

11.2 Construction Cost

11.2.1 Civil Works Cost

(1) Work quantities were calculated based on the design drawings annexed to Chapter 7, "Hydroelectric Power Generation Plan." The quantities of the principal works according to the item of works are shown in Table 10-1, "Construction Schedule."

(2) Of the reference unit prices, for those concerning materials and labor which can be procured in Bolivia and can be paid for with domestic currency, the values indicated in "Investigation of Data for Cost Estimation," submitted by ENDE were adopted.

As to the materials and equipment to be imported, those CIF prices have been estimated based on internationally competive FOB prices in Japan additioning the ocean freight and insurance.

The principal basic prices adopted are shown in Table 11-1.

(3) The unit construction costs are based on the above basic unit prices, and were calculated in accordance with the previously-mentioned construction schedule and work execution plan taking into consideration the regional and topographical conditions of the Pilaya site.

The principal unit construction prices are shown in Table 11-2.

Furthermore, it is assumed that principal gates and the like and penstocks will be manufactured abroad and supplied, and the costs of these were calculated including transportation to the field, all expenses concerned, and the costs of assembly and installation in the field.

T. B. M. is also planned to be imported, and all expenses are to be included in unit construction costs.

11.2.2 Electrical Works Costs

It was assumed that the principal equipment and materials (turbines, generators, main transformers, outdoor switchgear, steel towers, conductors, insulators, and telecommunications equipment) are all to be manufactured overseas and supplied, and the costs of such imported equipment requiring foreign currency were calculated as CIF prices based on internationally competitive FOB prices in Japan to which ocean freight and insurance were added. These were all calculated as foreign currency requirements.

All materials and equipment imported from Japan are to be landed at the port of Matarani in Peru, and then are to be transported approximately 1,700 km to the Pilaya project site by truck and by 40 ton trailer, and the cost of this overland transportation was calculated in the domestic currency requirement. Regarding the cost of the installation work, it was computed referring to past construction performances, and it was considered that all of the transmission line work would be covered with domestic currency, while power generating and transforming equipment were listed divided into foreign and domestic currency requirements.

Table 11-1 Adopted basic unit costs

Unit : US$

Item	Unit	Unit cost	Currency		Remarks
Labor cost					
Senior foreman	manth	10,000	F.C.	Included various bonifications	
Forman	day	32	D.C.	"	
Operator (A)	"	28	"	"	Heavy equipment
" (B)	"	22	"	"	Light equipment
Mechanician	"	28	"	"	
Carpenter	"	16	"	"	
Labor	"	8	"	"	
Driller	"	18	"	"	
Grout man	"	20	"	"	
Material cost					
Cement	pcs	6	D.C.	Included transportation cost	1 sack = 50 kg
Reinforcing bar	t	680	F.C.	"	
Gasoline	kl	240	D.C.	"	
Light oil	kl	240	"	"	
Steel	t	800	F.C.	"	
Dynamite	kg	2.7	"	"	

Table 11-2 Principal construction unit prices

Unit : US$

Item	Unit	F.C.	D.C.	Total
Open common excavation				
Dam	m^3	3.5	2.6	6.1
Powerhouse	"	2.8	2.0	4.8
Open rock excavation				
Dam	m^3	6.4	5.2	11.6
Tunnel excavation				
Sedimentation basin	m^3	55.2	37.0	92.2
Headrace tunnel (by conventional method)	"	61.6	71.4	133.0
" " (by T. B. M.)	"	113.6	90.9	204.5
Concrete				
Dam (Mass concrete)	m^3	52.3	50.0	102.3
" (Pier portion)	"	50.0	86.4	136.4
Sedimentation basin	"	44.1	85.5	129.6
Lining of headrace tunnel	"	75.0	95.5	170.5
Reinforcement	t	1,051	408	1,459
Boring				
Rotary type	m	51.8	36.8	88.6
Down the hole type	m	21.5	15.4	36.9
Grouting Case of Cement = 100 kg/m	t	263.6	486.4	750.0
Hydraulic equipment				
Spillway gates	t	4,320	1,130	5,450
Penstocks	"	2,270	1,130	3,400

11.2.3 Preparatory Works Costs

In order to secure the construction period of the main project, it is imperative that access roads be constructed at the dam site and the powerhouse site. Also, it will be necessary to have quarters and construction offices of ENDE and the Consultant's engineers provided in the vicinity of the project site. The construction costs of these have all been listed up as domestic currency requirements.

Further, in order to secure electric power supply for construction during the construction period, a 115 kV transmission line of 60 km between the powerhouse site and Tarija, and similarly, an 85 km long 24.9 kV distribution line between the construction site and Camargo to be used for power supply to the dam, are to be constructed in advance of the main project. (These construction costs are all estimated as being within the scope of the main project.)

11.2.4 Contingency Costs

As contingency costs, 5 % was considered for the foreign currency portion consisting of materials, equipment and services to be imported from overseas, while 10 % was considered for the domestic currency portion for inland transportation and installation.

11.2.5 Engineering Fee of Consultant and Cost of Administration by ENDE

With regard to engineering and administrative costs, the expenses required for definite design (DS) and work supervision (SV) to be carried out by a foreign consultant in the future were calculated under the foreign currency requirement, and the cost required for management of the construction work by ENDE under the domestic currency requirement.

11.2.6 Interest During Construction

For interest on the funds required for construction of this Project, rates of 3.5 %/yr on the foreign currency portion and 12.0 %/yr on the domestic currency portion were calculated.

11.2.7 Escalation of Construction Costs

Ever since the oil crisis of 1973 commodity prices have consistently been on an upward trend, and in the case of this Project with its long construction period the construction cost estimated based on present prices will become insufficient. Inflation can be seen in all countries of the free world, and escalation in oil prices having a close relation with commodity prices is thought to be unavoidable over the long term.

According to "Statistical Yearbook 1978" published by the United Nations, the trends in prices of industrial products in the world from 1970 to 1977 were as follows:

Industrial Products Wholesale Price Indices (1970 = 100)

	1977 Index	Annual Average Escalation Rate
Japan	159	6.8 %
U.S.A.	164	7.3 %
France	170	7.9 %
West Germany	144	5.3 %
Average	159	6.8 %

Source: Statistical Yearbook 1978, United Nations

Meanwhile, the consumer price indices in Bolivia are as shown below.

1980 Consumer Price Indices (1966 = 100)

	1980 Index	Annual Average
Overall	698.6	14.9 %
Foodstuffs	611.5	13.8 %
Housing	542.5	12.8 %
Clothing	607.2	13.8 %
Others	540.9	12.8 %

Source: Boletin Estadistico No.240
Banco Central de Bolivia, Dicember 1980

The rate of inflation in Bolivia is relatively low compared with other Latin American countries, but the rises in commodity prices in 1980 and 1981 were marked and reached annual averages of 20%.

In view of the above, in estimation of the construction cost for this Project, the escalation factors below are considered by year against the construction cost in December 1981.

Estimated Escalation Factor per Year

Year	Foreign Currency (%)	Domestic Currency (%)
1981	-	-
1982	7.0	15.0
1983	7.0	15.0
1984	7.0	12.0
1985	7.0	12.0
1986	6.0	10.0
1987	6.0	10.0
1988	6.0	10.0
1989	5.0	10.0
1990	5.0	10.0

Further, the report of the World Bank of March 1975 contains a prediction of inflation rates from 1979 to 1987 according to which it is suggested that annual escalation rates of 8 to 7% for machinery and 12 to 10% for civil works be applied.

11.3 Total Construction Cost and Construction Cost by Year

The construction cost as of December 1981 obtained based on the construction schedule, work execution plans, and conditions for construction cost estimation is US$279,295,000 of which the foreign currency portion is US$133,826,000 and the domestic currency portion US$145,469,000.

The construction period of the main works of this Project is to be 5.5 years, and if the 1.5 year period for preparatory works is added, the entire construction period will be 7 years, and estimating the payment terms for the foreign and domestic currency portions to be as indicated below, the abovementioned total construction cost was allocated by year. (Refer to Table 11-3.)

Foreign Currency Portion

	At Award of Contract	FOB	Installation Completed	Work Completed
- Transmission line materials	30 %	30 %	30 %	10 %
- Power generating, transforming equipment, telecommunications equipment	30 %	30 %	30 %	10 %

cont.

	At Award of Contract	FOB	Installation Completed	Work Completed
- Hydraulic equipment, (Gates, Penstocks, etc.)	30 %	30 %	30 %	10 %
- Constructional equipment to be imported*	Work accomplished basis			
- Imported materials	"			
- Domestic Currency Portion	"			
- Domestic Materials and labor	"			

*Note : Assuming that the constructional equipment be imported on the Contractor's own responsibility.

The total amount of indirect costs consisting of contingency costs, engineering fee of the Consultant, administrative expenses of ENDE, and interest during construction will be US$79,506,000, the ratio to direct construction cost being 28.5%.

Assuming that negotiations concerning loans for this Project proceed smoothly and the Project is completed at the end of 1990, the rise in the construction cost due to inflation is estimated will be 75.7% compared with the total construction cost based on December 1981 prices. In effect, the total construction cost taking escalation into account will be US$490,696,000, of which US$198,094,000 will be the foreign currency requirement and US$292,602,000 the domestic currency requirement.

The total construction cost and fund requirements by year are given in Table 11-3.

Table 11-3-(1) Fund Req

Items	Total			1983		
	F.C	D.C	Total	F.C	D.C	Total
A Generating facilities	76,921	50,667	127,588	—	—	—
A-1 Civil works	55,132	47,237	102,369	—	—	—
(1) Diversion works	6,000	5,655	11,655	—	—	—
(2) Dam and intake	9,736	9,541	19,277	—	—	—
(3) Sedimentation basin	9,459	7,423	16,882	—	—	—
(4) Headrace tunnel	16,727	15,178	31,905	—	—	—
(5) Surge tank	1,078	1,113	2,191	—	—	—
(6) Penstock foundation	1,182	1,341	2,523	—	—	—
(7) Powerhouse building	3,168	3,655	6,823	—	—	—
(8) Switchyard foundation	623	854	1,477	—	—	—
(9) Hydro mechanical equip.	7,159	2,477	9,636	—	—	—
a) Gates & penstock	4,296	1,137	5,433	—	—	—
b) Inland transportation	0	579	579	—	—	—
c) Installation	2,863	761	3,624	—	—	—
A-2 Electrical Equip.	21,789	3,430	25,219	—	—	—
(1) Turbines & generators	15,500	0	15,500	—	—	—
(2) Main Trans & Others	4,218	0	4,218	—	—	—
(3) Inland transportation	0	2,543	2,543	—	—	—
(4) Installation	2,071	887	2,958	—	—	—
B Transmitting facilities	26,920	20,770	47,690	—	—	—
B-1 Transmission lines	23,543	20,237	43,782	—	—	—
(1) Materials	17,089	0	17,089	—	—	—
(2) Inland transportation	0	1,613	1,613	—	—	—
(3) Installation	0	13,325	13,325	—	—	—
(4) Catavi-Potosi allocation	6,185	4,957	11,142	—	—	—
(5) 24.9 kV line	269	344	613	—	—	—
B-2 Transforming equip.	3,377	531	3,908	—	—	—
(1) Electrical equip.	3,056	0	3,056	—	—	—
(2) Inland transportation	0	394	394	—	—	—
(3) Installation	321	137	458	—	—	—
C Preparatory works	5,544	18,967	24,511	—	—	—
(1) Access road	5,544	18,287	23,831	—	—	—
(2) Temporary facilities	0	680	680	—	—	—
Direct cost (A+B+C)	109,385	90,404	199,789			
D Contingency	5,469	9,040	14,509	0	0	
E Engineering & ENDE adm.	6,000	3,340	9,340	640	200	84
Total cost (A through E)	120,854	102,784	223,638	640	200	84
F Interest during construction	12,972	42,685	55,657	11	12	2
Indirect cost (D+E+F)	24,441	55,065	79,506	651	212	86
G Total construction cost	133,826	145,469	279,295	651	212	86
H Escalation	64,268	147,133	211,401	70	50	12
I Total fund required	198,094	292,602	490,696	721	262	983

Conversion rate : 1US$ = 25$B = 220Yen

Table 11-3-(1) Fund Requirement for Pilaya Project

Unit: US$ 10^3

Items	Total			1983			1984			1985			1986		
	F.C	D.C	Total	F.C	D.C	Total	F.C	D.C	Total	F.C	D.C	Total	F.C	D.C	Total
A Generating facilities	76,921	50,667	127,588	—	—	—	—	—	—	4,441	3,183	7,624	12,458	10,609	23,067
A-1 Civil works	55,132	47,237	102,369	—	—	—	—	—	—	4,441	3,183	7,624	12,458	10,609	23,067
(1) Diversion works	6,000	5,655	11,655	—	—	—	—	—	—	191	205	396	5,059	4,836	9,895
(2) Dam and intake	9,736	9,541	19,277	—	—	—	—	—	—	—	—	—	—	—	—
(3) Sedimentation basin	9,459	7,423	16,882	—	—	—	—	—	—	—	—	—	527	537	1,064
(4) Headrace tunnel	16,727	15,178	31,905	—	—	—	—	—	—	2,773	2,359	5,132	5,063	4,282	9,345
(5) Surge tank	1,078	1,113	2,191	—	—	—	—	—	—	—	—	—	—	—	—
(6) Penstock foundation	1,182	1,341	2,523	—	—	—	—	—	—	—	—	—	255	204	459
(7) Powerhouse building	3,168	3,655	6,823	—	—	—	—	—	—	282	205	487	359	336	695
(8) Switchyard foundation	623	854	1,477	—	—	—	—	—	—	—	—	—	—	—	—
(9) Hydro mechanical equip.	7,159	2,477	9,636	—	—	—	—	—	—	1,195	414	1,609	1,195	414	1,609
a) Gates & penstock	4,296	1,137	5,433	—	—	—	—	—	—	717	190	907	717	190	907
b) Inland transportation	0	579	579	—	—	—	—	—	—	0	97	97	0	97	97
c) Installation	2,863	761	3,624	—	—	—	—	—	—	478	127	605	478	127	605
A-2 Electrical Equip.	21,789	3,430	25,219	—	—	—	—	—	—	—	—	—	—	—	—
(1) Turbines & generators	15,500	0	15,500	—	—	—	—	—	—	—	—	—	—	—	—
(2) Main Trans & Others	4,218	0	4,218	—	—	—	—	—	—	—	—	—	—	—	—
(3) Inland transportation	0	2,543	2,543	—	—	—	—	—	—	—	—	—	—	—	—
(4) Installation	2,071	887	2,958	—	—	—	—	—	—	—	—	—	—	—	—
B Transmitting facilities	26,920	20,770	47,690	—	—	—	2,692	2,133	4,825	0	0	0	0	0	0
B-1 Transmission lines	23,543	20,237	43,782	—	—	—	2,692	2,133	4,825	0	0	0	0	0	0
(1) Materials	17,089	0	17,089	—	—	—	2,423	0	2,423	0	0	0	0	0	0
(2) Inland transportation	0	1,613	1,613	—	—	—	0	193	193	0	0	0	0	0	0
(3) Installation	0	13,325	13,325	—	—	—	0	1,596	1,596	0	0	0	0	0	0
(4) Catavi-Potosi allocation	6,185	4,957	11,142	—	—	—	—	—	—	0	0	0	0	0	0
(5) 24.9 kV line	269	344	613	—	—	—	269	344	613	0	0	0	0	0	0
B-2 Transforming equip.	3,377	531	3,908	—	—	—	—	—	—	—	—	—	—	—	—
(1) Electrical equip.	3,056	0	3,056	—	—	—	—	—	—	—	—	—	—	—	—
(2) Inland transportation	0	394	394	—	—	—	—	—	—	—	—	—	—	—	—
(3) Installation	321	137	458	—	—	—	—	—	—	—	—	—	—	—	—
C Preparatory works	5,544	18,967	24,511	—	—	—	4,196	14,490	18,686	1,348	4,477	5,825	—	—	—
(1) Access road	5,544	18,287	23,831	—	—	—	4,196	13,810	18,006	1,348	4,477	5,825	—	—	—
(2) Temporary facilities	0	680	680	—	—	—	0	680	680	—	—	—	—	—	—
Direct cost (A+B+C)	109,385	90,404	199,789				6,888	16,623	23,511	5,789	7,660	13,449	12,458	10,609	23,067
D Contingency	5,469	9,040	14,509	0	0	0	344	1,662	2,006	289	766	1,055	623	1,061	1,684
E Engineering & ENDE adm.	6,000	3,340	9,340	640	200	840	260	440	700	620	300	920	570	300	870
Total cost (A through E)	120,854	102,784	223,638	640	200	840	7,492	18,725	26,217	6,698	8,726	15,424	13,651	11,970	25,621
F Interest during construction	12,972	42,685	55,657	11	12	23	153	1,148	1,301	401	2,795	3,196	757	4,036	4,793
Indirect cost (D+E+F)	24,441	55,065	79,506	651	212	863	757	3,250	4,007	1,310	3,861	5,171	1,950	5,397	7,347
G Total construction cost	133,826	145,469	279,295	651	212	863	7,645	19,873	27,518	7,099	11,521	18,620	14,408	16,006	30,414
H Escalation	64,268	147,133	211,401	70	50	120	1,407	7,969	9,376	1,903	6,567	8,470	5,028	11,860	16,888
I Total fund required	198,094	292,602	490,696	721	262	983	9,052	27,842	36,894	9,002	18,088	27,090	19,436	27,866	47,302

Conversion rate : 1US$ = 25$B = 220Yen

Table 11-3-(2) Fund Requirement for Pilaya Project

Unit: US$ 10^3

Items	1987			1988			1989			1990			Remarks
	F.C	D.C	Total	F.C	D.C	Total	F.C	D.C	Total	F.C	D.C	Total	
A Generating facilities	18,453	10,810	29,263	17,693	11,810	29,503	18,541	11,389	29,930	5,335	2,866	8,201	
A-1 Civil works	13,481	10,810	24,291	13,645	11,468	25,113	8,728	9,209	17,937	2,379	1,958	4,337	
(1) Diversion works	636	505	1,141	—	—	—	—	—	—	114	109	223	
(2) Dam and intake	2,063	1,791	3,854	3,314	3,309	6,623	4,132	4,177	8,309	227	264	491	
(3) Sedimentation basin	3,096	2,336	5,432	5,618	4,168	9,786	218	382	600	—	—	—	
(4) Headrace tunnel	5,063	4,282	9,345	1,873	1,700	3,573	1,419	1,859	3,278	536	696	1,232	
(5) Surge tank	14	14	28	582	654	1,236	482	445	927	—	—	—	
(6) Penstock foundation	555	600	1,155	317	437	754	41	73	114	14	27	41	
(7) Powerhouse building	777	809	1,586	627	691	1,318	827	1,159	1,986	296	455	751	
(8) Switchyard foundation	82	59	141	123	95	218	418	700	1,118	—	—	—	
(9) Hydro mechanical equip.	1,195	414	1,609	1,191	414	1,605	1,191	414	1,605	1,192	407	1,599	
a) Gates & penstock	717	190	907	715	190	905	715	190	905	715	187	902	
b) Inland transportation	0	97	97	0	96	96	0	96	96	0	96	96	
c) Installation	478	127	605	476	128	604	476	128	604	477	124	601	
A-2 Electrical equip.	4,972	0	4,972	4,048	342	4,390	9,813	2,180	11,993	2,956	908	3,864	
(1) Turbines & generators	4,550	0	4,550	3,100	0	3,100	6,300	0	6,300	1,550	0	1,550	
(2) Main Trans & Others	422	0	422	844	0	844	2,530	0	2,530	422	0	422	
(3) Inland transportation	0	0	0	0	254	254	0	1,780	1,780	0	509	509	
(4) Installation	0	0	0	104	88	192	983	400	1,383	984	399	1,383	
B Transmitting facilities	5,604	261	5,865	16,003	6,149	22,152	1,160	6,680	7,840	1,461	5,547	7,008	
B-1 Transmission lines	4,998	261	5,259	15,853	6,114	21,967	0	6,432	6,432	0	5,299	5,299	
(1) Materials	4,467	0	4,467	10,199	0	10,199	0	0	0	0	0	0	
(2) Inland transportation	0	18	18	0	485	485	0	520	520	0	397	397	
(3) Installation	0	143	143	0	4,010	4,010	0	4,293	4,293	0	3,283	3,283	
(4) Catavi-Potosi allocation	531	100	631	5,654	1,619	7,273	0	1,619	1,619	0	1,619	1,619	
(5) 24.9 kV line	0	0	0	0	0	0	0	0	0	0	0	0	
B-2 Transforming equip.	606	0	606	150	35	185	1,160	248	1,408	1,461	248	1,709	
(1) Electrical equip.	606	0	606	150	0	150	1,000	0	1,000	1,300	0	1,300	
(2) Inland transportation	—	—	—	0	20	20	0	187	187	0	187	187	
(3) Installation	—	—	—	0	15	15	160	61	221	161	61	222	
C Preparatory works	—	—	—	—	—	—	—	—	—	—	—	—	
(1) Access road	—	—	—	—	—	—	—	—	—	—	—	—	
(2) Temporary facilities	—	—	—	—	—	—	—	—	—	—	—	—	Temporary facilities are used for ENDE engineers and consultant engineers
Direct cost (A+B+C)	24,057	11,071	35,128	33,696	17,959	51,655	19,701	18,069	37,770	6,796	8,413	15,209	
D Contingency	1,203	1,107	2,310	1,685	1,796	3,481	985	1,807	2,792	340	841	1,181	
E Engineering & ENDE adm.	780	525	1,305	1,200	525	1,725	940	525	1,465	990	525	1,515	
Total cost (A through E)	26,040	12,703	38,743	36,581	20,280	56,861	21,626	20,401	42,027	8,126	9,779	17,905	
F Interest during construction	1,452	5,516	6,968	2,547	7,495	10,042	3,565	9,936	13,501	4,086	11,747	15,833	
Indirect cost (D+E+F)	3,435	7,148	10,583	5,432	9,816	15,248	5,490	12,268	17,758	5,416	13,113	18,529	
G Total construction cost	27,492	18,219	45,711	39,128	27,775	66,903	25,191	30,337	55,528	12,212	21,526	33,738	
H Escalation	11,794	16,670	28,464	20,190	30,719	50,909	15,291	39,954	55,245	8,585	33,344	41,929	
I Total fund required	39,286	34,889	74,175	59,318	58,494	117,812	40,482	70,291	110,773	20,797	54,870	75,667	

Conversion rate : 1US$ = 25$B = 220Yen

CHAPTER 12

POWER GENERATION

CHAPTER 12 POWER GENERATION

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FIGURE LIST

CHAPTER 12. POWER GENERATION

This Chapter is to determine the optimum installed generating capacity and annual available energy for Pilaya Power Plant by the performance record of discharge (by necessary correction or interpolation of discharge for the period with lack of data or unsuitable data) for 15 years from 1966 to 1980 as taken at the Chillcara Gauging Station referred to in Chapter 5 "Meteorology and hydrology."

12.1 Basic Data

(1) Hydrological Data

For the calculation of available energy, the data should preferrably cover as longest a period as available. The Survey Team therefore made its own assumption of the discharge at Chillcara Gauging Station from the record of precipitation taken at meteorological observatories existing within the whole catchment area of Pilaya Hydro Power Project, apart from the record of discharge as measured at Chillcara Gauging Station for the period of August 1972 to December 1980 (including 11 months in failure of measurement) and used the discharge recorded data for 15 years from January 1966 to December 1980 as the basic discharge data for planning of the Project.

The Pilaya Project has a daily regulating reservoir for power generation, therefore daily run-off data is required to determine available generating energy. In effect, in determination of available discharge and generating energy for the Pilaya Project at the time of no data available, complementary coefficient which are calculated from daily and monthly generating discharge were adopted.

Therefore, with regard to available discharge for the Project, the discharge as recorded from January 1966 to December 1980 will be used for calculation of available energy.

Table 12-1 shows monthly average available water for power generation estimated over 15 years.

(2) Gross Head

A hydro power development project needs the topographic map of fullest accuracy. That is to say, knowledge is required with accuracy with regard to the available head to be created between the water level at the intake and the position of the vertical-shaft Pelton turbine to be installed inside the Pilaya power house. By correction of the topographic map (to correct from EL. 1,330 m for the Pilla site to EL. 1,370 m) prepared by ENDE after its land surveying in September 1981, the Survey Team determined the intake water level at EL. 1,793 m (as normal intake level) and the installed elevation of vertical-shaft Pelton turbine at 1,365 m (as the turbine center). The gross head of 428 m thus obtained will be made available for Pilaya Power Plant, from which maximum output and available energy will be sought.

12.2 Effective Head, Efficiency and Maximum Discharge

(1) Effective Head

The section with largest loss of head in water way system designed for the Pilaya Project is the headrace of 10.4 km length. Therefore, to determine the economic optimum size of section for the headrace tunnel, the loss of head has been assessed at unit cost of *57.38 US mills per kWh as the incremental marginal cost for the future power system as presented by ENDE. As the result, effective head for the Pilaya Project is as follows:

Pilaya Reservoir N.W.L.	EL 1,793 m
Center Line of Turbine	EL 1,365 m
Total Static Head	428 m
Loss head	30 m
(Penstocks)	(6 m)
(Headrace tunnel)	(21 m)
(Sedimentation basin & others)	(3 m)
Net Effective Head	398 m

As aforestated, net effective head to be made available for the Project is determined at 398 m.

(2) Turbine Efficiency

Efficiency of the Pelton turbine may be varied depending upon the rate of specific speed (Ns). The value Ns to be expected for the highest efficiency is around 16. As mentioned in the foregoing sub-item 7.9.1, if the value Ns for the Pelton turbine is selected to be the highest, the generator directly connected with the turbine can be designed at its increased revolution speed, thereby reducing its size and weight most economically. The Survey Team has reached the following conclusion after study on the correlation between change in the efficiency of Pelton turbine and the value Ns:

	Revolution of turbine	
	375 rpm	429 rpm
Specific speed (Ns)	18.4	21.0
Turbine efficiency (%)	89.0	88.5
Annual energy production (GWh)	535.5	532.5
Incremental energy (GWh)	3.0	0

As indicated in the Table above, annual incremental energy of 3.0 GWh will be made available by selection of the Pelton turbine at a value of Ns = 18.4.

Although the price of generator at Ns = 18.4 is higher by 380 thousand U.S. dollars for three (3) units, as compared with that at Ns = 21.0, such price gap can be paid off within three years by sales of incremental energy expected from the turbine efficiency difference.

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* Refer to Chapter 14 Economic Evaluation

Table 12-1-(1) Available

Year	Item (Month)	Dry Season					
		May	Jun.	Jul.	Aug.	Sep.	Oct.
1965/'66	Inflow	—	—	—	—	—	—
	Available discharge	—	—	—	—	—	—
	Over-flow	—	—	—	—	—	—
1966/'67	Inflow	17.9	15.5	13.2	10.8	8.4	6.0
	Available discharge	17.4	15.5	13.2	10.8	8.4	5.7
	Over-flow	0.5	0	0	0	0	0.3
1967/'68	Inflow	20.5	17.7	15.0	12.2	9.5	6.7
	Available discharge	19.8	17.7	15.0	12.2	9.5	6.3
	Over-flow	0.7	0	0	0	0	0.4
1968/'69	Inflow	21.3	18.4	15.6	12.7	9.8	7.0
	Available discharge	20.6	18.4	15.6	12.7	9.8	6.6
	Over-flow	0.7	0	0	0	0	0.4
1969/'70	Inflow	15.9	13.8	11.7	9.6	7.6	5.5
	Available discharge	15.4	13.8	11.7	9.6	7.6	5.2
	Over-flow	0.5	0	0	0	0	0.3
1970/'71	Inflow	29.1	25.1	21.1	17.1	13.1	9.1
	Available discharge	25.2	25.1	21.1	17.1	13.1	8.6
	Over-flow	3.9	0	0	0	0	0.5
1971/'72	Inflow	16.6	14.4	12.2	10.0	7.8	5.7
	Available discharge	16.1	14.4	12.2	10.0	7.8	5.3
	Over-flow	0.5	0	0	0	0	0.4
1972/'73	Inflow	21.5	18.6	15.7	11.8	8.6	13.0
	Available discharge	20.8	18.6	15.7	11.8	8.6	9.9
	Over-flow	0.7	0	0	0	0	3.1
1973/'74	Inflow	33.4	63.5	21.0	16.5	10.3	5.7
	Available discharge	21.7	25.5	21.0	16.5	10.3	5.7
	Over-flow	11.7		0	0	0	0
1974/'75	Inflow	23.8	22.1	19.9	16.7	10.1	4.8
	Available discharge	23.8	22.1	19.9	16.5	10.1	4.8
	Over-flow	0	0	0	0.2	0	0
1975/'76	Inflow	22.8	19.8	17.4	15.0	12.4	9.8
	Available discharge	22.8	19.8	17.4	15.0	12.4	9.8
	Over-flow	0	0	0	0	0	0

Table 12-1-(1) Available Discharge for Pilaya Project

Unit : m3/s-d

Year	Item \ Month	Dry Season								Rainy Season						Total
		May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Sub total	Dec.	Jan.	Feb.	Mar.	Apr.	Sub total	
1965/'66	Inflow	—	—	—	—	—	—	—	—	—	61.2	96.9	42.0	42.0	7,172.4	7,172.4
	Available discharge	—	—	—	—	—	—	—	—	—	25.2	25.7	25.5	24.4	3,023.3	3,023.3
	Over-flow	—	—	—	—	—	—	—	—	—	36.0	71.2	16.5	17.6	4,149.1	4,149.1
1966/'67	Inflow	17.9	15.5	13.2	10.8	8.4	6.0	19.1	2,774.9	41.1	63.4	148.5	62.3	39.8	10,522.8	13,297.7
	Available discharge	17.4	15.5	13.2	10.8	8.4	5.7	15.5	2,642.1	19.8	25.2	25.7	25.5	24.4	3,637.1	6,279.2
	Over-flow	0.5	0	0	0	0	0.3	3.6	132.8	21.3	38.2	122.8	36.8	15.4	6,885.7	7,018.5
1967/'68	Inflow	20.5	17.7	15.0	12.2	9.5	6.7	8.5	2,757.4	56.8	123.4	879.3	75.6	32.0	34,389.5	37,146.9
	Available discharge	19.8	17.7	15.0	12.2	9.5	6.3	6.9	2,675.3	19.8	25.2	25.7	25.5	24.4	3,662.8	6,338.1
	Over-flow	0.7	0	0	0	0	0.4	1.6	82.1	37.0	98.2	853.6	50.1	7.6	30,726.7	30,808.8
1968/'69	Inflow	21.3	18.4	15.6	12.7	9.8	7.0	23.9	3,317.6	14.4	195.1	144.0	36.7	32.6	12,642.2	15,959.8
	Available discharge	20.6	18.4	15.6	12.7	9.8	6.6	19.4	3,148.5	11.0	25.2	25.7	25.5	24.4	3,364.3	6,512.8
	Over-flow	0.7	0	0	0	0	0.4	4.5	169.1	3.4	169.9	118.3	11.2	8.2	9,277.9	9,447.0
1969/'70	Inflow	15.9	13.8	11.7	9.6	7.6	5.5	10.6	2,283.7	131.5	170.2	160.1	110.8	53.0	18,860.3	21,144.0
	Available discharge	15.4	13.8	11.7	9.6	7.6	5.2	8.6	2,198.9	19.8	25.2	25.7	25.5	24.4	3,637.1	5,836.0
	Over-flow	0.5	0	0	0	0	0.3	2.0	84.8	111.7	145.0	134.4	85.3	28.6	15,223.2	15,308.0
1970/'71	Inflow	29.1	25.1	21.1	17.1	13.1	9.1	10.3	3,823.4	44.6	146.8	938.5	42.8	31.2	34,474.2	38,297.6
	Available discharge	25.2	25.1	21.1	17.1	13.1	8.6	8.3	3,627.0	19.8	25.2	25.7	25.5	24.4	3,637.1	7,264.1
	Over-flow	3.9	0	0	0	0	0.5	2.0	196.4	24.8	121.6	912.8	17.3	6.8	30,837.1	31,033.5
1971/'72	Inflow	16.6	14.4	12.2	10.0	7.8	5.7	19.9	2,642.5	28.3	155.5	229.3	72.2	37.1	15,698.7	18,341.2
	Available discharge	16.1	14.4	12.2	10.0	7.8	5.3	16.1	2,500.6	19.8	25.2	25.7	25.5	24.4	3,662.8	6,163.4
	Over-flow	0.5	0	0	0	0	0.4	3.8	141.9	8.5	130.3	203.6	46.7	12.7	12,035.9	12,177.8
1972/'73	Inflow	21.5	18.6	15.7	11.8	8.6	13.0	19.5	3,323.0	38.1	83.0	74.9	80.8	36.9	9,463.1	12,786.1
	Available discharge	20.8	18.6	15.7	11.8	8.6	9.9	13.5	3,025.2	19.0	24.9	24.8	26.0	25.0	3,611.3	6,636.5
	Over-flow	0.7	0	0	0	0	3.1	6.0	297.8	19.1	58.1	50.1	54.8	11.9	5,851.8	6,149.6
1973/'74	Inflow	33.4	63.5	21.0	16.5	10.3	5.7	4.6	4,726.6	33.0	114.6	286.4	79.2	49.8	16,544.0	21,270.6
	Available discharge	21.7	25.5	21.0	16.5	10.3	5.7	4.6	3,223.9	14.3	25.2	26.0	25.8	25.8	3,526.3	6,750.2
	Over-flow	11.7		0	0	0	0	0	1,502.7	18.7	89.4	260.4	53.4	24.0	13,017.7	14,520.4
1974/'75	Inflow	23.8	22.1	19.9	16.7	10.1	4.8	8.2	3,233.2	59.5	232.5	413.3	58.0	33.3	23,421.4	26,654.6
	Available discharge	23.8	22.1	19.9	16.5	10.1	4.8	8.2	3,227.0	18.2	24.7	26.0	25.5	24.4	3,580.4	6,807.4
	Over-flow	0	0	0	0.2	0	0	0	6.2	41.3	207.8	387.3	32.5	8.9	19,841.0	19,847.2
1975/'76	Inflow	22.8	19.8	17.4	15.0	12.4	9.8	10.2	3,287.0	34.9	116.1	98.4	78.0	27.8	10,786.6	14,073.6
	Available discharge	22.8	19.8	17.4	15.0	12.4	9.8	10.2	3,287.0	22.2	25.8	26.0	22.8	25.4	3,710.8	6,997.8
	Over-flow	0	0	0	0	0	0	0	0	12.7	90.3	72.4	55.2	2.4	7,075.8	7,075.8

Table 12-1-(2) Available Discharge for Pilaya Project

Unit : m^3/s-d

Year \ Item \ Month		Dry Season								Rainy Season						Total
Year	Item	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Sub total	Dec.	Jan.	Feb.	Mar.	Apr.	Sub total	
1976/'77	Inflow	21.8	17.5	13.7	10.8	10.0	7.5	43.5	3,797.8	155.4	137.1	293.8	72.9	33.5	20,558.8	24,356.6
	Available discharge	21.8	17.5	13.7	10.8	10.0	7.1	21.1	3,113.4	19.8	25.2	25.7	25.5	24.4	3,637.1	6,750.5
	Over-flow	0	0	0	0	0	0.4	22.4	684.4	135.6	111.9	268.1	47.4	9.1	16,921.7	17,606.1
1977/'78	Inflow	22.0	17.2	14.2	11.1	7.8	12.5	74.7	4,844.8	123.0	194.5	371.0	90.4	34.8	24,076.9	28,921.7
	Available discharge	21.3	17.2	14.2	11.1	7.8	11.5	16.4	3,043.1	20.1	26.0	26.0	26.0	25.9	3,740.1	6,783.2
	Over-flow	0.7	0	0	0	0	1.0	58.3	1,801.7	102.9	168.5	345.0	64.4	8.9	20,336.8	22,138.5
1978/'79	Inflow	22.5	19.8	16.8	13.3	9.2	7.6	17.9	3,273.2	106.8	642.0	292.3	146.3	47.0	37,342.5	40,615.7
	Available discharge	22.5	19.8	16.8	13.3	9.2	7.6	13.8	3,150.2	22.5	26.0	26.0	26.0	26.0	3,817.5	6,967.7
	Over-flow	0	0	0	0	0	0	4.1	123.0	84.3	616.0	266.3	120.3	21.0	33,525.0	33,648.0
1979/'80	Inflow	31.3	27.8	24.7	19.3	13.4	9.1	13.9	4,269.4	91.1	69.8	43.5	77.5	22.2	9,317.9	13,587.3
	Available discharge	26.0	26.0	24.7	19.3	13.4	9.1	13.5	4,039.1	19.8	26.0	24.1	26.0	19.0	3,494.7	7,533.8
	Over-flow	5.3	1.7	0	0	0	0	0.4	230.3	71.3	43.8	19.4	51.5	3.2	5,823.2	6,053.5
1980/'81	Inflow	15.8	15.9	13.2	10.9	7.7	8.9	10.0	2,520.8	10.1	—	—	—	—	313.1	313.1
	Available discharge	15.8	15.9	13.2	10.9	7.7	8.4	9.3	2,484.3	9.1	—	—	—	—	282.1	282.1
	Over-flow	0	0	0	0	0	0.5	0.7	36.5	1.0	—	—	—	—	31.0	31.0
Average	Inflow	22.4	21.8	16.4	13.2	9.7	7.9	19.6	3,391.7	64.6	166.5	298.0	75.0	36.9	19,009.9	22,401.6
	Available discharge	20.7	19.2	16.4	13.2	9.7	7.4	12.4	3,024.0	18.3	25.4	25.7	25.5	24.5	3,602.2	6,626.2
	Over-flow	1.7	.6	0	0	0	0.5	7.2	367.7	46.3	141.1	272.3	49.5	12.4	15,407.7	15,775.4

Note :

* The estimation of available discharge due to lacking of data was done employing ratio of daily available discharge and monthly average run-off computed by existing data.

Month	Ratio	Month	Ratio
Jan.	0.97	Jul.	1.00
Feb.	0.99	Aug.	1.00
Mar.	0.98	Sep.	1.00
Apr.	0.94	Oct.	0.94
May	0.97	Nov.	0.81
Jun.	1.00	Dec.	0.76

(3) Maximum Discharge for Power Plant

Pilaya Power Plant may be, by its nature, fallen into the category of the run-of-river type. Since the existing power system throughout the country of Bolivia constitutes mainly hydro power generating sources, determination on the optimum size of Pilaya Project may be largely influenced by the operating patterns, in both dry and wet seasons, of all the other existing hydro power plants before Pilaya will enter into initial operation. From this point of view, the Survey Team made its study on the suitability, as stated in Chapter 4 "Power Demand Forecast", on estimated available energy, in both dry and wet seasons, from all the existing power plants including those proposed for construction earlier than 1991 scheduled for initial operation of Pilaya Power Plant, by comparative review with balancing between demand and supply. The result of study revealed that demand and supply could be well balanced at average throughout the year by combined operation with the existing reservoir type Corani and Santa Isabel Power Plants and with Icla and other power plants proposed for construction.

This means, however, that if the installed capacity of Pilaya Project is determined from available discharge during the rainy season it would cause decline of the plant factor of the power facilities and result in excessive investment. With this in mind, the Survey Team determined the maximum discharge for Pilaya Project at 26.0 m^3 per second which may permit continuous peak-load operating for five (5) to six(6) hours, with the run-off of 95 percent probability (secured run-off for 347 days per year) after drafting the annual run-off duration curves obtained from the existing daily run-off data recorded from 1972 to 1980.

The results of the study on the generation costs which were calculated by use of the available discharge for power generation as a parameter were obtained as shown in Table 12-2.

Table 12-2 Comparison of Energy Cost

Maximum discharge (m^3/S)	Maximum output (MW)	Equalized annual energy (GWh)	Energy cost at generating end (US mills/kWh)
32.0	107.7	516.6	48.4
29.0	97.6	490.6	48.1
26.0	87.0	469.4	47.9
23.0	77.4	445.2	48.0
20.0	67.3	418.2	48.3

Note : Calculated energy cost does not include any costs of transmission and substation systems necessary for and connected with Pilaya Hydro Project.

Relation between the construction costs and generating costs is indicated in Table 12-3.

Table 12-3 Generating Cost at Generating End

Maximum discharge (m^3/s)	Max. output (MW)	Construction cost (US\$ 10^3)	Annual cost (US\$ 10^3)	Available energy (GWh)	Equalized energy (GWh)	Generating cost (US mills/kWh)
32.0	107.7	189,350	24,994	603.0	516.6	48.4
29.0	97.6	178,784	23,599	566.0	490.6	48.1
26.0	87.0	170,247	22,472	535.5	469.4	47.9
23.0	77.4	162,006	21,384	502.0	445.2	48.0
20.0	67.3	153,054	20,203	465.1	418.2	48.3

Capital opportunity cost : 12.0%/year
Operation & maintenance cost : 1.2% of construction cost
Service life : 50 years

Therefore, Annual cost factor : 0.132

It is clear, as shown in Fig. 12-1, that Pilaya Hydro Project would not be able, in any ways, to increase its available energy production, even though its installed capacity may be increased to make effective use of discharge available for 7 dry months to the possible extent. In other words, it would be meaningless to increase its scale of capacity beyond 30 m^3 per second in the discharge rate as far as discharge in the dry season is concerned. On the other hand, however, as the installed capacity grows larger there would be larger increase in available energy as far as discharge in 5 rainy months is concerned. Incremental energy in the rainy season, compared with that in the dry season does not become effective energy for three years from the time of start of operation of the Pilaya Project even if the installed capacity is larger.

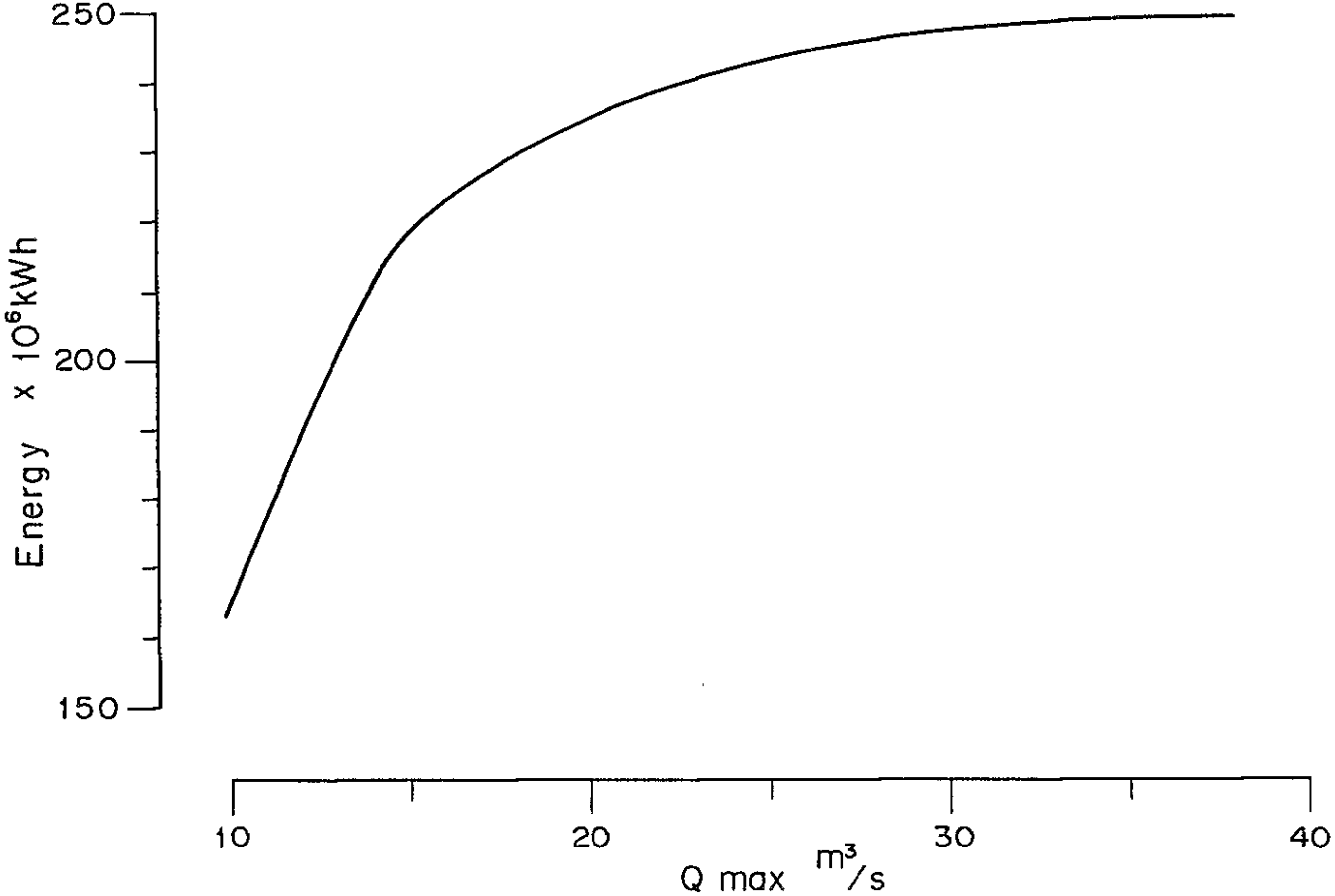
12.3 Installed Output and Unit Capacity

(1) Installed Output

Utilizing the 600,000 m^3 and 10 m available water depth regulating capacity designed for the reservoir, it is possible to operate peak-load operation for five (5) to six (6) hours for the Pilaya Project during the dry season.

The Survey Team determined the intake water level as the reference factor to determine the installed output by choice of the two-third (2/3) as the weighted mean water level of 10 m available water depth, thereby to determine the optimum installed output on the basis of the 398 m effective head to be made available between the normal intake water level of EL. 1,793 m

Fig 12-1 Available Production Energy in Dry Season (1966~1980)
(May to November)



thus determined and EL. 1,365 m as the designed center for setting of the Pelton turbine.

To further explain the above by calculation formula,

$$P = 9.8\ HQ\eta_T \cdot \eta_G = 9.8 \times 398 \times 26.0 \times 0.89 \times 0.97$$
$$= 87.547\ \text{kW}$$
$$\fallingdotseq 87,000\ \text{kW}$$

where,

H : Effective head (m)
Q : Maximum discharge (m^3/sec)
ηT : Turbine efficiency
ηG : Generator efficiency

(2) Unit Capacity and Number of Generators

Required number of generators for operation of a power plant may be determined after consideration of transport limitation, manufacturing capability, economy and coordination with the existing power system. Although it is most desirable to reduce the machinery size and weight to possible minimum because of accessibility to Pilaya Project, it may be considered reasonable to determine the optimum number of generators mainly from the service reliability as represented by close relationship between the power system and its economy. As the usual tendency, the service reliability of a power plant can be improved with increased number of generators to be installed.

On the other hand, however, if the number of generators is increased, there may be such disadvantages that the equipment cost would rise up as compared with any other alternative power plant of identical output capacity and, besides that, the floor area of the building to house the equipment would be increased accordingly. Therefore, it can be said that determination of the required number of units, that is to say, the unit capacity, of the plant should be related closely to the problem of how to keep balance between service reliability versus construction cost. In line with this basic conception, the Survey Team determined the required number of generators (i.e. unit generator capacity) after the following studies.

Normally, the forced outage rate* (q = Number of outage days/number of operating days + Number of outage days) is estimated within a range of 0.01 to 0.03. In the case of Pilaya Power Plant, it may be probable that should the generating unit be fallen into outage a relatively longer time would be required until recovery of operation since all electrical equipment will be purchased from abroad. For this reason, the forced outage rate for Pilaya Power Plant is assumed as $q = 0.03$.

The outage probability of "x" units of generators in the total number "n" can be attained from binomial distribution $\binom{n}{x} q^x \cdot p^{n-x}$. The probability "p" of supply per unit is $p = 1-q$.

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* The forced outage rate includes time of scheduled outage.

a) Variation of number "n" of generators versus supply reliability of total power plant

Supply reliability of a power plant can be improved higher with increases in the number of generators.

The outage probability between the "n" and "x" is as follows:

n	x	p	Outage cap. (MW)	* System reserve capacity in MW (5%)	(10%)	(15%)	(20%)
2	2	0.0009	87.0	30	60	90	120
2	1	0.0582	43.5	30	60	90	120
3	3	0.000027	87.0	30	60	90	120
3	2	0.002619	58.0	30	60	90	120
3	1	0.008468	29.0	30	60	90	120
4	4	0.0000008	87.0	30	60	90	120
4	3	0.0001048	65.3	30	60	90	120
4	2	0.0050808	43.5	30	60	90	120
4	1	0.1095208	21.8	30	60	90	120

Note: * Denotes the rate against maximum demand of 600 MW.

b) Number of generators versus reserve capacity of power system

Usually, the forced outage of generator can be compensated by reserve capacity of the power system. ENDE determines the target reserve capacity of power system at 10 percent for its power development program. Since total power demand by 1991 scheduled for initial operation of Pilaya Hydro Project is estimated at 600 MW. Probable loss of load kW and energy kWh resulting from forced outage of the generator may be calculated as follows for Pilaya Project by use of the reserve capacity as a parameter.

n	x	p	Shortage capacity & energy							
			* (5%)		(10%)		(15%)		(20%)	
			MW	(MWh)	(MW)	(MWh)	(MW)	(MWh)	(MW)	(MWh)
2	2	0.0009	57.0	315	27.0	149	0	0	0	0
2	1	0.0582	13.5	4,839	0	0	0	0	0	0
3	3	0.000027	57.0	9	27.0	4	0	0	0	0
3	2	0.002619	28.0	451	0	0	0	0	0	0
3	1	0.008468	0	0	0	0	0	0	0	0
4	4	0.0000008	57.0	0	27.0	0	0	0	0	0
4	3	0.0001048	35.3	0	5.3	0	0	0	0	0
4	2	0.0050808	13.5	0	0	0	0	0	0	0
4	1	0.1095208	0	0	0	0	0	0	0	0

Note: * Reserve capacity in percentage

In short, therefore, the problem of how to determine required number of generators for Pilaya Power Plant lies in the selection as to whether the required number of generators should be two (2) or three (3) units when viewed from the probability of loss power and energy. If the reserve capacity of the power system can be maintained at 10 percent firmly, choice of two (2) units would be preferrable. If the reserve capacity falls to 5 percent, three (3) units should be required.

After detailed study on the relationship between the ENDE's power development program and the required reserve capacity, the Survey Team arrived at its conclusion that total number of generators for Pilaya Project should be determined at three (3) units, as there is every reason to believe that the net reserve capacity of the power system is estimated at around 5 percent, taking into account the scheduled outage of generators for maintenance works such as periodic overhauling inspection of the gas turbine unit and the hydro power unit.

Each unit capacity of generators to be put in service on the power system by 1991 scheduled for initial operation of Pilaya Hydro Plant is estimated at 30 MW or so without exception.

By means of installation of three (3) generators at Pilaya Power Plant, the maximum load of transport would be well below 38 tons and could be carried by trailer truck now mobilizable in Bolivia.

12.4 Firm Energy

Available energy from a hydro power plant may be subject to change depending upon the discharge in the river. The driest record of Pilaya River in the past was experienced in 1969. Therefore, firm energy for Pilaya Power Plant can be determined naturally from the discharge recorded in 1969. The hydrological year being adopted by ENDE covers the period from May as the stating month of dry season to April in the following year as the terminating month of rainy season.

Table 12-4 shows the trend of available energy by month from January 1966 up to and including December 1980. As noted from this Table, firm energy for the Pilaya Project is estimated at 471.6 million kWh.

The following relationship exists between average and maximum available energy for the past 15 years.

Unit: GWh

	Dry season	Rainy season	Total
Firm energy	177.6	294.0	471.6 (88.1)
Average available energy	244.4	291.1	535.5 (100.0)
Maximum available energy	326.5	282.3	608.8 (113.7)

Fig. 12-2 shows parallel average of available power duration curve of the Pilaya Project in the driest 1969, the wetest 1979 and for 15 years.

The driest month for the past 15 years falls upon November 1973 and available energy for the month is recorded at 11.1 million kWh. Therefore, the peak-load duration of Pilaya Power Plant can be estimated at about 4.3 hours.

12.5 Average Available Energy

The following is the monthly trend of average available energy for the past 15 years from January 1966 to December 1980.

Dry Season	GWh	%	Rainy Season	GWh	%
May	51.7	9.6	December	45.8	8.6
June	46.5	8.7	January	63.5	11.8
July	41.0	7.7	February	58.6	10.9
August	33.0	6.2	March	63.8	11.9
September	23.6	4.4	April	59.4	11.0
October	18.6	3.5	Subtotal	(291.1)	(54.3)
November	30.0	5.6	Total	535.5	100.0
Subtotal	(244.4)	(45.7)			

Table 12-4 Energy Production

(Unit : 10^6 kWh)

Year	Dry Season								Rainy Season						
	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Sub total	Dec.	Jan.	Feb.	Mar.	Apr.	Sub total	Total
1965/'66	—	—	—	—	—	—	—	—	—	63.2	58.2	63.8	59.3	244.5	(244.5)
1966/'67	43.5	37.7	33.0	27.0	20.4	14.2	37.6	213.4	49.5	63.2	58.2	63.8	59.3	294.0	507.4
1967/'68	49.7	43.0	37.6	30.6	23.0	15.9	16.6	216.4	49.5	63.2	60.3	63.8	59.3	296.1	512.5
1968/'69	51.7	44.6	39.0	31.7	23.8	16.4	47.0	254.2	27.5	63.2	58.2	63.8	59.3	272.0	526.2
1969/'70	38.6	33.5	29.4	24.1	18.3	12.9	20.8	177.6	49.5	63.2	58.2	63.8	59.3	294.0	471.6
1970/'71	63.2	60.8	52.9	42.8	31.8	21.5	20.2	293.2	49.5	63.2	58.2	63.8	59.3	294.0	587.2
1971/'72	40.2	34.8	30.6	25.1	19.0	13.3	39.1	202.1	49.5	63.2	60.3	63.8	59.3	296.1	498.2
1972/ 73	52.2	45.1	39.4	29.5	21.0	24.9	32.7	244.8	47.6	62.3	56.1	65.1	60.6	291.7	536.5
1973/'74	54.3	61.9	52.7	41.2	25.0	14.2	11.1	260.4	35.7	63.2	58.8	64.7	62.4	284.8	545.2
1974/'75	59.7	53.6	49.9	41.4	24.4	12.0	20.0	261.0	45.5	62.0	58.8	63.8	59.3	289.4	550.4
1975/'76	55.3	48.1	43.5	37.5	30.1	24.7	24.8	264.0	55.2	64.7	60.9	57.1	61.7	299.6	563.6
1976/'77	54.5	42.5	34.3	27.0	24.3	17.8	51.1	251.5	49.5	63.2	58.2	63.8	59.3	294.0	545.5
1977/'78	53.4	41.7	35.6	27.8	18.9	28.7	39.8	245.9	50.4	65.1	58.8	65.1	62.9	302.3	548.2
1978/'79	56.4	48.1	42.1	33.3	22.4	18.9	33.6	254.8	56.3	65.1	58.8	65.1	63.0	308.3	563.1
1979/'80	65.1	63.0	61.9	48.4	32.5	22.9	32.7	326.5	49.7	65.1	56.4	65.1	46.0	282.3	608.8
1980/'81	39.5	38.6	33.1	27.4	18.6	21.1	22.6	200.9	22.8	—	—	—	—	22.8	(223.7)
Average	51.7	46.5	41.0	33.0	23.6	18.6	30.0	244.4	45.8	63.5	58.6	63.8	59.4	291.1	535.5

The average driest month for the past 15 years falls upon October and available energy for the month is recorded at 18.6 million kWh. Then, the peak-load duration of Pilaya Power Plant can be estimated at about 6.9 hours.

Annual peak-load duration of Pilaya Power Plant is averaged at 16.9 hours, especially at about 22.3 hours very close to 24 hour continuous operation in the rainy season.

Fig 12-2 (1) Monthly Available Energy duration Curve

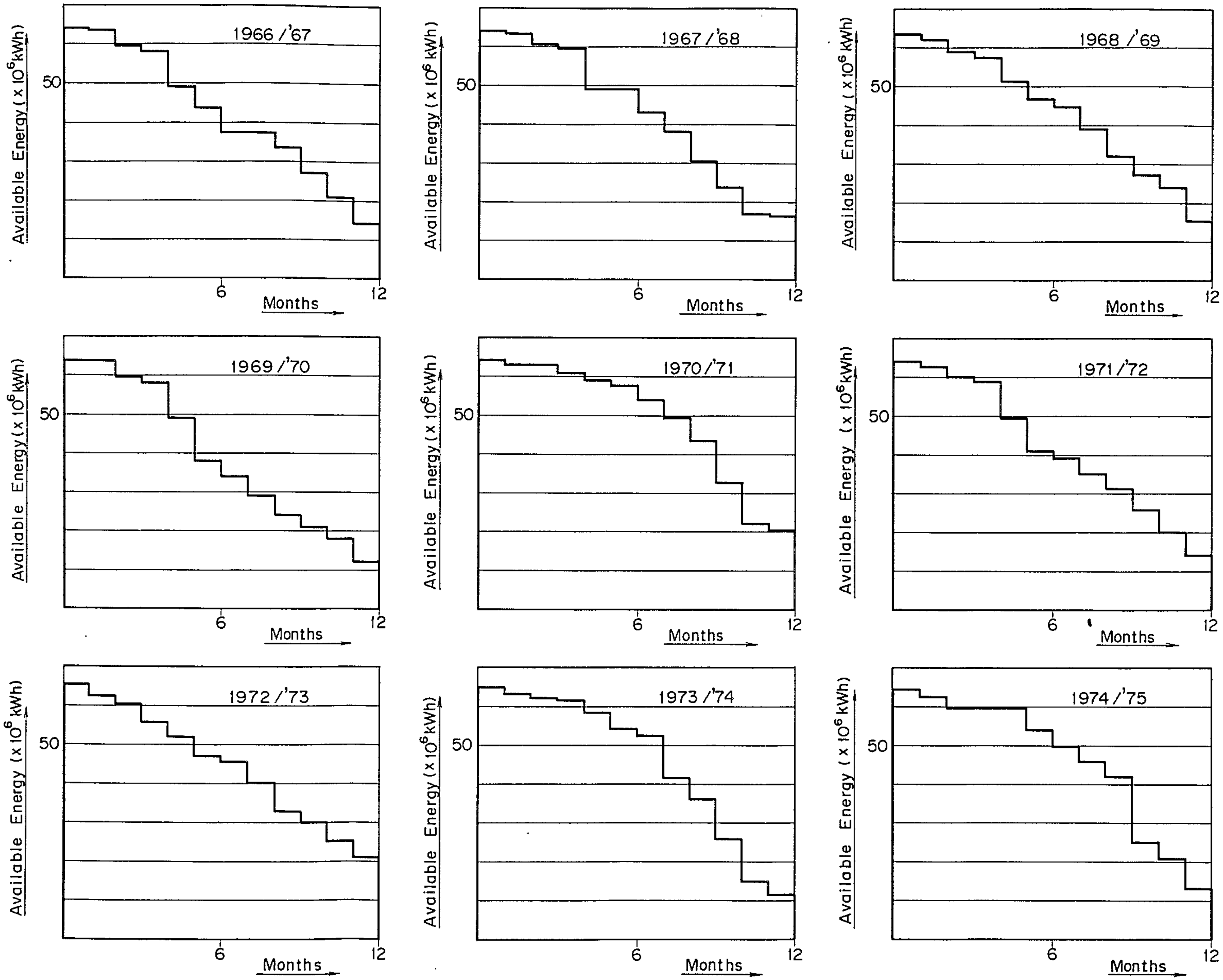
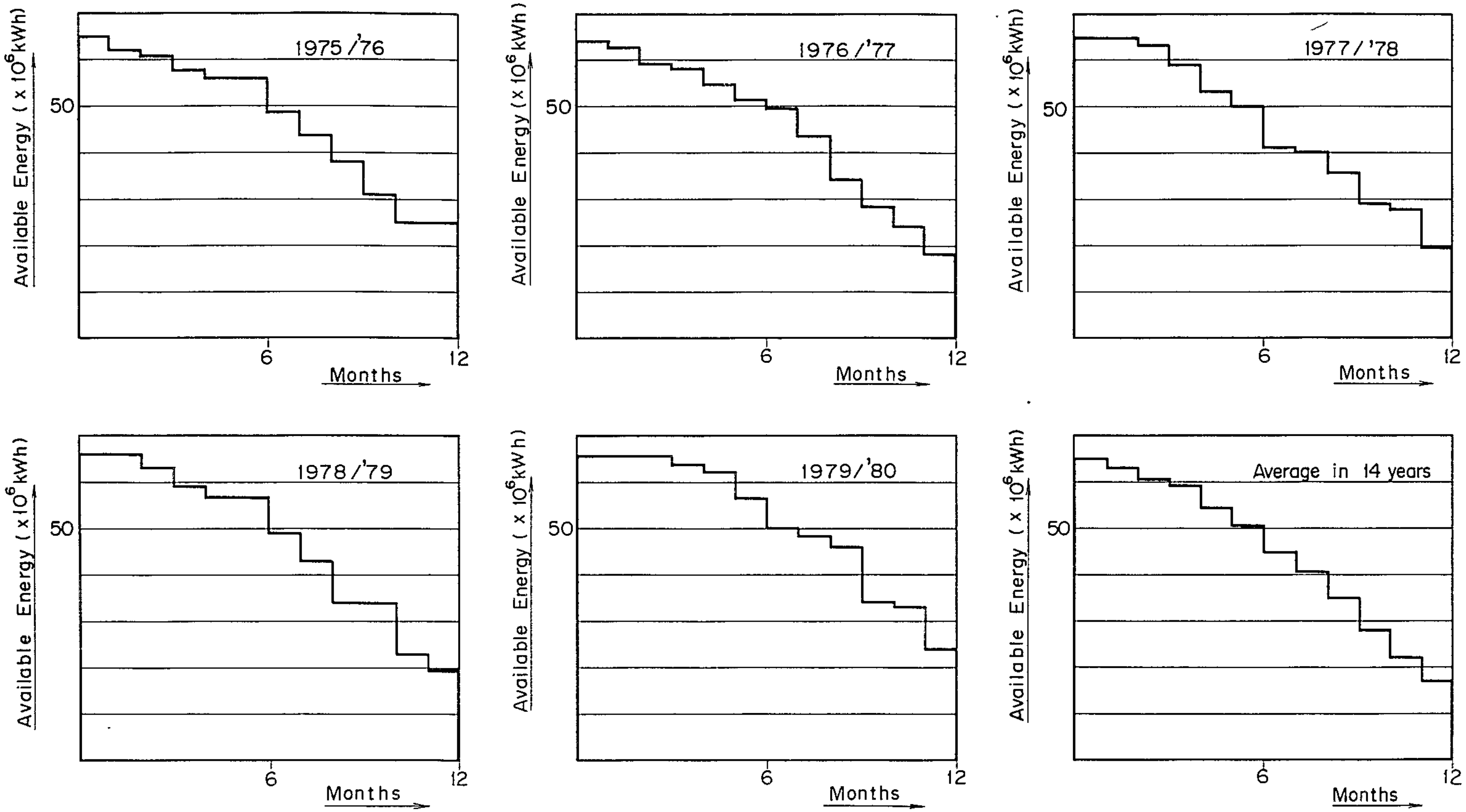


Fig 12-2 (2) Monthly Available Energy duration Curve



CHAPTER 13

POWER SYSTEM ANALYSIS

CHAPTER 13 POWER SYSTEM ANALYSIS

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FIGURE LIST

CHAPTER 13. POWER SYSTEM ANALYSIS

The power consuming area supplied by the Pilaya Hydro Power Project covers mainly three southern provinces of Potosi, Chuquisaca and Tarija of Bolivia. However, the Survey Team will make extensive study of the whole National Power System for supply of power generated from Pilaya Hydro Power Plant, taking into consideration the relationships with the existing power system and the power development scheme proposed by ENDE.

In analyzing the power system, the Survey Team will take the same conception being applied by ENDE to the National Power System to determine the basic design requirements for power transmission plan for the Pilaya Project, such as line voltage power transmission capacity, service reliability of power system and number of line circuits in full consideration of the land expansion of Bolivia, power demand density and local distribution of power generating facilities. Therefore,required number of circuits for the transmission line is limited to the minimum of a single circuit wherever possible and line voltage is well accorded with the voltage rating for the existing transmission line and substation facilities so as to enable omission of additional transforming equipment. In other words, top priority is given to the system economy in planning the transmission and substation construction schemes.

13.1 Premises to Power System Analysis

The Pilaya Hydro Power Project includes the construction plan of transmission lines and substations. The Survey Team will make analysis of the power system based on the data and information on the future National Power System, furnished by ENDE, such as impedance maps of transmission lines, machine constants of generators and substation facilities. Major elements required for the power system analysis consist of the following items.

(1) Years for System Analysis

Power system analysis will be made for the year 1991 which is start of operation of the Pilaya Project and also for the year 1993 which is put into service of Misicuni Hydro Power Plant as the subsequent project to the construction of Pilaya Power Plant.

(2) Composition of Power System for Analysis

The National Power System will be taken up as the objective power system for analysis. By end of 1984 all the existing power systems throughout the country of Bolivia will be interconnected with only one exception of the isolated system in Tarija City, which will be incorporated into the National Power System by 1991 when Pilaya Project will be completed. However, for the 115 kV transmission lines to supply power to Villamontes and Bermejo in Tarija province any new construction of transmission line is not contemplated because of relatively small power demand.

When Pilaya Hydro Power Plant will be put into service by 1991 as the new generating source connected to the National Power System, power to be required for the Eastern Power System will be transmitted by way of the Central Power System from the Southern Power System, as the result of which the transmission line will extend over a total length of about 950 km from Pilaya Power Plant to Waracachi Gas-turbine Power Plant. In particular, it should be noted that the phase angle between Catavi Substation on the Central Power System and Potosi Substation on the Southern Power System will become wide-open. This means that stability of the system at normal operation would be turned into unstability. For this reason, the Survey Team has decided to take up Misicuni Hydro Power Plant as the object for system analysis on assumption that the said power plant would be connected to the Central Power System, in place of Pilaya Hydro Power Plant, by 1991.

(3) Power Demand at Substation End

Power demand at the substation end is estimated on the basis of the data furnished by ENDE. By the way, power demand at the generating end of the total power system in 1991 and 1993 is estimated at somewhat lower figures obtained from the power demand forecast.

The load power factor at each substation end is determined for each substation with a range of 0.80 to 0.97 by due reference to the data furnished by ENDE.

(4) Voltage Regulation

Power system analysis will be made without regard to the tap of main transformer installed at each power plant and substation. Required condenser or reactor capacity has been sought as against the target voltage variation of plus or minus 10 percent. Therefore, for voltage control it may be possible to maintain secondary side voltage of the substations within the acceptable variation range of plus or minus 5 percent by handling of the main transformer tap.

(5) Priority in Operation of Power Generating Facilities

As stated earlier in Chapter 4, the power generating sources of future development in Bolivia will be available mainly from hydro power. Since it is therefore anticipated that the ratio of hydro power generation in the total power system will grow to an overwhelmingly larger share, those generating sources will be put into operation in parallel to the power system by sequential order from the existing hydro power plants to the new power plants. Gas-turbine plants at Oruro and Waracachi will be put into full-time operation for voltage adjustment and correction of unbalanced power flow, together with full operation of the gas-diesel plant at Sucre. This means that all the existing oil-fired diesel power plants will be shut down out of service.

(6) Line and Machine Constants

Line constants will be determined from the data furnished by ENDE. Constants for transformer and generator are determined as specified hereunder:

Primary transient impedance:		
Water turbine-generator	Xd' = 35%	(Machine-based)
Other generators	Xd' = 25%	(")
Main transformer impedance:		
220 kV transformer	X_T = 12%	(Transformer-based)
115 kV transformer	X_T = 10%	(")
66 kV transformer	X_T = 7%	(")
Inertia constant:		
Water turbine generator	M = 7.0	(Machine-based)
Gas-turbine generator	M = 6.0	(")
Diesel generator	M = 9.0	(")

Line constants are as shown in Fig. 13-1. Main transformer capacity and interconnected transformer capacity of the substations are determined from the probable scale of load and from the scale of power flow respectively.

13.2 Power Flow

13.2.1 Premises

(1) In view of the fact that the National Power System may be divided into four different power systems such as North, Central, South and East, the total generating output should be adjusted so as to enable both demand and supply to be kept in balance to the possible extent for each power system separately.

(2) The Southern Power System is featured by its extremely small supply capacity in comparison with probable size of demand until scheduled completion of Pilaya Hydro Power Plant. Therefore, power requirement to cover shortage of supply capacity will be available from hydro power gener ating sources connected to either Central Power System or Northern Power System. However, if Pilaya Hydro Power Plant is put into operation in advance of Misicuni Hydro Power Plant, the Southern Power System will be featured by its excessive large supply capacity over demand. This surplus power will then be transmitted into the Eastern Power System by way of the Central Power System. This means that additional installation of either two (2) circuits of 115 kV transmission or single circuit of 220 kV transmission should be required in parallel with the existing 115 kV transmission line interconnecting over 187 km between the Central Power System and the Southern Power System. Because of this, the Survey Team will make comparative study on the condition that Misicuni Hydro Power Plant is put in operation in 1991 in place of the Pilaya Project.

(3) Any transmission line in question with probable neck of power flow is assumed to have additional installation of the identical transmission line in parallel.

That is to say, there certainly exist same sections where transmission capacity must be increased by construction of another new line in addition to the existing transmission line and the presently proposed new line. Those sections are shown by dotted lines in Fig. 13-2 thru 13-4.

(4) With regard to necessary static condenser capacity or reactor capacity for voltage adjustment of the National Power System, it is planned that the static power condenser or reactor should be installed so as to enable 66 kV bus voltage on the secondary side of the main substation to be maintained at a constant voltage.

13.2.2 Calculation Result

(1) Power Flow Adjustment

Although the National Power System consists of 220 kV and 115 kV transmission lines as the trunk line, it is considered preferrable that the backbone line should be at the rating of 220 kV when viewed from the topographical expansion of the national land in Bolivia. As a normal practice, in any case where power is transmitted through the 115 kV line over a long distance of 100 km, transmission capacity per one circuit may be estimated at about 35 MW. In particular, as the transmission line between Catavi Substation and Potosi Substation extends over 187 km, the phase angle at transmitting and receiving ends of the transmission line will become wide open.

When in 1991 Pilaya Hidro Power Plant will be put into operation throughout the Southern Power System, power output from Pilaya Hydro Power Plant will be transmitted, as viewed from power flow, into the Eastern Power System by way of the Central Power System. If so, it will become essential to construct two (2) circuits of the 115 kV line or a single circuit of 220 kV line in parallel with the existing 115 kV transmission line between Catavi Substation and Potosi Substation. As noted from Fig. 13-2, the phase angle will be limited to 22.1° between both-end substations by installation of the 115 kV 3 circuit line. However, by installation of the 115 kV 2 circuit line the angle will exceed 30° and then the phase angle between Pilaya Power Plant and Waracachi Gas-turbine Power Plant will become wide open, thus causing a problem with regard to synchronizing operation between synchronous generators.

On the other hand, in the Eastern Power System consisting of the 66 kV transmission lines, all the 66 kV lines proposed at present will have to be converted into double circuits in the latter half of the 1980s so as to meet increasing demand.

Besides all those lines stated above, a new 66 kV line will have to be constructed in parallel with the existing 66 kV transmission line from Carachipampa Substation to Sucre Substation. Incidentally, power supply to the FANCESA cement factory to Sucre should be planned by 66 kV transmission to prevent possible voltage drop.

(2) Voltage Adjustment

Voltage adjustment must be made to ensure required balancing by use of the generators and static power condensers or reactors connected to the power system and, besides, must be made by the transformer tap.

After power flow adjustment to seek required condenser capacity so as to maintain possible voltage within a tolerance of plus or minus 10 percent at main power plants or substations without handling of the transformer tap, the following values are obtained.

Plants	1991 with Pilaya (MVAR)	1991 with Misicuni (MVAR)	1993 (MVAR)
Kenko	53.4	54.2	63.8
Vinto	-25.5	-25.5	-25.4
Tarucapata	-1.5	-1.5	7.0
Cochabamba	41.9	38.4	44.8
Catavi	23.1	20.2	21.5
Oruro	45.7	45.7	45.7
Telamayu	4.1	4.1	9.9
Waracachi	66.6	66.6	79.7
Total	207.8	202.2	247.0

The load power factor of the National Power System would range from 0.8 to 0.97, as stated earlier, but generally at average of 0.85. For supply of reactive power there are to be considered two alternative methods of supply by way of generators or static power condensers to be installed at substations near power demand consuming area.

Since the National Power System constitutes the long-distance transmission line, it would be most appropriate to install static power condensers at any large substation close to power demand consuming area in view of the merits to mitigated power transmission loss and to maintain proper voltage regulation.

As Pilaya Hydro Power Plant is situated at the extreme south of the Southern Power System, bus voltage will be apt to rise up. However, by tap adjustment of the main transformer, it would be possible to maintain the secondary bus boltage within a tolerance of plus or minus 5 percent of the rating voltage.

13.3 System Stability

Since the National Power System expands far and wide over the large territory of Bolivia, special care must be taken so as to maintain the system stability. Especially, since ENDE gives the first priority to the economy the transmission line is, in many instances, interconnected by a single circuit between the power systems. Normally, the existing 115 kV transmission line is designed for a transmitting capacity of 90 MW per each circuit as may be determined from current capacity of the conductor. It should be borne in mind, however, that the capacity should be limited to about 35 MW when the total length exceeds 100 km.

13.3.1 System Disturbance Conditions

Stability calculation is made on the basis of 1993 when Misicuni Hydro Power Plant will be put into operation in the National Power System. No remarkable change will arise, after that year, in the composition of power systems of North, Central, South and East.

Stability calculation is based chiefly upon the Pilaya Hydro Power Project and assumption that there would occur 3 phase short-circuit fault in the following transmission sections, so that study has been made to see if the main generator connected to the National Power System can still continue its stabilized operation after remedy of such fault.

Fault transmission lines

Pilaya - Tarija :	115 kV, 1 cct line
Pilaya - Camargo :	115 kV, 2 cct lines
Camargo - Telamayu :	115 kV, 1 cct line
Camargo - Potosí :	115 kV, 1 cct line
Potosí - Catavi :	115 kV, 3 cct lines

Generator stability to be checked

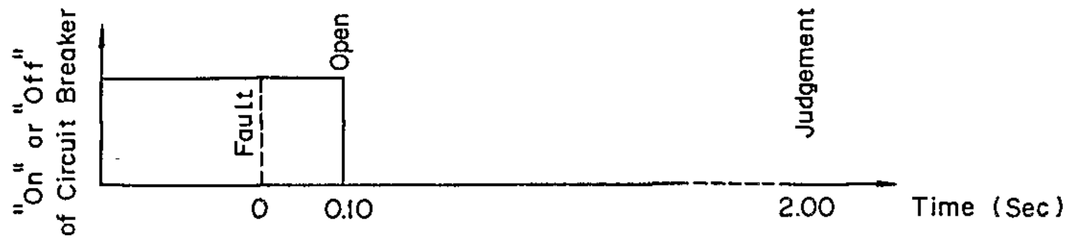
Sakhahuaya (1), Tiquimani (2), Corani (3), Sta. Isabel (4), Palillada (5), Pilaya (6), Icla (7), Waracachi I (8), Waracachi II (9), Misicuni (10)

In the judgement from the calculation result, possibility of stabilized operation of generators has been assured if all the generators at 10 power plants aforementioned can continue operation without step out as the result of 2 second stability calculation after remedy at 5 Hz from short circuit fault occurrence on the 3 phase, single circuit in the transmission lines.

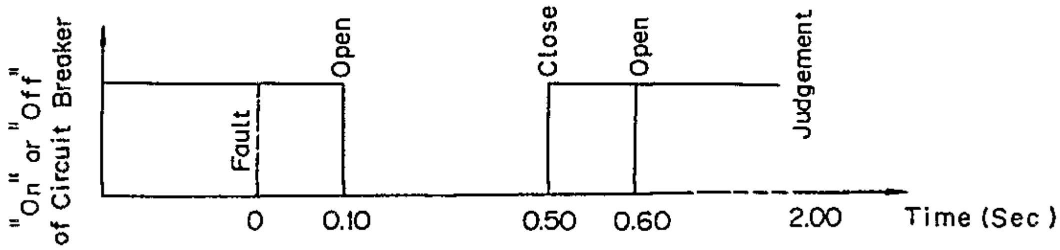
With regard to the transmission lines of more than 2 circuits between Pilaya Power Plant and Camargo Substation and between Potosí Substation and Catavi Substation, the assumed condition is such that the fault section due to 3 phase short circuit on one circuit would be once reclosed for continuation of the fault and then succeed in final interruption.

Fault conditions are illustrated as follows:

In case of 1cct,



In case of more than 2cct



Generally in many instances, the transmission line fault arises from single phase grounding fault. However, if transient stability can be secured at 3 phase short-circuit fault, it may be justifiable to see that single phase reclosing (or 3 phase reclosing) due to single phase grounding fault should be more stabilized. 3 phase reclosing on the one route, single circuit transmission line (between Camargo Substation and Potosí Substation or Camargo Substation and Telamayu Substation) is possible on such condition that other circuits from the loop system. By this way it is possible to increase stability of the power system.

13.3.2 Calculation Result

The result of stability calculation is as shown in Table 13-1. Generator swing curves are shown from Fig. 13-5 thru Fig. 13-10.

Table 13-1 Result of Transient Stability

Fault lines	Kind of fault	Fault clearing time	Judgement	Case
Pilaya-Tarija	3LG-O	0.10 sec	Stable	No.1
Pilaya-Camargo	3LG-O-C-O	0.10 sec	"	No.2
Camargo-Telamayu	3LG-O	0.10 sec	"	No.4
Camargo-Potosi	3LG-O	0.10 sec	"	No.6
Potosi-Catavi	3LG-O-C-O	0.10 sec	Step out	No.5
Potosi-Catavi	3LG-O-C	0.10 sec	Stable	N0.3

The transmission line between Potosí Substation and Catavi Substation is featured by its greatest power flow throughout the whole National Power System and, besides, by its longest distance. Therefore, if one out of the three circuits goes into final interruption due to the line fault, the two power plants of Icla and Pilaya in the South Power System sould go into final interruption and the National Power System would then he forced into abrupt load shedding in consequence.

13.4 Short Circuit Capacity

In calculating the short circuit capacity, study will be made on the basis of power flow simulating the power system to be operated in 1993. Namely, study will be based on the prerequisite condition that generators fully capable of meeting demand on the power systems in 1993 will be paralleled into the power system and the transmission lines and transformers should be those to be required for constitution of the power system in 1993.

13.4.1 Premise

The value Xd' will be used to express the generator reactance and the positive phase impedance will be used for both transmission line and transformer.

13.4.2 Calculation Result

Short circuit capacity on the 115 kV bus related directly to the Pilaya Hydro Power Project is calculated as follows:

	Short circuit capacity on 115 kV buses (MVA)	(kA)
Pilaya	375	984
Camargo	357	936
Potosí	488	1,279
Telamayu	234	614
Tarija	217	570

From the calculated result above, required breaking capacity for the circuit breaker directly related to the Pilaya Hydro Power Project may be determined as follows, even allowing for possible future increase of short circuit capacity on the 115 kV side due to the power system expansion:

Circuit breaker for 115 kV line

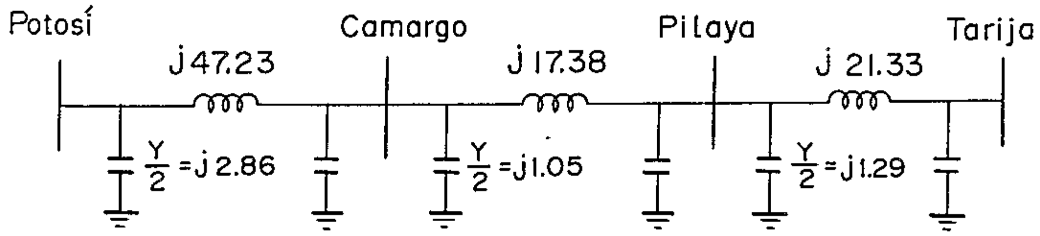
3,140 MVA (IEC code 145 kV, 12.5 kA)

Interrupting capacity for the 115 kV circuit breaker as above is of minimum requirement. Fig. 13-11 shows short circuit capacity on each bus of power plants and substations in the National Power System.

13.5 Ferranti Effect on Pilaya Transmission Line

Total length from Potosí Substation to Tarija Substation extends over about 300 km. Therefore, if the 115 kV transmission line is charged from Potosí Substation to Tarija Substation via Camargo Substation and Pilaya Power Plant, voltage rise may be anticipated from Ferranti effect on the receiving end.

The Survey Team has obtained the following values after study on possible voltage rise by due reference to line constants shown in Fig. 13-1.



$$\left|Er\right| = \frac{\left|Es\right|}{1 + j\frac{Y}{2} \times jZ} = \frac{\left|Es\right|}{1 + j0.0286 \times j0.4723} = 1.014\left|Es\right|$$

	Potosi	Camargo	Pilaya	Tarija
Voltage	100.0 %	101.4 %	102.6 %	104.7%

Highest voltage rise is anticipated for Tarija Substation due to Ferranti effect on the transmission line related to the Pilaya Hydro Power Project. As far as the power system analysis result is concerned, voltage on the 115 kV bus of Potosí Substation is estimated nearly at 100 percent. Therefore, in case of charging into the transmission line in sequence from Potosí Substation to Tarija Substation, possible voltage rise from Ferranti effect on each 115 kV bus of Camargo Substation, Pilaya Power Plant and Tarija Substation can be restrained within allowable limit.

13.6 Problem Involved in Power System Composition

The following problems exist from view points of wide land expansion of Bolivia and distribution of power generating sources in comparison with their scale and distribution of power demand.

(a) Power demand in the Southern Power System by 1984 scheduled for completion of Icla Hydro Power Plant is estimated at 50.2 MW. Therefore, the balance of 49.4 MW after subtraction of 50.2 MW demand from total capacity of 99.6 MW totalling available generating capacity of 90 MW plus Icla Hydro Power plus 9.6 MW available from other hydro power sources will have to be transmitted into the Central Power System. This means construction of a new transmission line.

(b) Power flow into the Central Power System will grow larger when Pilaya Power Plant will be completed. To further explain this, it should be noted that hydro power supply capacity in the Southern Power System by 1991 scheduled for completion of Pilaya Power Plant is estimated at 186.6 MW while power demand at generating end is estimated at 74.4 MW. This necessitates transmission of more than 100 MW into the Central Power System.

(c) Transmission capacity of the existing 115 kV line between Potosí Substation and Catavi Substation is estimated at about 35 MW when viewed from its line length and conductor size. Therefore, at completion of Icla Hydro Power Plant either single circuit of 220 kV transmission line or double circuit of 115 kV transmission line should be newly constructed, allowing for probable power flow increase resulting from completion of Pilaya Hydro Power Plant.

The Survey Team made comparative study on the alternative plans for construction of 2 circuit of 115 kV line or 1 circuit of 220 kV line. The result reveals that in case of 220 kV line both Pilaya and Icla Hydro Power Plants would step out by any fault occur while those hydro power plants could still continue stabilized operation if any fault should occur on 1 circuit of 115 kV line.

With this result in mind, the Survey Team has made its study on the condition that the new 2 circuit of 115 kV transmission line would be constructed between Potosí Substation and Catavi Substation.

(d) The 2 circuit of 115 kV transmission line are to be planned for construction between Potosí Substation and Catavi Substation with regard to the Icla Hydro Power Plant. However, construction cost for one of two circuits should be shared by Pilaya Project.

APPENDIX-IV shows power flow and stability calculation result for the 220 kV interconnection between Potosí Substation and Catavi Substation.

Fig. 13-1 IMPEDANCE MAP

INTERCONNECTED POWER SYSTEM

Year : 1993

Unit : 100 MVA Base

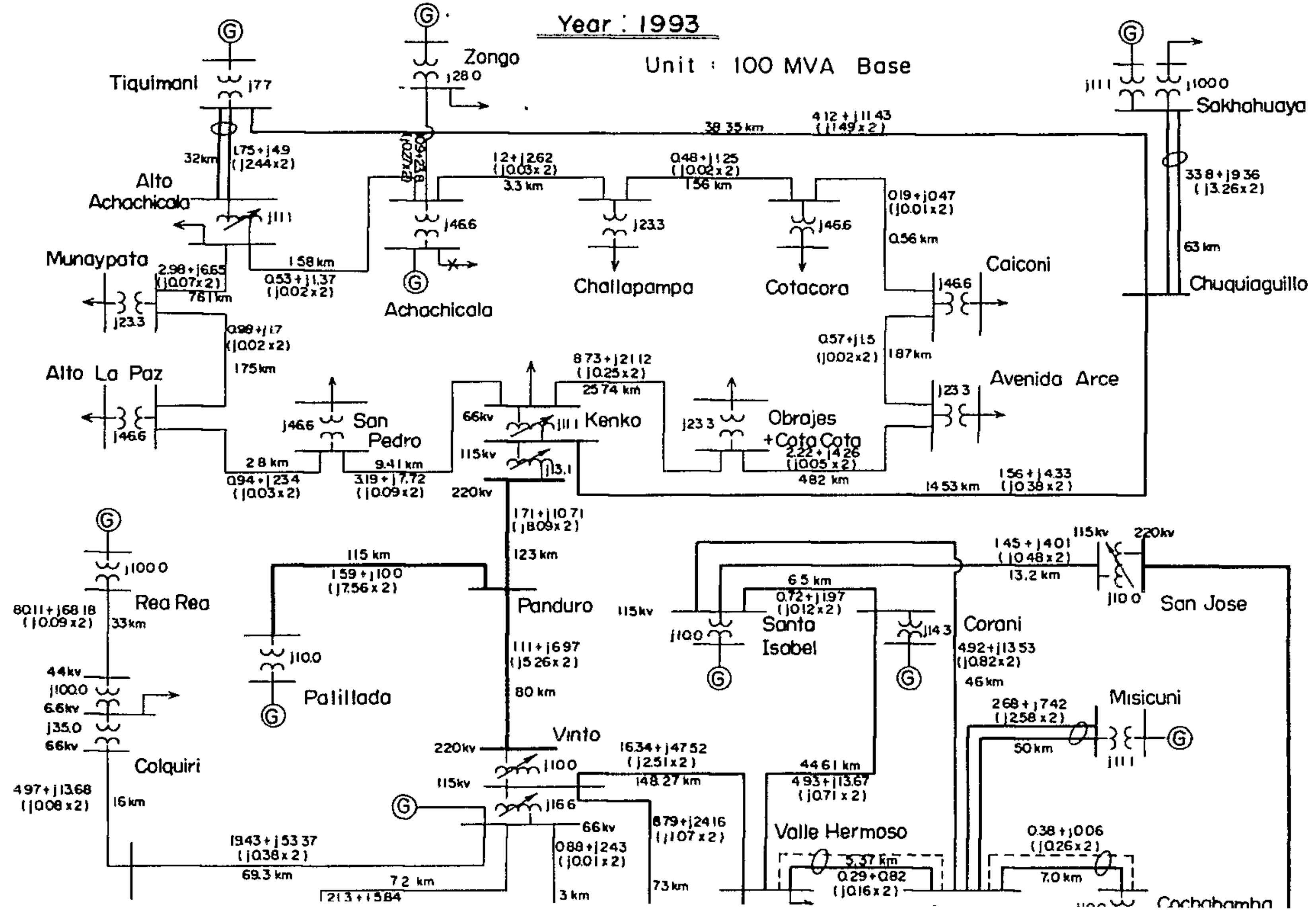


Fig. 13-1 IMPEDANCE MAP

INTERCONNECTED POWER SYSTEM

Year : 1993

Unit : 100 MVA Base

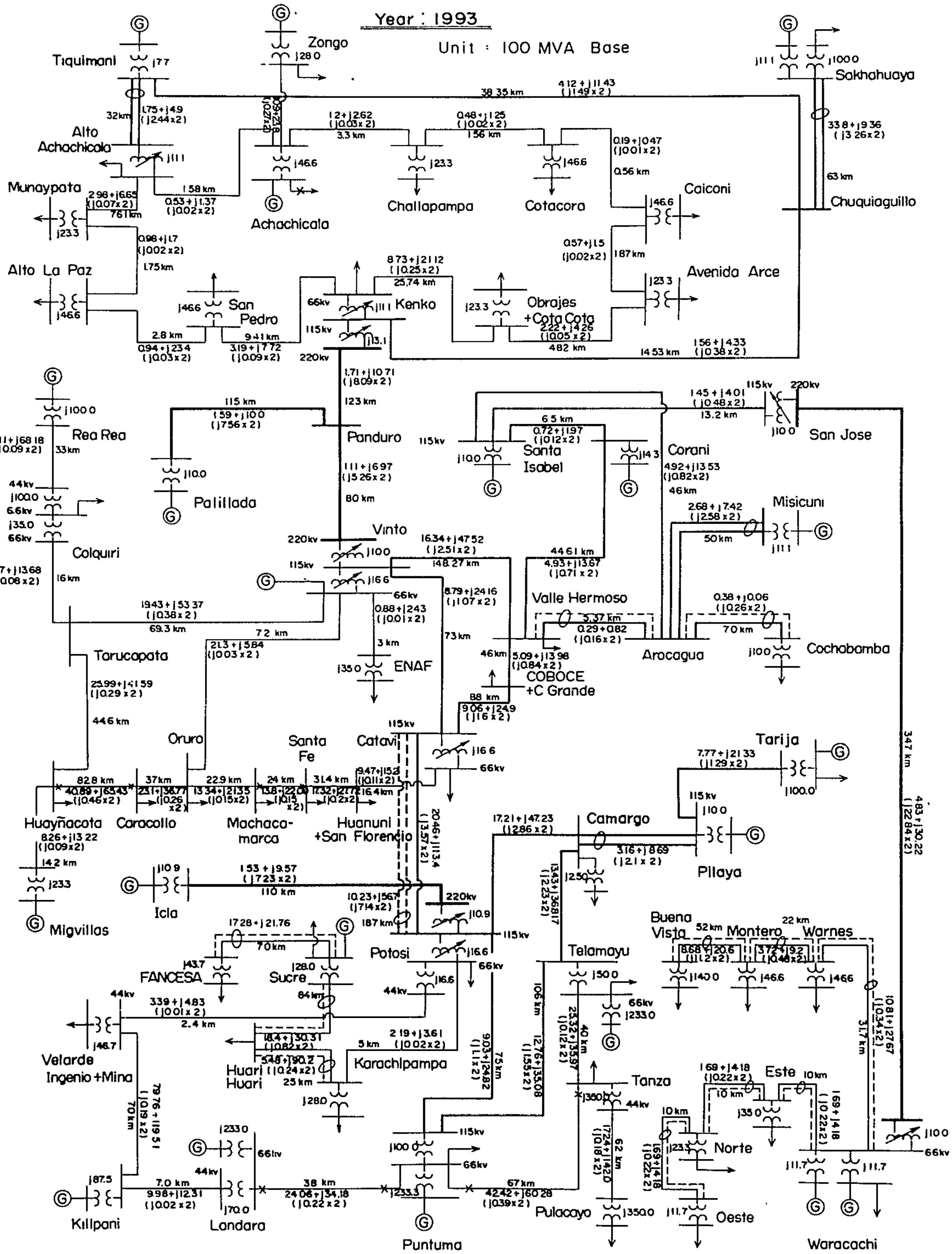


Fig. 13-2 POWER FLOW with PILAYA

INTERCONNECTED POWER SYSTEM

Year : 1991

Unit : MW+jMVAR, % Voltage, |Phase Angle

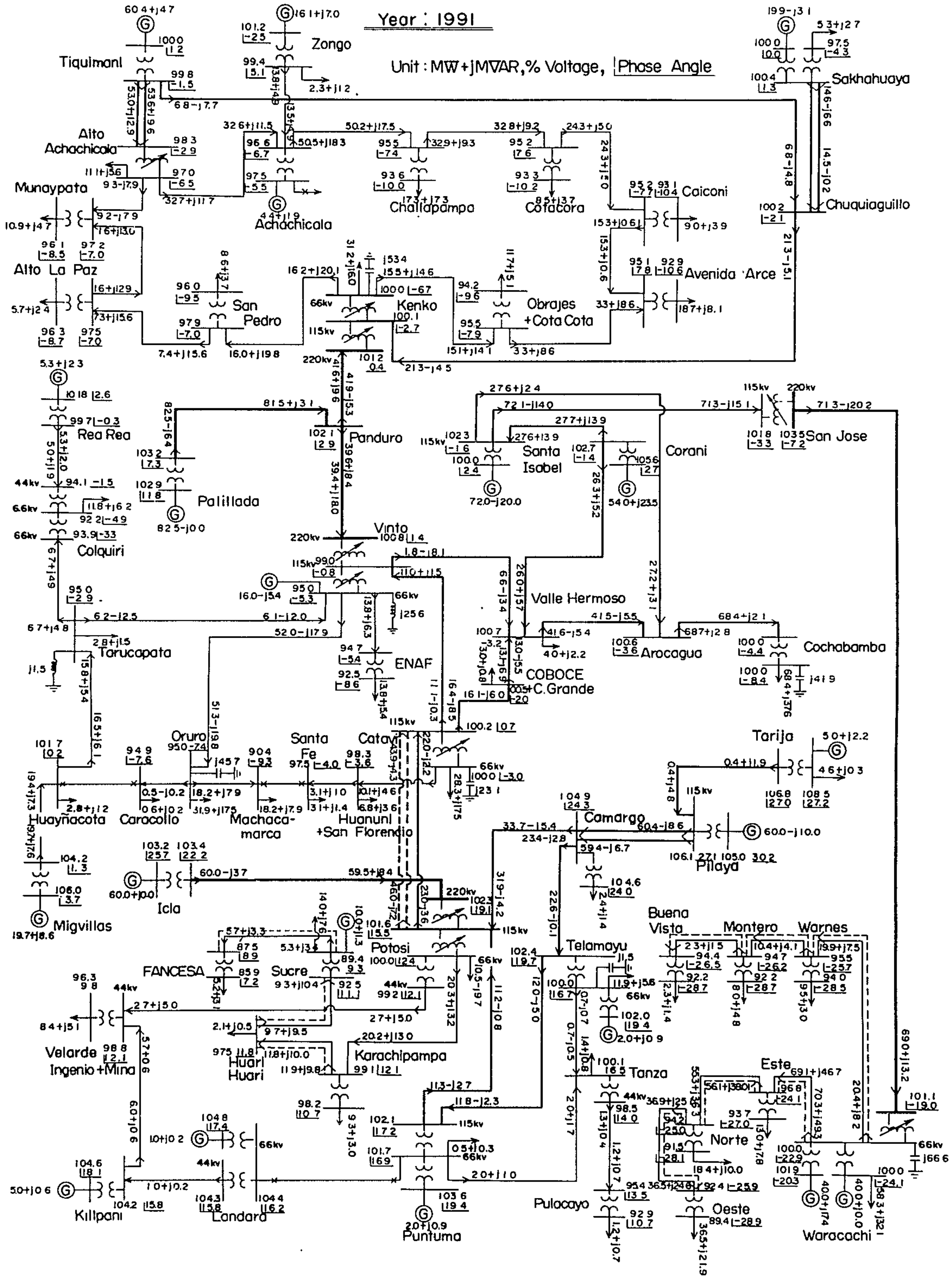


Fig. 13-3 POWER FLOW with MISICUNI

INTERCONNECTED POWER SYSTEM

Year : 1991

Unit: MW + jMVAR, % Voltage, |Phase Angle

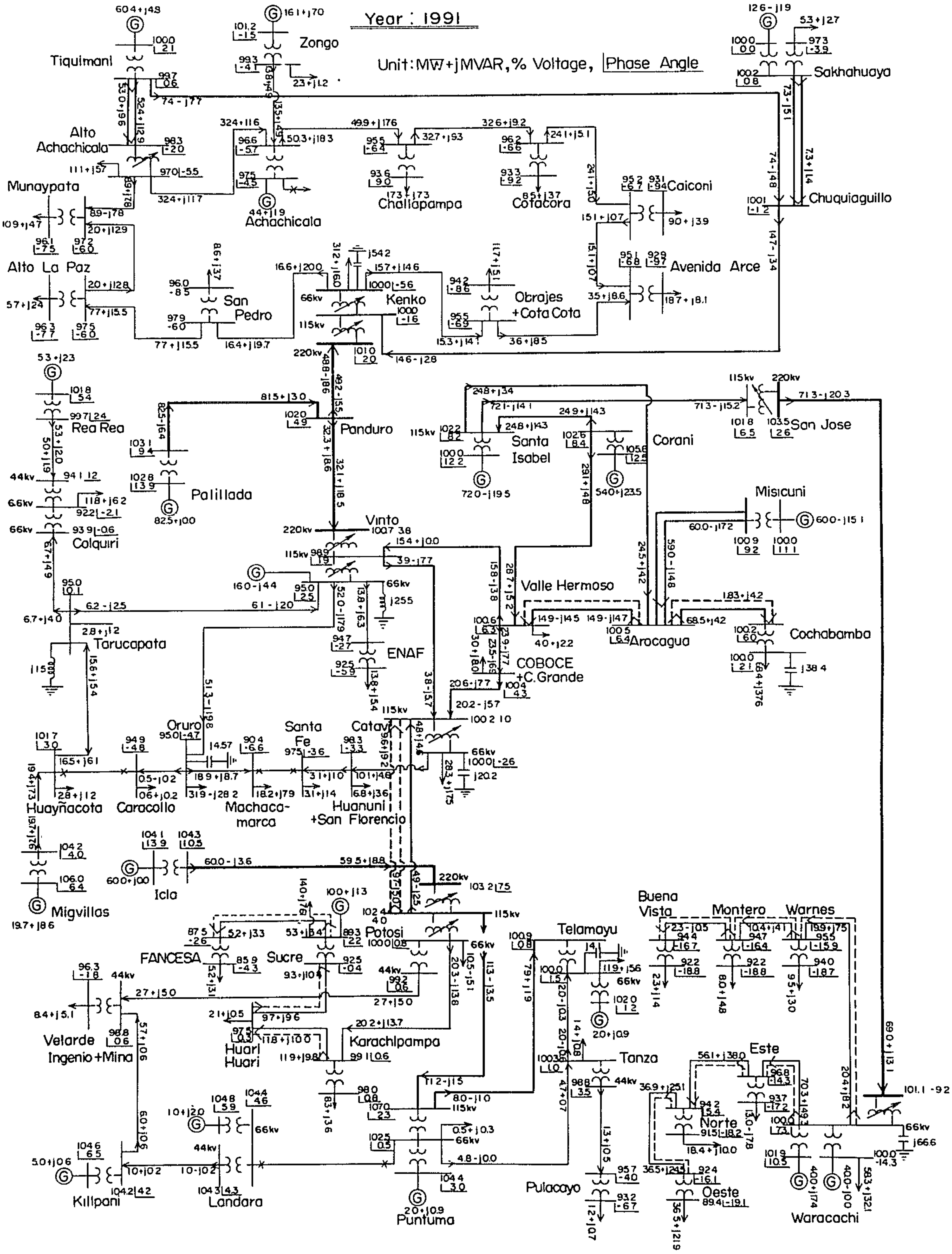


Fig. 13-4 POWER FLOW

INTERCONNECTED POWER SYSTEM

Year : 1993

Unit: MW+jMVAR, % Voltage, |Phase Angle

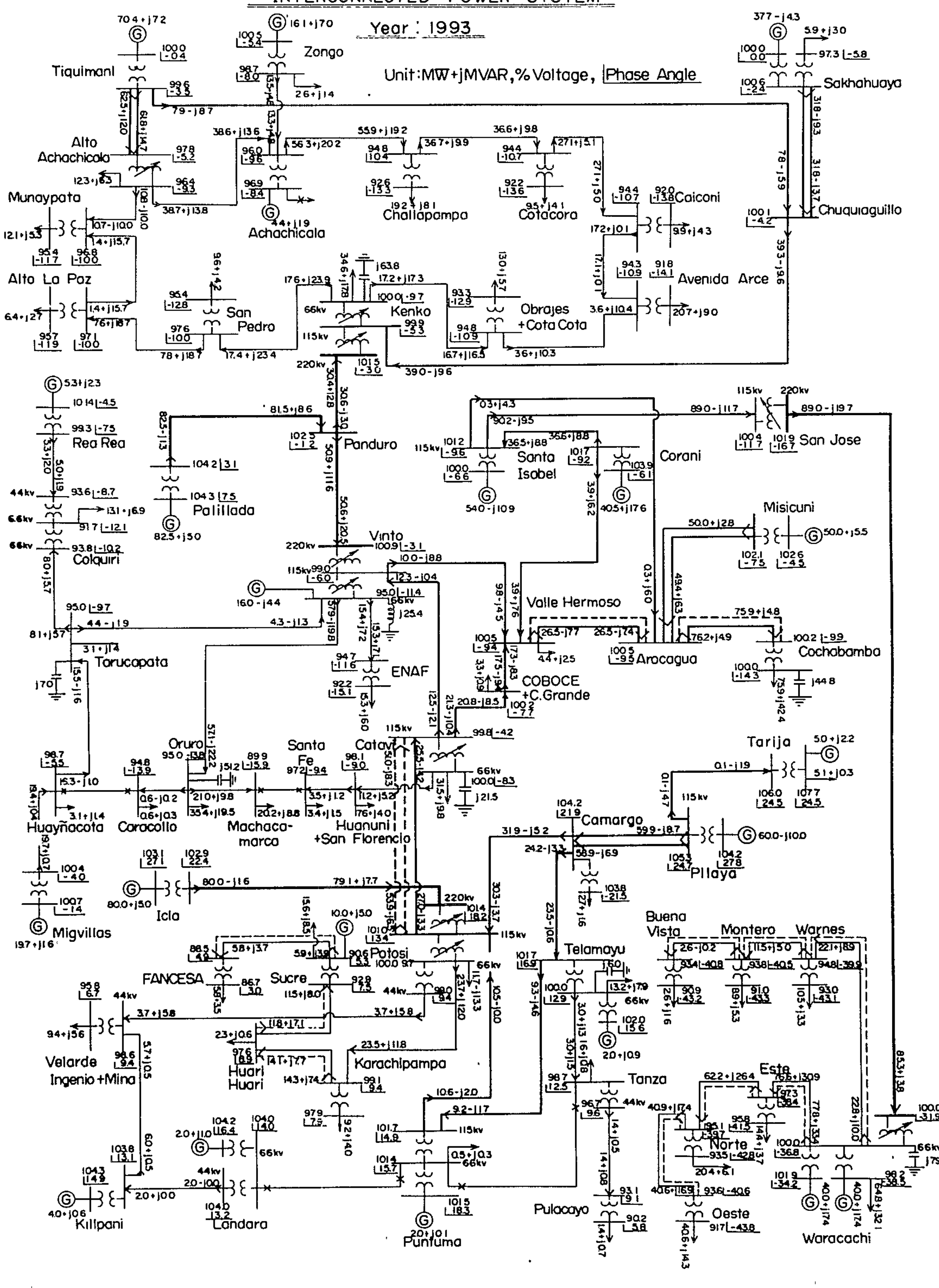


Fig. 13-5 Case No.1 Pilaya-Tarija Open

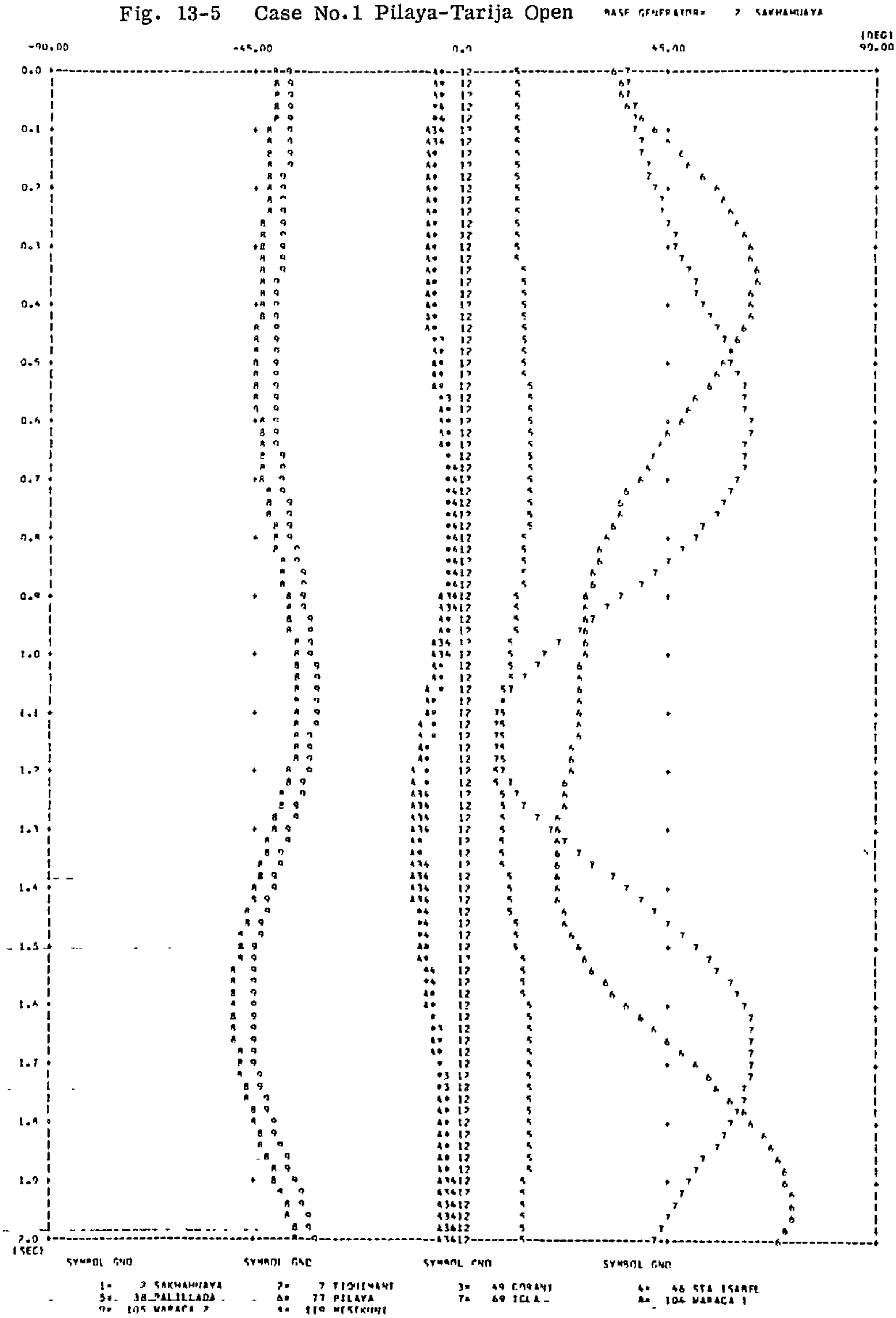


Fig. 13-6 Case No.2 Pilaya-Camargo 1-CCT Open BASE GENERATOR= 2 SAKHAHUAYA

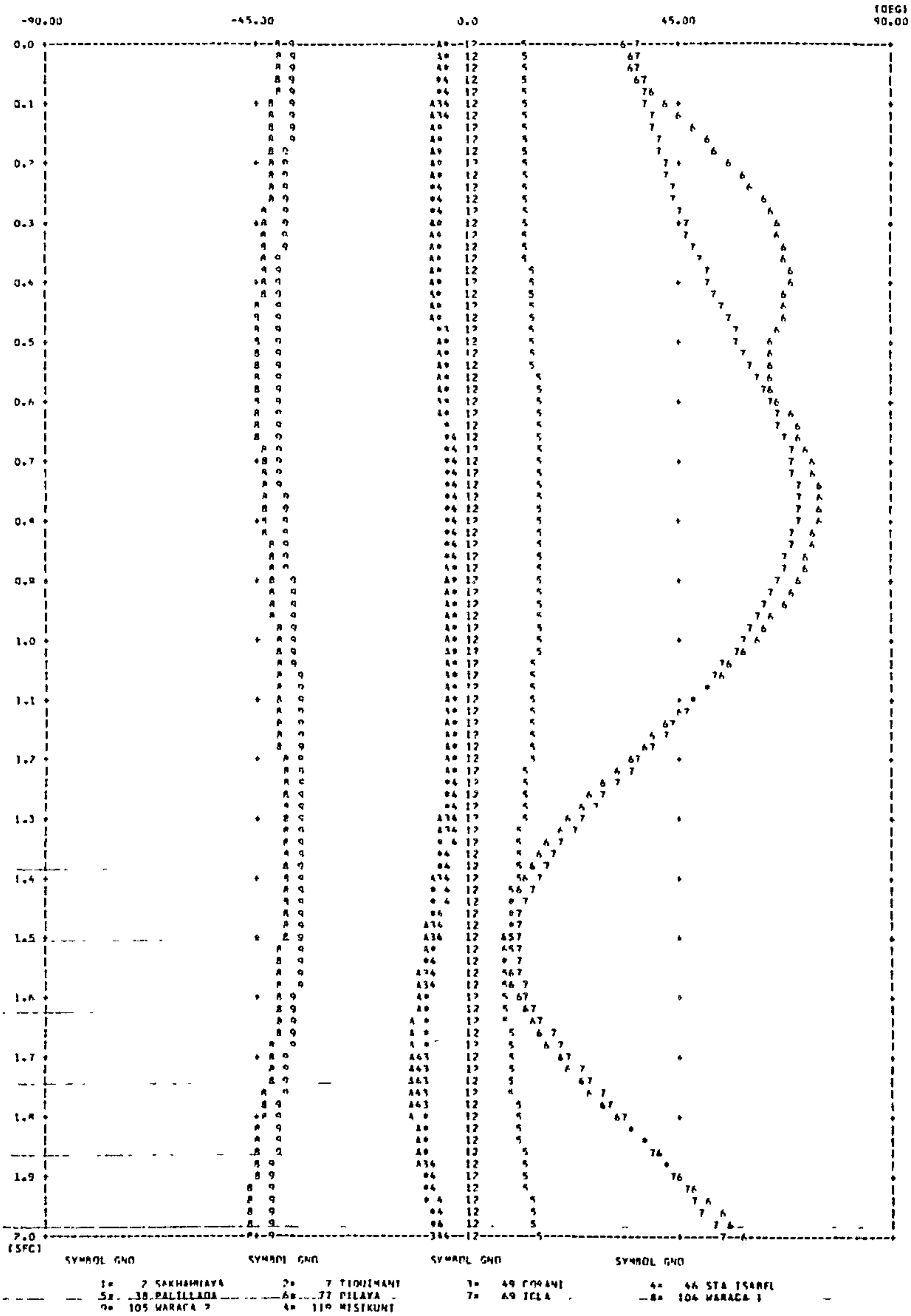


Fig. 13-7 Case No.3 Potosi-Catavi 1-CCT Rec BASE GENERATOR= 2 SAKHAHUAYA

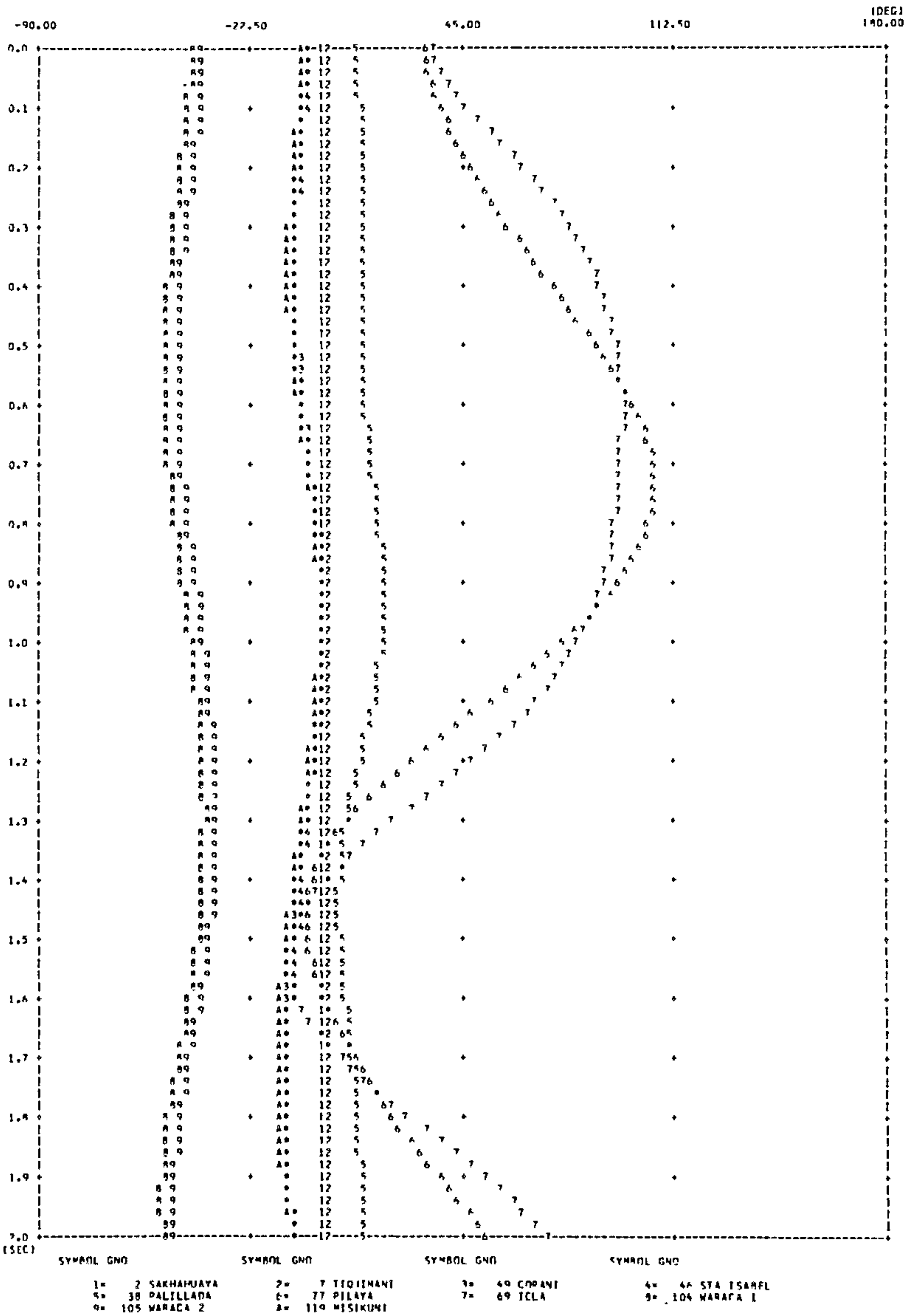
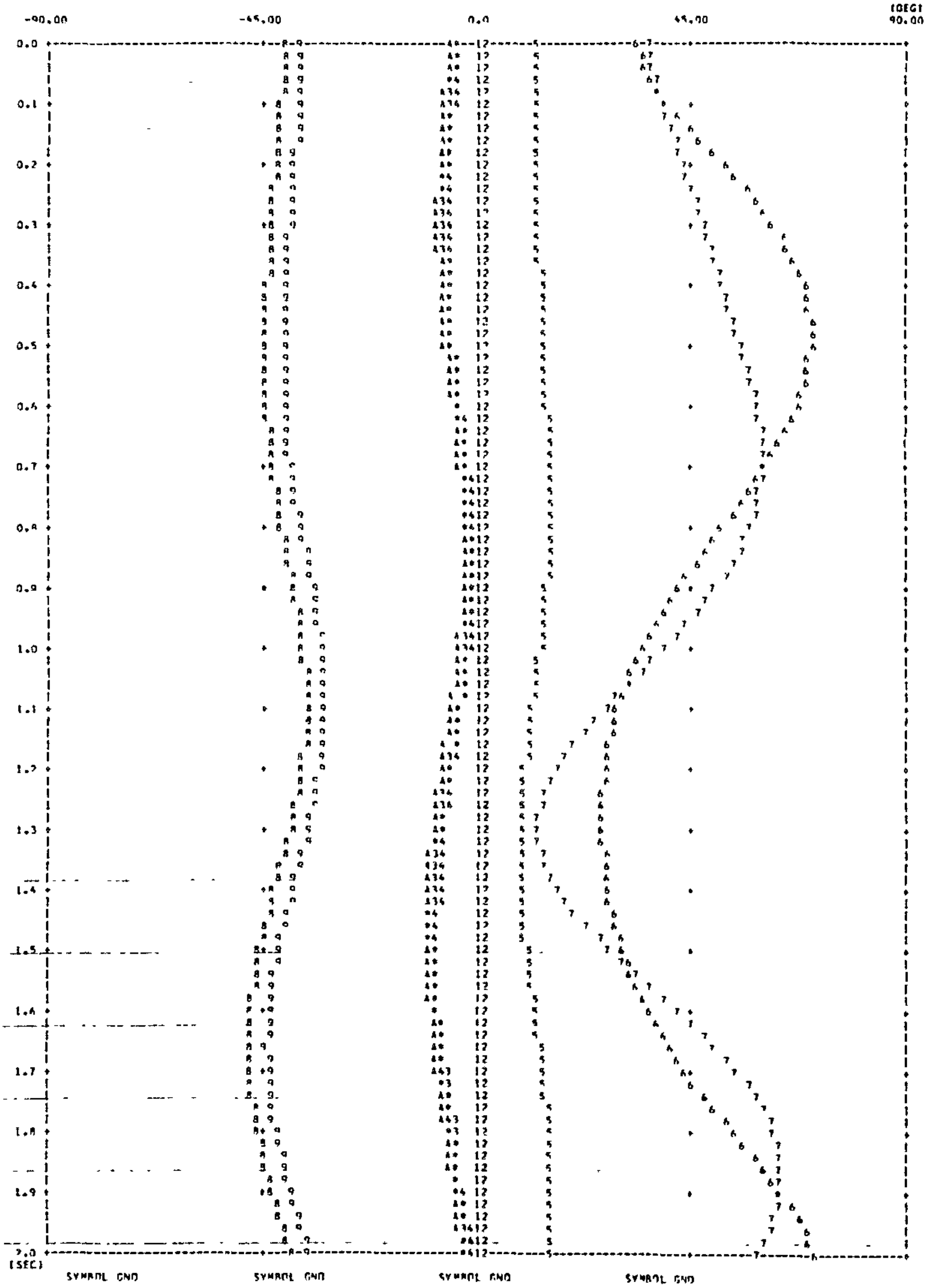


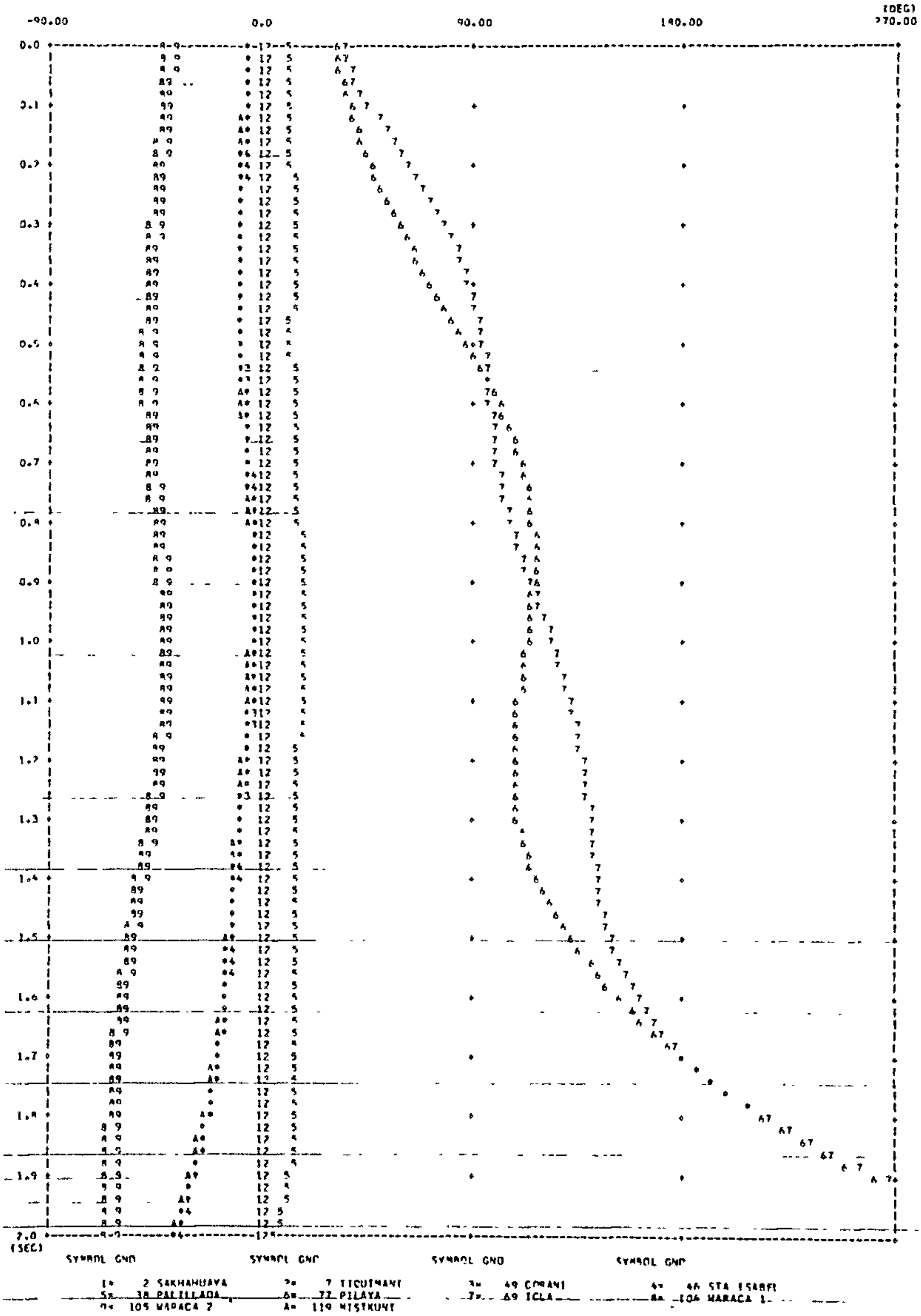
Fig. 13-8 Case No.4 Camargo-Telamayu Open BASE GENERATOR= 2 SAKHAHUAYA



SYMBOL GNO

1= 2 SAKHAHUAYA	2= 7 TIQUIMANI	3= 49 CORANI	4= 46 STA ISABEL
5= 38 PALILLADA	6= 77 PELAYA	7= 69 ICLA	8= 104 MARACA 1
9= 105 MARACA 2	A= 119 MESIKUNI		

Fig. 13-9 Case No.5 Potosí-Catavi 1-CCT Open BASE GENERATOR= 2 SAKHAHUAYA



SYMBOL GND	SYMBOL GND	SYMBOL GND	SYMBOL GND
1= 2 SAKHAHUAYA	2= 7 TICUIMANI	3= 49 CORANI	4= 46 STA ISABEL
5= 38 PALILLADA	6= 72 PILAYA	7= 69 ICLA	8= 104 MARACA 1
9= 105 MARACA 2	A= 119 MISTKUNI		

Fig. 13-10 Case No.6 Camargo-Potosí Open

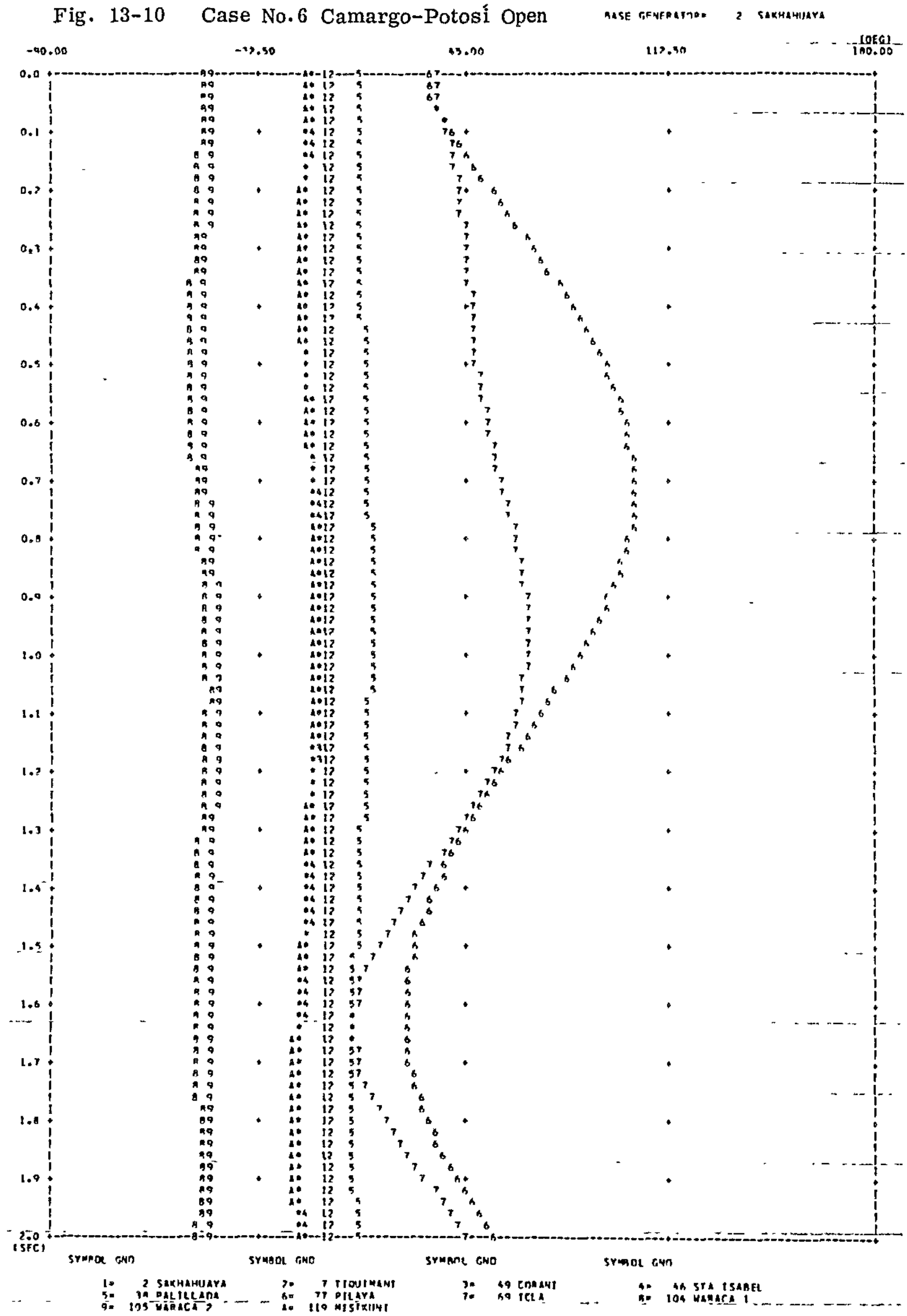


Fig.13-11 SHORT CIRCUIT CAPACITY

INTERCONNECTED POWER SYSTEM

Year : 1993

Unit : MVA

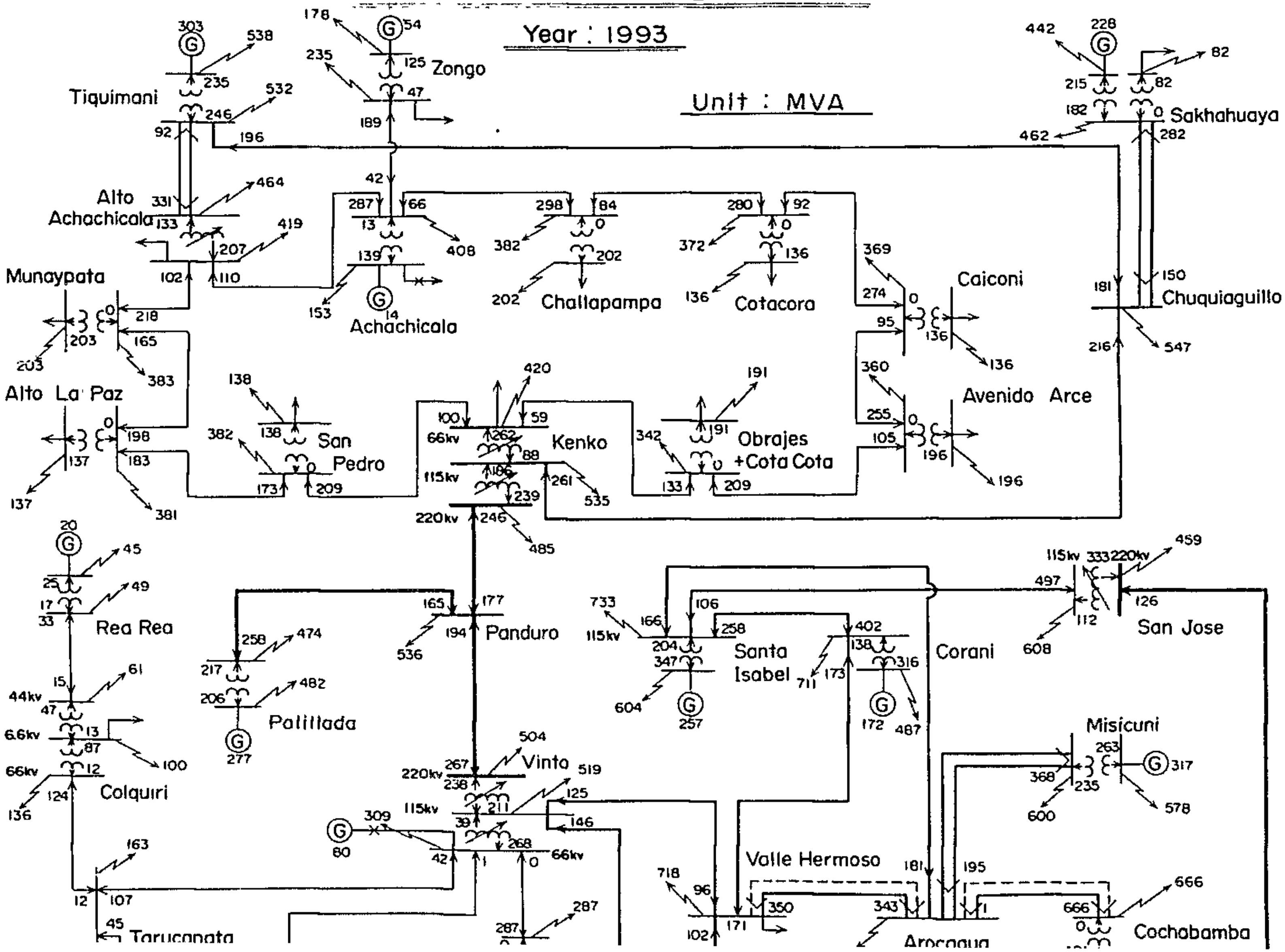
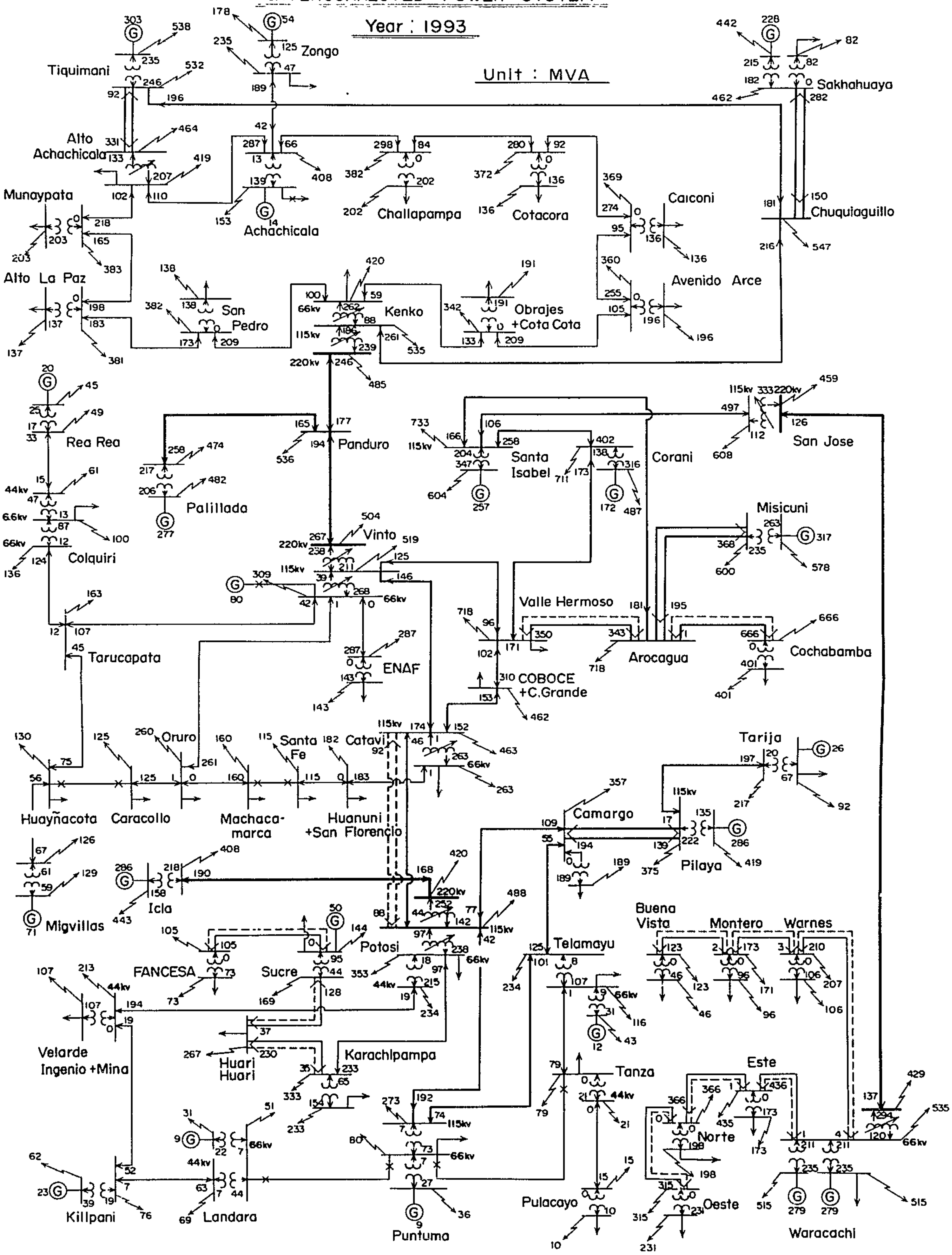


Fig. 13-11 SHORT CIRCUIT CAPACITY

INTERCONNECTED POWER SYSTEM

Year : 1993

Unit : MVA



CHAPTER 14

ECONOMIC EVALUATION

CHAPTER 14 ECONOMIC EVALUATION

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CHAPTER 14. ECONOMIC EVALUATION

14.1 Basic Considerations

14.1.1 General

The Pilaya Project is to follow the "Electric Power Development Program (1980-1990)" presently being planned by ENDE, and is for studying whether the Pilaya Hydro Power Project among a number of hydroelectric development schemes can emerge in the 1990s as an undertaking which is feasible.

With regard to the Project, a study report (Planta Hidroelectrica Pilaya, Estudio de Factibilidad) was prepared by ENDE in April 1978, while further, a preliminary investigation report was prepared by a JICA Survey Team in March 1980. Based on this report, investigation works necessary for feasibility level study were carried out on the dam site and the powerhouse site. As a result of these investigation works, it was found that the thickness of the sand-gravel layer deposited at the river bed of the dam site was 20 m greater than assumed in the preliminary investigation report. It was also found that access roads are longer than the roads estimated in the preliminary investigation report and construction of sedimentation basins of grand surface type impracticable so that it would be unavoidable for them to be provided inside a tunnel, as a result of which the cost of the Project will be higher than that in the preliminary investigation report. Meanwhile with regard to electricity facilities, it was found that in order for Pilaya Hydro Power Plant to be interconnected with the National Power System it will be necessary to add a 115 kV transmission line with double circuits, parallel to the existing 187 km, 115 kV transmission line between Potosi Substation and Catavi Substation. Consequently, the construction cost of the Pilaya Hydro Power Project including the necessary power transmission, distribution and transforming facilities was greatly increased. The economic evaluation described in this chapter was carried out based on the revised construction cost.

14.1.2 Method of Evaluation

(1) The evaluation of the economic effect of a power generation project is done in the form of a cost comparison with an alternative project which offers "equal service" as the said project. The alternative project offering "equal service" in this case does not mean another hydro power project* but an alternative thermal plant which would be a measure for all power development projects.

Concerning the selection of alternative generating facility capable of offering such "equal service" that would be fitting in view of the conditions for

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* Regarding the order of development of hydro power project proposed, a thermal power plant serving as an alternative project is used as a measure, and their development should be commenced from the hydro power project which will provide the greatest benefit.

procuring combustibles in Bolivia and the fact that thermal power generating facilities planned for the future are all gas turbines, a gas turbine using natural gas as combustibles would be optimum. Therefore, a gas turbine generating facility is the most suitable taking into consideration of the real situation in Bolivia, an oil-fired thermal or coal-fired thermal not being appropriate as an alternative facility in Bolivia.

(2) The combustibles for the alternative thermal power generating facility at present and in the future will be natural gas. The price of natural gas presently being purchased by ENDE is free of charge at the well head. This is, ENDE is only paying to the Yacimientos Petroliferos Fiscales Bolivianos (YPFB) what corresponds to the cost of laying a pipeline, and therefore, the fuel cost (2.7 US mills/kWh) is very low. However, the International Bank for Reconstruction and Development (World Bank), as will be described later, has advised ENDE to evaluate the price of natural gas by opportunity cost, and ENDE is using this opportunity cost for making comparisons with future hydro power development projects.

(3) The costs of the Pilaya Hydro Power Project and the alternative gas turbine power plant are both economic costs. In effect, direct taxes, indirect taxes and government subsidies are not included. Further, regarding the shadow prices of labor and Bolivian currency, it was considered that they would be evaluated by market prices and the official rate. These costs would consist of construction cost, operation and maintenance costs, fuel cost (case of gas turbine), and cash flows developing these by year are to be discounted by the opportunity cost of capital for both the Pilaya Hydro Power Project and the alternative gas turbine project.

(4) Discount Rate and Opportunity Cost of Capital

The discount rate, i, being applied to many projects in Bolivia is 12%. This is the marginal rate of return expected of all projects irrespective of the actual interest rates at which loans are made to the projects. The Survey Team, upon discussions with ENDE, will discount the cash flows at the above-mentioned i = 12%, but at the same time, will carry out studies for i = 10% and i = 14%.

14.2 Total Cost of Pilaya Hydro Power Project

The total cost of the Pilaya Hydro Power Project will consist of the construction costs of the dam, powerhouse, transmission lines, substations, etc., operation and maintenance costs, and facilities renewal costs after elapsing of the economical service lives.

14.2.1 Construction Cost

(1) Power Generating Facilities

As shown in Table 11-3, the total construction cost (without interest during construction) of Pilaya Hydro Power Plant, including the cost of preparatory works, is estimated to be US$152,099,000 of which the foreign currency portion would amount to US$82,465,000 (54.2%) and the domestic currency portion US$69,634,000 (45.8%).

	US Dollars
Generating Facilities	127,588,000
Preparatory Works	24,511,000
Total	152,099,000

(2) Power Transmission and Transformation Facilities

The construction cost of these facilities which are connected with the Pilaya Hydro Power Plant are as follows:

	US Dollars
Transmission Lines	43,782,000
Transforming Equipment	3,908,000
Total	47,690,000

(3) Contingency, Consultant Fee and ENDE Administration Cost

As contingency costs 5% of the foreign currency portion and 10% of the domestic currency portion of the direct construction cost were respectively considered. The consultant fee and the ENDE administration cost were computed based on man-months necessary for implementing the Project. These costs are as indicated below.

	US Dollars
Contingency	14,509,000
Engineering fee and ENDE Administration Cost	9,340,000
Total	23,849,000

The breakdown of disbursements by year of the various costs under Clauses (1), (2) and (3) above are as shown in Table 14-1.

Table 14-1 Annual Construction Cost

Unit: US$$10^3$

	1983	1984	1985	1986	1987	1988	1989	1990	Total
1. Construction cost for Pilaya Project									
A Generating facilities	0	0	7,624	23,067	29,263	29,503	29,930	8,201	127,588
B Transmitting facilities	0	4,825	0	0	5,865	22,152	7,840	7,008	47,690
C Preparatory works	0	18,686	5,825	0	0	0	0	0	24,511
D Contingency	0	2,006	1,055	1,684	2,310	3,481	2,792	1,181	14,509
E Engineering & ENDE adm.	840	700	920	870	1,305	1,725	1,465	1,515	9,340
Total	840	26,217	15,424	25,621	38,743	56,861	42,027	17,905	223,638
2. Construction cost for alternative gas turbine									
A Generating facilities	-	-	-	-	-	-	26,190	17,460	43,650
B Contingency and ENDE adm.	-	-	-	-	-	-	2,401	2,401	4,802
Total	-	-	-	-	-	-	28,591	19,861	48,452

14.2.2 Operation and Maintenance Cost

The operation and maintenance cost may be divided into personnel allowance and maintenance and repair cost, and the ratios of these costs to direct construction cost are statistics-wise more or less the same for all countries. However, taking it into consideration how the hydro power facilities in the possession of ENDE and BPC in Bolivia have been operated actually, the operation and maintenance cost for the various facilities will be as indicated below.

a) Pilaya Hydro Power Plant

152,099,000 x 0.006 = US$913,000

b) 115 kV Transmission Lines

43,782,000 x 0.010 = US$438,000

c) 115 kV Substation and Telecommunications Equipment

3,908,000 x 0.0125 = US$49,000

Total (a + b + c) = US$1,400,000

The operation and maintenance costs by year are as shown in Table 14-5.

14.2.3 Equipment Renewal Cost

Although depreciation schedules for equipment and civil and building structures differ according to country, there are more or less standards regarding economic service lives. The Survey Team, upon discussions with ENDE, set the service lives given below, and accordingly listed up replacement costs.

Hydro Power Plant	50 years (average)
Civil Structure	60 years
Hydraulic Equipment	40 years
Generating Equipment	40 years
Transforming Equipment	30 years
Transmission Line	30 years
Substation	30 years

14.3 Total Cost of Alternative Gas Turbine Project

The total cost of the alternative gas turbine project will consist of construction costs of a gas turbine power plant equalized to the Pilaya Hydro Power Plant and of appurtenant power transforming facilities, operation and maintenance cost, natural gas cost and the cost of replacing equipment.

14.3.1 Construction Cost

(1) Gas Turbine Power Plant

In general, the outage rate (outage due to faulting and repairs) of a hydroelectric power plant is about 2.0%, but in case of the Pilaya Hydro Power Project, it is thought considerable lengths of time will be required in obtaining repair parts, etc., and therefore, 3% is to be taken into account. Consequently, the dependable output averaged for a year in contrast to the installed capacity will be the following:

kW Correction Factor =(1 - Faulting Rate) × (1 - Repair Rate) = 0.97

Installed Capacity x kW Correction Factor = 87,000 kW x 0.97

= 84,400 kW

Meanwhile, the outage rates of gas turbine according to a publication of EEI of the U.S.A. are calculated from statistical data to be the following:

Forced outage rate in percent per year	9.0
Unexpected maintenance outage rate in percent per year	2.0
Planned maintenance outage rate in percent per year	2.0
Total	13.0

Therefore, the output of the alternative gas turbine power plant would be as follows:

87,000 kW x 0.97 ÷ (1 - 0.130) = 97,000 kW

The gas turbine which ENDE has installed at Santa Cruz has a turbine generator output of 24,250 kW with inlet air temperature of 15°C and atmospheric pressure of 760 mmHg. The relations between elevations and outputs of gas turbine units are as shown below.

Iso-rating, 15°C

EL. 460 m	22,400 kW at Santa Cruz
EL. 1,000 m	21,700 kW
EL. 2,000 m	20,400 kW
EL. 3,000 m	19,100 kW
EL. 4,000 m	17,900 kW

Sucre or Potosi will be reasonable as the place for installation of the alternative gas turbine in consideration of existing and future gas pipeline projects, and the service area of Pilaya Hydro Power Plant. Since Sucre is situated at an elevation of 2,790 m the output of one gas turbine unit will be approximately 19,700 kW, while since Potosi is at an elevation of 3,976 m the output will be 17,900 kW. Accordingly, the gas turbine units required at Sucre and Potosi when adjustments are made for elevation will be the following:

Sucre Site

97,000 kW ÷ 19,700 ≒ 5 units

Potosi Site

97,000 kW ÷ 17,900 ≒ 6 units

By providing three out of six gas turbine units at Sucre and the remaining three at Potosi it will be possible to offer service equal to the Pilaya Hydro Power Project. In effect, it will be unnecessary to consider the construction of a 115 kV transmission line if the gas turbine units are installed divided at the said two locations.

The construction cost of a gas turbine power plant will differ greatly depending on the kind of combustibles used (natural gas, light oil, heavy oil, etc.). The Survey Team estimated the construction cost by year of the gas turbine power plants including appurtenant power transforming facilities referring to technical specifications and the like for the No. 5 unit (using natural gas as combustibles) planned by ENDE for construction at Santa Cruz.

1989	US$26,190,000
1990	US$17,460,000
Total	US$43,650,000

The construction period is to be two years from placement of order with disbursements for equipment assumed as 10% at the time of ordering, 50% on lading on board ship, and 40% on start-up.

(2) Contingency, Consultant Fee and ENDE Administration Cost

Contingency is to be 5% of the direct construction cost. The engineering fee for supervisory works and the administrative cost of ENDE engineers engaged in the project construction are to be 6% of the direct construction cost. In effect, the amount will be the following:

43,650,000 x 0.11 = US$4,802,000

The breakdown of disbursements by year of the costs of (1) and (2) above is given in Table 14-1.

14.3.2 Operation and Maintenance Cost (Excluding Natural Gas Cost)

The operation and maintenance cost may be divided into the personnel allowance and the costs of maintenance and repair, and according to statistics the ratios to direct construction cost are more or less the same in all countries. The operation and maintenance cost of the gas turbine power plants will be the following:

US$43,650,000 x 0.025 = US$1,091,000

The operation and maintenance costs by year are shown in Table 14-5.

14.3.3 Natural Gas Cost

The fossil combustibles available in Bolivia are petroleum and natural gas. Petroleum, in view of the amount of production (27,400 bbl/day) is not suitable for consideration as fuel for electric power generation. That is, a part of the petroleum is being used for power generation, but at present domestic consumption and production are roughly equal, while imported petroleum cannot compete with the abundant natural gas available when transportation costs are taken into consideration.

Natural gas in Bolivia is available in abundant quantities and 220 million ft^3 per day (37,700 bbl/day converted to petroleum) are presently being exported to Argentina, while further, it has been agreed to export 400 million ft^3 per day of natural gas to Brazil for 20 years.

With such abundant natural gas as the basis, ENDE has provided gas turbines amounting to a total installed capacity of 80 MW at Santa Cruz, and also has plans for installation of gas turbines at Potosi and Oruro in the future.

Consequently, the alternative thermal facility for the Pilaya Hydro Power Project would consist of gas turbine units and the combustibles cannot be anything other than natural gas.

(1) Opportunity Cost of Natural Gas

The price of natural gas presently being purchased by ENDE from the YPFB is free of charge at the well head. In effect, this signifies that natural gas is not being utilized for other purposes and the use for electric power generation does not involve a sacrificial cost. Seen from such a standpoint, if a thermal power plant were to be constructed at the point of natural gas extraction, it would be unnecessary to consider any natural gas cost.

However, the Bolivian Government has decided to export natural gas laying a pipeline of 1,940 km to Sao Paulo in Brazil, and this means that if natural gas were to be used for power generation a sacrificial cost would be incurred. Accordingly, the World Bank has advised measuring natural gas by an opportunity cost and using this in considering hydroelectric power development projects in Bolivia.

Bolivia is already exporting natural gas to Argentina, but it is difficult to set an opportunity cost for natural gas in comparison with petroleum prices, because the natural gas consumption area of Argentina is relatively closed to the Bolivian border.

a) Transportation Cost of Natural Gas Pipeline

The Bolivian Government has agreed upon construction of a 1,940 km pipeline from Santa Cruz to Sao Paulo, and the transportation cost of natural gas is calculated to be as follows:

$$\frac{\text{Annual Cost of Pipeline}}{\text{Annual Transmitted Gas Quantity}} = \frac{\text{US\$}255 \times 10^6}{400 \times 10^6 ft^3 \times 365}$$

$$= \text{US\$}1.75/10^3 ft^3$$

where,

Salable gas quantity to Brazil: $400 \times 10^6 ft^3$/day

Pipeline construction cost: US$1,700 x 10^6

Capital opportunity cost in Brazil: 11.0%/yr

Service life: 20 yr

Variable cost: 2.5% of pipeline construction cost

b) Opportunity Cost of Natural Gas

The natural gas transmitted from Santa Cruz to Sao Paulo can be compared in price with petroleum purchased at Sao Paulo.

On October 30, 1981, the Organization of Petroleum Exporting Countries (OPEC) decided on a uniform price of US$34.0/bbl for benchmark crude (Arabian Light), although price differences remain between grades. Therefore, the opportunity cost of natural gas calculated from the calorific value of 1 barrel of petroleum and the calorific value of 1 cubic foot of natural gas will be the following:

$$\frac{\text{US\$34.0}}{5,695 \text{ BTU} \times 10^3} \times 1,045 \text{ BTU} \times 10^3 = \text{US\$6.28}/10^3\text{ft}^3$$

where,

Petroleum price: US$34.0/bbl

Calorific value of petroleum: $5,659 \times 10^3$BTU/bbl

Calorific value of natural gas: 1,045 BTU/ft^3

c) Opportunity Costs of Natural Gas at Sao Paulo Site and Gas Turbine Power Plant Sites

The opportunity cost of natural gas compared with petroleum at the Sao Paulo site may be converted to the opportunity cost at Santa Cruz by deducting the transportation cost of natural gas through pipeline. By adding the transportation costs by pipeline to Potosi and Sucre, the opportunity costs of natural gas at the gas turbine power plant sites may be calculated.

(2) Opportunity Cost of Natural Gas and Natural Gas Cost

Although the natural gas of Bolivia is available in abundant quantity there is no question that it is a finite resource. It may also be considered that prices of fossil fuels will continue to rise in the future in view of the energy demand forecast for the future. The World Bank advises that hydroelectric power projects in Bolivia be evaluated by the opportunity cost of natural gas assuming that the natural gas reserves of the country will be exhausted in the year 2000 and the year 2010, while petroleum prices will rise 100% and 50%, respectively.

It is judged that this evaluation method is reasonable for determining the opportunity cost of natural gas. Therefore, the Survey Team calculated the opportunity cost at the well head as shown in Table 14-2 based on the petroleum price of OPEC at the Sao Paulo site as of December 1981, and further, calculated the opportunity costs of natural gas by year at the Sucre and

Potosi sites.

Table 14-3 shows opportunity costs of petroleum by year, and Table 14-4 fuel costs per million kWh.

Table 14-2 Opportunity Cost of Natural Gas in Bolivia

		Cost in US$ per 10^3ft^3	
		Alternative I	Alternative II
a)	Assumed year at which gas reserve depleted	2000	2010
b)	World oil price at the end of 1981 (equivalent)	6.28	6.28
c)	World oil price at depletion date	+100%=12.56	+50%=9.42
d)	Additional premium for gas quality	+10%	+10%
e)	Deduct cost of gas transportation	1.75	1.75
f)	Resulting value at depletion date	12.07	8.61
g)	Discount at 11%, in 1981	1.65	0.41
h)	Add cost of extraction (at 4 cent US$) to get opportunity cost at well head in 1981	1.69	0.45

Table 14-3 Opportunity Cost of Natural Gas per Year

Unit: US$/$10^3$ft^3

	Well head		Sucre or Potosí	
Year	Alt. I	Alt. II	Alt. I	Alt. II
1981	1.69	0.45	2.03	0.79
1985	2.57	0.68	2.91	1.02
1990	4.32	1.12	4.66	1.46
1995	7.28	1.86	7.62	2.20
2000	12.07	3.10	12.41	3.44
2005	*10.81	5.16	*11.15	5.50
2010	*10.81	8.61	*11.15	8.95

Note: Transportation cost to the power plant:

US$0.34/$10^3$ft^3 at Sucre and Potosí

* Without premium of gas.

Table 14-4 Fuel Price for Gas Turbine in Sucre or Potosí (Opportunity Cost)

Unit: US$$10^3$/GWh

Year	Alternative I	Alternative II	Year	Alternative I	Alternative II
1981	26.8	10.6	1996	112.6	32.3
1982	29.4	11.3	1997	124.1	35.3
1983	32.3	12.1	1998	136.9	38.6
1984	35.5	12.8	1999	150.9	42.2
1985	39.0	13.7	2000	166.4	46.1
1986	42.9	14.7	2001	149.5	50.6
1987	47.1	15.8	2002	149.5	55.6
1988	51.8	17.0	2003	149.5	61.1
1989	56.9	18.2	2004	149.5	67.1
1990	62.5	19.6	2005	149.5	73.7
1991	68.9	21.3	2006	149.5	81.2
1992	76.1	23.1	2007	149.5	89.6
1993	83.9	25.1	2008	149.5	98.7
1994	92.6	27.2	2009	149.5	108.9
1995	102.1	29.5	2010	149.5	120.0

Note: Gas turbine efficiency : 14,000 BTU/kWh

14.3.4 Equipment Renewal Cost

(1) Service Life of Gas Turbine Unit

The service life of a gas turbine unit is determined by the degree of fatigue of materials resulting from thermal stresses of turbine blades accompanying operation and shut-down. The calculation formula for the service life of a gas turbine unit normally used is as follows:

$$Z_e = \underbrace{b_B \cdot Z_B + b_P \cdot Z_P + b_R \cdot Z_R}_{\text{Life based on number of hours operated}} + \underbrace{a_n \cdot N_n + a_f + N_f}_{\text{Life based on number of times started}}$$

where, Z_e : 80,000 hr

Z_B: number of hours operated for base load (no overload operation)

Z_P: number of hours operated for peak load (8.5% overload operation)

Z_R: number of hours operated in emergency (13% overload operation)

N_n : number of times started in normal operation

N_f : number of times started for rapid operation

b_B : constant, 1

b_P : constant, 5

b_R : constant, 12

a_n : 5 hours

a_f : 20 hours

The outage rate of Pilaya Hydro Power Plant will be 3.0%. Since the available energy production is 535.5 GWh the effective energy will be 519.4 GWh. Consequently, the number of hours of operation converted by full-load operation of the power station will be 6,011 hours annually. In effect, the alternative gas turbine unit will be required to be operated about 5,000 hours* a year.

The annual operating conditions for a gas turbine unit are assumed as follows:

Dry Season

Number of times started in normal operation	N_n = 2 (daily)
Number of hours operated for base load	Z_B = 8 (daily)

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* The actual operating performance of a gas turbine at Santa Cruz is close to 5,000 hours.

Number of times started in rapid operation $N_f = 1/7$ (once/week)

Number of hours operated for peak load $Z_P = 2/7$ (2 hr/week)

Wet Season

Number of times started in normal operation $N_n = 2/7$ (twice/week)

Number of hours operated for base load $Z_B = 20.6$ (6 day/week)

$$Z_e = b_B . Z_B + b_P . Z_P + a_n . N_n + a_f . N_f = 8{,}094 \text{ hours}$$

Against a service life of 80,000 hours of operation of a gas turbine unit the number of hours of operation in one year will be 8,094 hours, and if operation equal to Pilaya Hydro Power Plant is performed, the service life will be approximately 10 years. (In Japan, the service life of a gas turbine for peaking operation belonging to an electric power enterprise is stipulated to be 15 years according to the Corporate Tax Law.)

(2) Equipment Renewal Cost

A gas turbine power plant has appurtenant power transforming facilities. The service life of such a facility is 30 years. Consequently, only the gas turbine would be replaced every 10 years.

14.4 Benefit-Cost Ratio

If the Pilaya Hydro Power Project was to be realized, it would become unnecessary for the alternative gas gurbine project to be implemented. Since expenditures for the alternative gas turbine project would not be made through realization of the Pilaya Hydro Power Project it can be looked upon as a benefit of the Pilaya Project.

Table 14-5 shows the respective expenditures by year for the Pilaya Hydro Power Project and the alternative gas turbine project for the case of a discount rate of 12%. The cases of 10% and 14% classified according to type of fuel are as shown below.

Discount Rate (%)	Pilaya Project (10^3US$) C	Gas Turbine Project (10^3US$) B	Benefit cost ratio B/C
Natural gas price (Alternative I)			
10	308,713	539,815	1.75
12	322,177	467,046	1.45
14	337,226	409,014	1.21
Natural gas price (Alternative II)			
10	308,713	247,518	0.80
12	322,177	214,874	0.67
14	337,226	187,514	0.56

Table 14-5 Comparison of Total Present Value of Pilaya Project and Alternative Gas Turbine Project

No.	Year	Discount rate i=12%	Salable energy (GWh)	Cost: Pilaya Project: Construction cost (US$ 10^3)	Cost: Pilaya Project: O & M cost (US$ 10^3)	Cost: Pilaya Project: Replacement cost (US$ 10^3)	Cost: Pilaya Project: Total cost (US$ 10^3)	Cost: Present value in 1991 (US$ 10^3)	Benefit = Cost of Alternative: Gas Turbine Project: Construction cost (US$ 10^3)	Gas Turbine Project: O & M cost (US$ 10^3)	Gas Turbine Project: Fuel cost (Alt. I) (US$ 10^3)	Gas Turbine Project: Replacement cost (US$ 10^3)	Gas Turbine Project: Total cost (US$ 10^3)	Present value in 1991 (US$ 10^3)	Fuel cost (Alt. II) (US$ 10^3)	Present value in 1991 (US$ 10^3)
-9	1982	2.475														
-8	1983	2.210		840			840	1,856								
-7	1984	1.973		26,217			26,217	51,726								
-6	1985	1.762		15,424			15,424	27,177								
-5	1986	1.573		25,621			25,621	40,302								
-4	1987	1.404		38,743			38,743	54,395								
-3	1988	1.254		56,861			56,861	71,304								
-2	1989	1.120		42,027			42,027	47,070	28,591				28,591	32,022		32,022
-1	1990	1.000		17,905			17,905	17,905	19,861				19,861	19,861		19,861
1	1991	0.892	277.1		1,400	0	1,400	1,249		1,091	19,092	0	20,183	18,003	9,546	6,237
2	1992	0.797	330.6		1,400	0	1,400	1,116		1,091	25,159	0	26,250	20,921	12,580	6,956
3	1993	0.711	426.9		1,400	0	1,400	995		1,091	35,817	0	36,908	26,242	17,909	8,394
4	1994	0.635	498.7		1,400	0	1,400	889		1,091	46,180	0	47,271	30,017	23,090	9,307
5	1995	0.567	498.7		1,400	0	1,400	794		1,091	50,917	0	52,008	29,488	25,459	8,960
6	1996	0.506	498.7		1,400	0	1,400	708		1,091	56,153	0	57,244	28,965	28,077	8,703
7	1997	0.452	498.7		1,400	0	1,400	633		1,091	61,889	0	62,980	28,467	30,945	8,450
8	1998	0.403	498.7		1,400	0	1,400	564		1,091	68,273	0	69,364	27,954	34,137	8,197
9	1999	0.360	498.7		1,400	0	1,400	504		1,091	75,254	22,873	99,218	35,718	37,627	16,203
10	2000	0.321	498.7		1,400	0	1,400	449		1,091	82,984	15,889	99,964	32,088	41,492	12,830
11	2001	0.287	498.7		1,400	0	1,400	402		1,091	74,556	0	75,647	21,711	37,278	7,555
12	2002	0.256	498.7		1,400	0	1,400	358		1,091	74,556	0	75,647	19,366	37,278	7,377
13	2003	0.229	498.7		1,400	0	1,400	321		1,091	74,556	0	75,647	17,323	37,278	7,227
14	2004	0.204	498.7		1,400	0	1,400	286		1,091	74,556	0	75,647	15,432	37,278	7,049
15	2005	0.182	498.7		1,400	0	1,400	255		1,091	74,556	0	75,647	13,768	37,278	6,888
16	2006	0.163	498.7		1,400	0	1,400	228		1,091	74,556	0	75,647	12,330	37,278	6,778
17	2007	0.145	498.7		1,400	0	1,400	203		1,091	74,556	0	75,647	10,969	37,278	6,637
18	2008	0.130	498.7		1,400	0	1,400	182		1,091	74,556	0	75,647	9,834	37,278	6,541
19	2009	0.116	498.7		1,400	0	1,400	162		1,091	74,556	0	75,647	8,775	37,278	6,426
20	2010	0.103	498.7		1,400	0	1,400	144		1,091	74,556	0	75,647	7,792	37,278	6,276
	Total	-	9,512.5	223,638	28,000	0	251,638	322,177	48,452	21,820	1,267,278	38,762	1,376,312	467,046	633,642	214,874

Salable energy = Effective energy x (1 - Transmission line loss factor)

As shown in the above table, the conclusion regarding the Pilaya Hydro Power Project will differ according to the opportunity cost of natural gas utilized for the gas turbine power generation project.

In other words, if it were assumed that natural gas will be depleted in the year 2000, and in addition, if the price of petroleum were to rise to double from the present US$34.0/bbl, it may be said that the Pilaya Hydro Power Project will be feasible. However, if on the other hand, natural gas were to become depleted in 2010 and the escalation in the petroleum price were to be 50%, the Pilaya Hydro Power Project would be inferior to the alternative gas turbine project.

It is said from the reserves presently confirmed that the natural gas will be exhausted between the years 2000 and 2010, and this has been acknowledged by the Bolivian Government.

As for the period considered in economic analysis, it is 20 years from start of operation of Pilaya Power Plant, but seen from the discount rate applied, it would be possible for an economic evaluation of the Project to be made through discounting of the cash flow for an approximately 30 year period.

14.5 Economic Internal Rate of Return (EIRR)

ENDE has computed the costs of the entire National Power System required by year up to the year 2035 based on the required costs of generation, power transmission and transforming facilities up to 1990 for which development was decided by "Plan Nacional de Electrificacion," and further, on all development projects scheduled for the period up to the year 2000. The total cost by year consists of investment required for construction of power generating, transmitting and transforming facilities, operation and maintenance cost, and combustibles cost.

The values of costs per kWh calculated changing the discount rates between new power demands corresponding to these new power generating, transmitting and transforming facilities are as indicated below. However, the prices are as of December 1980.

Unit: US mills/kWh

Discount rate	Natural gas price Alt. I	Natural gas price Alt. II	Average cost
10%	41.13	41.09	41.10
12%	50.72	50.41	50.56
14%	60.97	60.37	60.67

Source: "Determinación del costo de la energía Eléctrica a mediano Plazo y Largo Plazo" 20 de Octubre de 1981, ENDE

In effect, the average unit price at a discount rate of 12% (rate of return which can be anticipated for the investment made) is 50.56 US mill/kWh at the generating end.

The method of establishing the electricity rate (cost per kWh) by such a method is called marginal cost theory, and in calculation of the economic internal rate of return in relation with new projects, it is judged to be reasonable as revenue versus the cost.

Therefore, the Survey Team, upon discussion with ENDE, converted the above-mentioned electricity rate to prices as of December 1981, and calculation of the economic internal rate of returns for the costs of the Pilaya Hydro Power Project were made.

Electricity rate corresponding to Pilaya Hydro Power Project:

61.7 US mill/kWh in December 1981 price, wholesale price at the receiving end

As shown in Table 14-6, the economic internal rate of return of the Pilaya Hydro Power Project will be 9.2%.

14.6 Sensitivity Analaysis

The accuracies of the construction costs of the Pilaya Hydro Power Project and the alternative gas turbine project are fairly high. However, of the construction cost of the Pilaya Hydro Power Project, the civil work cost which makes up approximately 50% is thought will vary considerably depending on geologic conditions. Electrical equipment and materials also are closely linked to the price of petroleum which is expected to rise.

Accordingly, the Survey Team studied the benefit-cost ratios in the cases of 90%, 110% and 120% over the estimated figure for the construction cost of the Pilaya Hydro Power Project and the results are as shown below.

	Pilaya construction cost in %			
	90	100	110	120
Benefit-cost ratio Discount rate				
10%	1.94	1.75	1.58	1.46
12%	1.61	1.45	1.31	1.21
14%	1.34	1.21	1.09	1.00

Note: Based on the natural gas price of alternative I

Table 14-6 Economic Internal R

No.	Year	Salable energy (GWh)	Power rate (US mills/ kWh)	(B) Revenue (US$ 10³)	Construction cost (US$ 10³)	O & M cost (US$ 10³)	Replaceme cost (US$ 10³)
-9	1982						
-8	1983				840		
-7	1984				26,217		
-6	1985				15,424		
-5	1986				25,621		
-4	1987				38,743		
-3	1988				56,861		
-2	1989				42,027		
-1	1990				17,905		
1	1991	277.1	61.7	17,097		1,400	0
2	1992	330.6	61.7	20.398		1,400	0
3	1993	426.9	61.7	26,340		1,400	0
4	1994	498.7	61.7	30,770		1,400	0
5	1995	498.7	61.7	30,770		1,400	0
⋮	⋮	⋮	⋮	⋮		⋮	⋮
28	2018	498.7	61.7	30,770		1,400	0
29	2019	498.7	61.7	30,770		1,400	21,460
30	2020	498.7	61.7	30,770		1,400	21,460
⋮	⋮	⋮	⋮	⋮		⋮	⋮
38	2028	498.7	61.7	30,770		1,400	0
39	2029	498.7	61.7	30,770		1,400	11,349
40	2030	498.7	61.7	30,770		1,400	11,349
⋮	⋮	⋮	⋮	⋮		⋮	⋮
48	2038	498.7	61.7	30,770		1,400	0
49	2039	498.7	61.7	30,770		1,400	0
50	2040	498.7	61.7	30,770		1,400	0
	Total	24,473.5	-	1,510,025	223,638	70,000	65,618

Table 14-6 Economic Internal Rate of Return

No.	Year	Salable energy (GWh)	Power rate (US mills/ kWh)	(B) Revenue (US$ 10³)	Construction cost (US$ 10³)	O & M cost (US$ 10³)	Replacement cost (US$ 10³)	(C) Total (US$ 10³)	(B) - (C) (US$ 10³)	Discount rate i=9.2%	Present value (US$ 10³)
-9	1982										
-8	1983				840			840	-840	1.851	- 1,554
-7	1984				26,217			26,217	-26,217	1.695	-44,437
-6	1985				15,424			15,424	-15,424	1.552	-23,938
-5	1986				25,621			25,621	-25,621	1.421	-36,407
-4	1987				38,743			38,743	-38,743	1.302	-50,443
-3	1988				56,861			56,861	-56,861	1.192	-67,778
-2	1989				42,027			42,027	-42,027	1.092	-45,893
-1	1990				17,905			17,905	-17,905	1.000	-17,905
1	1991	277.1	61.7	17,097		1,400	0	1,400	15,697	0.915	14,362
2	1992	330.6	61.7	20.398		1,400	0	1,400	18,998	0.838	15,920
3	1993	426.9	61.7	26,340		1,400	0	1,400	24,940	0.767	19,128
4	1994	498.7	61.7	30,770		1,400	0	1,400	29,370	0.703	20,647
5	1995	498.7	61.7	30,770		1,400	0	1,400	29,370	0.644	
⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮	⋮		n=24 29,370 × 9.554 × 0.703 = 197,262
28	2018	498.7	61.7	30,770		1,400	0	1,400	29,370	0.085	
29	2019	498.7	61.7	30,770		1,400	21,460	22,860	7,910	0.077	609
30	2020	498.7	61.7	30,770		1,400	21,460	22,860	7,910	0.071	561
⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮	⋮		n=8 29,370 × 5.493 × 0.071 = 11,454
38	2028	498.7	61.7	30,770		1,400	0	1,400	29,370	0.035	
39	2029	498.7	61.7	30,770		1,400	11,349	12,749	18,021	0.032	576
40	2030	498.7	61.7	30,770		1,400	11,349	12,749	18,021	0.029	527
⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮	⋮		n=10 29,370 × 6.361 × 0.029 = 5,417
48	2038	498.7	61.7	30,770		1,400	0	1,400	29,370	0.014	
49	2039	498.7	61.7	30,770		1,400	0	1,400	29,370	0.013	
50	2040	498.7	61.7	30,770		1,400	0	1,400	29,370	0.012	
	Total	24,473.5	-	1,510,025	223,638	70,000	65,618	359,256	1,150,769	-	-1,892

CHAPTER 15

FUNDING PLAN AND FINANCIAL ANALYSIS

CHAPTER 15 FUNDING PLAN AND FINANCIAL ANALYSIS

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CHAPTER 15. FUNDING PLAN AND FINANCIAL ANALYSIS

15.1 Basic Considerations

As is well known, electric power facilities (power generating and transmission facilities) require huge sums to be invested. Even when investment is made, a construction period over a number of years is required, and returns from investment will only start to come several years later. The service lives of the facilities completed are fairly long compared with durable equipment in general. Such a situation means that repayment of principal along with interest will necessarily be spread over a long period of time.

Accordingly, it is an indispensable condition for construction of electric power facilities to procure funds of low interest rate, long grace period, and moreover, long repayment period. The Survey Team assumed that the funds for this Project would need to be procured outside of Bolivia, with the foreign currency requirement assumed to be met with loans based on government-to-government development aid, while with regard to the domestic currency portion, recent cases of financing by the World Bank made available to Latin American countries were referred to in assumptions of loans, based on which the terms of loans were set up.

Revenue as the returns from investment will consist of electricity charges. The prevailing electricity rates of ENDE are wholesale rates set by bloc (by electric power company). The electricity rates of electric power companies tied in with the National Power System are relatively cheap, and amortization of the Project will be difficult with the prevailing electricity rates unchanged. On examination of the past trends in electricity rates, they have been revised roughly every two years, and it is expected there will have been a substantial rise by the beginning of 1991 when operation of the Pilaya Hydro Project will be started.

The formulation of the funding plan and financial analysis of the Project will be made by the Survey Team comprehensively taking into account the amount required to be invested in the Project, the prevailing electricity rate system, lending terms of international financing institutions, and the terms conceivable in case of government-to-government developing aid.

15.2 Funding Plan

The construction cost of the Project will be as much as a total of US$490,696,000 by the year 1990 including escalation. Of this amount, US$198,094,000 will comprise the foreign currency portion and US$292,602,000 the domestic currency portion. The direct construction costs, indirect construction costs, escalation and total construction cost will be as follows:

Unit: US$$10^3$

	F.C.	D.C.	Total
Direct const. cost	109,385	90,404	199,789
Indirect const. cost	24,441	55,065	79,506
Escalation	64,268	147,133	211,401
Total const. cost	198,094	292,602	490,696

The scale of the Bolivian Government budget in 1979 was US$2,744 million, while the amount of lending by the Central Bank in 1980 was US$540 million. It is thought difficult for the construction funds required for the Project to be disbursed within these budget and lending limits. Consequently, the Survey Team assumed that all of the necessary construction funds would be covered with loans from abroad, while seen from the conclusions of the financial analysis, it is imperative to procure loans of low interest rates and long repayment periods so that it is desirable for funds from government-to-government aid to be borrowed for the foreign currency portion, and loans to be secured from international financing institutions such as the World Bank for the domestic currency portion.

	US$$10^3$
Government-to-Government Development Aid (Foreign Currency Portion)	198,094
International Financing Institution (Domestic Currency Portion)	292,602
Total (Construction Funds Required)	490,696

15.3 Financial Analysis

ENDE revised electricity rates in February 1980 and raises averaging 60% were made. Consequently, the average electricity rate in the month of June 1981 was 45.6 US mill/kWh.

The start of operation of the Project is to be at the end of 1990, and ENDE is planning to invest 443.2 million US dollars in the 1980s to develop a total of 220 MW of power generating facilities. With regard to estimating electricity rates in 1991 when Pilaya Hydro Power Plant will be completed, it is difficult since the economy of Bolivia is fluid and the situation 10 years from now cannot be predicted. Accordingly, the Survey Team set electricity rates of its own which would be in step with the investment (including escalation) for the Project, thereby clarifying the relations with the current electricity rates.

15.3.1 Preconditions

(1) Total Investment Amount and Operation and Maintenance Cost of Pilaya Hydro Power Project

In financial analysis, escalation of costs occurring until completion of the

Project is to be included. Consequently, the construction funds required, as shown in Table 15-1, will be US$490,696,000 including interest during construction.

The operation and maintenance cost and depreciation cost of the Project are to be calculated based on 1990 prices.

Table 15-1 Fund Requirement

Unit: US$$10^3$

		1981 Price	1990 Price
A	Generating facilities	127,588	244,248
B	Transmitting facilities	47,690	83,909
C	Preparatory works	24,511	43,181
D	Contingency	14,509	25,516
E	Engineering & ENDE adm.	9,340	16,193
F	Interest during construction	55,657	97,649
	Total	279,295	490,696

Operating Cost in 1991

Generation

$224,248 \times 10^3 \times 0.006 =$ US$$1,345 \times 10^3$

Transmission and transformation

$83,909 \times 10^3 \times 0.0125 =$ US$$1,049 \times 10^3$

Depreciation Cost: US$$12,038 \times 10^3$

Generation

$323,859 \times 10^3 / 50 =$ US$$6,477 \times 10^3$

Transmission and transformation

$166,837 \times 10^3 / 30 =$ US$$5,561 \times 10^3$

(2) Conditions for Fund Procurement

Of the total investment amount from 1983 to 1990, it was assumed that the foreign currency portion of US$198.1 million would consist of loans based on government-to-government development aid and the domestic currency portion of US$292.6 million of loans from an international financing institution such as the World Bank, and these were set as follows:

Foreign Currency Portion (Government-to-Government Development Aid)

Interest rate: 3.5%/yr

Repayment period: 25 yr (incl. 5 years deferment)

Repayment method: Principal in equal installments

Domestic Currency Portion (International Financing Institution such as World Bank)

Interest rate: 9.6%/yr

Repayment period: 17 yr (incl. 7 years deferment)

Repayment method: Principal and interest in equal installments

Commitment charge: 0.75%/yr

The interest rate of the World Bank is linked with interest rates of city banks within the U.S.A., and considering the recent trend of reduction there may be a possibility for the rate to be lowered in the future, but the rate given above was assumed taking into account the situation in loans connected with electric power in Colombia and Peru.

(3) Prevailing Electricity Rates

The unit electricity sales price of ENDE by bloc recorded are as follows:

Table 15-2 Actual Power Tariff Rate

	1979		1980		1981	
	$B/kWh	US mills/kWh	$B/kWh	US mills/kWh	$B/kWh	US mills/kWh
ENDE	0.55	22.0	0.69	27.6	1.18	47.2
BPC (La Paz)	0.61	24.4	0.81	32.4	1.35	54.0
BPC (Oruro)	0.52	20.8	0.75	30.0	0.93	37.2
CRE	0.93	37.2	1.15	46.0	1.78	71.2
ELFEC	0.88	35.2	1.11	44.4	1.70	68.0
CESSA	0.88	35.2	1.21	48.4	1.66	66.4
CEPSA	0.94	37.6	1.42	56.8	2.00	80.0
SETAR	1.53	61.2	1.88	75.2	2.46	98.4
ELFEO	0.46	18.4	0.66	26.4	1.15	46.0
COSERELEC	2.45	98.0	2.98	119.2	3.30	132.0

Conversion Rate: 25.0 $B/1 US$

The average electricity sales performance obtained from sales and electricity charge income of ENDE from January to June 1981 was B$1.141/kWh (US45.6 mill/kWh).

15.3.2 Results of Financial Analysis

The prevailing electricity rates are wholesale rates which were established centered on cheap natural gas prices and the hydro power generation facilities of Santa Isabel (72.0 MW) and Corani (54.0 MW). Bolivia is a country where electric power load centers are scattered over a vast land area so that the proportion made up by power transmitting and transforming facilities which are the means of transportation of electric power is large. In the case of the Pilaya Hydro Power Project, the ratios of investment amounts are 70% for generating facilities, and 30% for transmitting and transforming facilities. Accordingly, the electricity rates necessary for recovering the investments for these facilities will be high compared with the approximately 20% investment ratio for transmission and transformation facilities in a country such as Japan or the U.S.A.

As shown in Table 15-3, if the current electricity rate of US45.6 mill/kWh is raised to be tripled by 1991, the Project can be said to be financially feasible.

In effect, the cash balance will turn to a surplus in the third year after start of operation, while the cumulative cash balance will show a surplus after 6 years, and in 2000, after 10 years, a surplus of US$51.9 million will be produced.

Table 15-3 Statement of Income

		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
(A) Energy sales													
Energy sold	(GWh)	277.1	330.6	426.9	498.7	498.7	498.7	498.7	498.7	498.7	498.7	498.7	498.7
Electricity rate per kWh	(US$/MWh)	136.9	136.9	136.9	136.9	136.9	136.9	136.9	136.9	136.9	136.9	136.9	136.9
Gross revenue	(US$$10^6$)	37.9	45.3	58.3	68.3	68.3	68.3	68.3	68.3	68.3	68.3	68.3	68.3
(B) Operating cost Generation													
Generation	(US$$10^6$)	1.3	1.4	1.5	1.6	1.7	1.9	2.0	2.2	2.3	2.5	2.5	2.5
Transmission & transf.	(US$$10^6$)	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9	1.9
Depreciation	(US$$10^6$)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Total	(US$$10^6$)	14.3	14.5	14.7	14.9	15.1	15.4	15.6	15.9	16.1	16.4	16.4	16.4
(C) Operating income:													
(A) - (B)	(US$$10^6$)	23.6	30.8	43.6	53.4	53.2	52.9	52.7	52.4	52.2	51.9	51.9	51.9
(D) Financial expenses													
Interest on F.C.	(US$$10^6$)	6.8	6.8	6.7	6.2	6.0	5.7	5.4	5.1	4.8	4.6	3.9	3.7
Interest on D.C.	(US$$10^6$)	28.1	26.3	24.4	22.3	19.9	17.4	14.6	11.5	8.2	4.5	0	0
Total	(US$$10^6$)	34.9	33.1	31.1	28.5	25.9	23.1	20.0	16.6	13.0	9.1	3.9	3.7
(E) Net income:													
(C) - (D)	(US$$10^6$)	-11.3	-2.3	12.5	24.9	27.3	29.8	32.7	35.8	39.2	42.8	48.0	48.2

Table 15-4 Amortization Schedule

No.	Year	* Borrowing	Foreign currency portion redemption			* Borrowing	Domestic currency portion redemption			* Borrowing	Total redemption		
		Investment (US$10^6)	Principal (US$10^6)	Interest (US$10^6)	Total (US$10^6)	Investment (US$10^6)	Principal (US$10^6)	Interest (US$10^6)	Total (US$10^6)	Investment (US$10^6)	Principal (US$10^6)	Interest (US$10^6)	Total (US$10^6)
1	1982	0		0	0	0		0	0	0		0	0
2	1983	0.7		0	0	0.3		0	0	1.0		0	0
3	1984	9.1		0.3	0.3	27.7		2.7	2.7	36.8		3.0	3.0
4	1985	9.0		0.6	0.6	18.1		4.4	4.4	27.1		5.0	5.0
5	1986	19.4		1.0	1.0	27.9		7.1	7.1	47.3		8.1	8.1
6	1987	39.3		2.7	2.7	34.9		10.5	10.5	74.2		13.2	13.2
7	1988	59.3		4.8	4.8	58.5		16.1	16.1	117.8		20.9	20.9
8	1989	40.5	0.5	6.2	6.7	70.3		22.8	22.8	110.8	0.5	29.0	29.5
9	1990	20.8	1.0	6.9	7.9	54.9		28.1	28.1	75.7	1.0	35.0	36.0
10	1991		2.0	6.8	8.8		18.4	28.1	46.5		20.4	34.9	55.3
11	1992		4.0	6.8	10.8		20.2	26.3	46.5		24.2	33.1	57.3
12	1993		7.0	6.7	13.7		22.1	24.4	46.5		29.1	31.1	60.2
13	1994		9.0	6.2	15.2		24.2	22.3	46.5		33.2	28.5	61.7
14	1995		10.0	6.0	16.0		26.6	19.9	46.5		36.6	25.9	62.5
15	1996		10.0	5.7	15.7		29.1	17.4	46.5		39.1	23.1	62.2
16	1997		10.0	5.4	15.4		31.9	14.6	46.5		41.9	20.0	61.9
17	1998		10.0	5.1	15.1		35.0	11.5	46.5		45.0	16.6	61.6
18	1999		10.0	4.8	14.8		38.3	8.2	46.5		48.3	13.0	61.3
19	2000		10.0	4.6	14.6		42.0	4.5	46.5		42.0	9.1	51.1
20	2001		10.0	3.9	13.9		0	0	0		10.0	3.9	13.9
21	2002		10.0	3.7	13.7		0	0	0		10.0	3.7	13.7
	Total	198.1	103.5	88.2	191.7	292.6	287.8	268.9	556.7	490.7	381.3	357.1	738.4

* Including interest during construction.

Table 15-5 Statement of Cash Flow

	1 1982	2 1983	3 1984	4 1985	5 1986	6 1987	7 1988	8 1989	9 1990	10 1991	11 1992	12 1993	13 1994	14 1995	15 1996	16 1997	17 1998	18 1999	19 2000
(A) Cash receipts		1.0	36.8	27.1	47.3	74.2	117.8	110.8	75.7	0.7	9.7	24.5	36.9	39.3	41.8	44.7	47.8	51.2	54.8
1) Net income		-	-	-	-	-	-	-	-	-11.3	-2.3	12.5	24.9	27.3	29.8	32.7	35.8	39.2	42.8
2) Depreciation		-	-	-	-	-	-	-	-	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
3) Borrowings		1.0	36.8	27.1	47.3	74.2	117.8	110.8	75.7										
F.C. portion		0.7	9.1	9.0	19.4	39.3	59.3	40.5	20.8										
D.C. portion		0.3	27.7	18.1	27.9	34.9	58.5	70.3	54.9										
(B) Cash disbursements		1.0	38.8	29.0	48.9	75.6	118.7	111.7	76.7	20.4	20.2	22.1	24.2	26.6	29.1	31.9	35.0	38.3	42.0
1) Commitment charge		0	2.0	1.9	1.6	1.4	0.9	0.4	0										
2) Construction		1.0	36.8	27.1	47.3	74.2	117.8	110.8	75.7										
3) Repayment of debt								0.5	1.0	20.4	24.2	29.1	33.2	36.6	39.1	41.9	45.0	48.3	42.0
Principal of F.C. portion		-	-	-	-	-	-	0.5	1.0	2.0	4.0	7.0	9.0	10.0	10.0	10.0	10.0	10.0	10.0
Principal of D.C. portion		-	-	-	-	-	-	-	-	18.4	20.2	22.1	24.2	26.6	29.1	31.9	35.0	38.3	42.0
(C) Cash balance: (A) - (B)		0	-2.0	-1.9	-1.6	-1.4	-0.9	-0.9	-1.0	-19.7	-10.5	2.4	12.7	12.7	12.7	12.8	12.8	12.9	12.8
(D) Accumulated total		0	-2.0	-3.9	-5.5	-6.9	-7.8	-8.7	-9.7	-29.4	-39.9	-37.5	-24.8	-12.1	-0.6	13.4	26.2	39.1	51.9