CHAPTER 6

POWER SYSTEM ANALYSIS AND OPERATION

CHAPTER 6 POWER SYSTEM ANALYSIS AND OPERATION

6-1 Basic Criteria for Power System Study

A power system is an organic entity, comprising stages ranging from power generation to distribution and requiring a match of actual demand conditions and a simultaneous guarantee of prescribed levels of service.

With the completion of the 230kV east-west interconnection line between the Ishurdi substation and the Bheramara power station, presently in planning stage and expected to be commissioned in 1983, in addition to the Bheramara-Faridpur-Madaripur-Barisal east circuit of this project, which will form a trunk loop together with the existing west circuit, the system will offer considerable reinforcement.

The power system study in question should be performed paying special attention to the following points:

a. Concurrent with the increase in demand, there will be a shortage of reactive power source.

b. Due to the great length of the transmission line, the voltage drop will increase concurrently with the increase in demand. Adequate power source arrangements, installation of capacitor, etc., should be taken into account in order to achieve a balance between power demand and supply, minimizing voltage drop and the power loss.

c. After completion of this project and the east-west interconnector, the grids of both zones will be interconnected, and in addition, the grid of the western zone will form a loop system. Consequently, a comprehensive study of the whole system is required.

6-2 Power Flow Analysis

With the completion of the Bheramara-Faridpur-Madaripur-Barisal transmission line in 1986, this new circuit will be interconnected with the existing west circuit (Bheramara-Goalpara-Barisal).

Power flow analysis by computer has been executed, aiming at investigation of the power flow situation and voltage fluctuation under both normal and interrupted conditions in this grid system.

6-2-1 Condition of System Study

(1) System Configuration

a. Configuration of the power system in the western grid is shown in Figure 6-1 and is analyzed as a loop system.

b. Operation of the Bheramara-Faridpur-Madaripur-Barisal transmission line of this project is assumed to commence in 1985/86.

(2) Busbar Voltage

a. It is assumed that the voltage of the busbars at each substation will be maintained as follows at the 33kV load side.

Under normal conditions	95% or more
Under interrupted conditions	90% or more

b. Although the transformer (LRT) has a tap changer of ±10%, calculation is made under the assumption that the intermediate tap is fixed as a computer input condition.

(3) Power Factor and Impedance

a. The main load will be composed of irrigation pumps, and the load power factor at each substation is assumed to be 80%, taking into consideration as well the present load conditions.

b. The line impedance is assumed to be the same value of ACSR 477MCM as the existing transmission line. (Shown in Table 6-1.)

c. Calculation is made on the assumption that the capacity of substation will correspond to the increase in demand and assuming a 10% impedance at the 10MVA base. (The average value of the existing transformers is 10% at 10MVA.)

(4) Power Plant Output

a. The outputs of each power generation plant of the grid system at 1986 is assumed to be as follows:

Bheramara	60 MW
Goalpara	180.4 MW
Barisal	25.5 MW
Total	265.9 MW

b. The supply capacity from the east-west interconnection line via Ishurdi is assumed to be as follows:

Conductor size	ACSR 795MCM
No. of circuits	2cct
Current capacity	835A
Circuit voltage	132kV (up to 1989)
	230kV (1990 and after)

Consequently, each circuit will have the following power transmission capacity, assuming a power factor of 80%.

Up to 1989	153MW (at 132kV)
1990 and after	266MW (at 230kV)

(5) Demand Forecast and Year Studied

The loads of each substation are based upon the long term demand forecast for the western zone. Year to be studied is 1986, 1990, 1992 and 1995, respectively.

(6) Transmission Capacity

The transmission capacity of the grid system is assumed to be ACSR 477MCM 108MW for both existing and newly constructed lines.

(7) Contents of Study

a. Power flow and voltage under normal conditions

b. Power flow and voltage for one (1) circuit interruption. Interruption should be assumed as most severe condition.

6-2-2 Power Flow for 1986 (Year of Commercial Operation)
Refer to Annex II-1

(1) Power Demand and Supply

In 1986, the year of commercial operation of the east circuit, power demand within the grid system will be 218MW. Generator output will be 266MW, therefore guaranting a sufficient supply to cope with demand.

(2) Power Flow

Maximum power flow between Goalpara and Jessore will be 32.7MW. Even when one (1) circuit is interrupted, the remaining circuit will not be overloaded.

(3) Voltage

The voltages of the busbars on the 33kV load side in each of the substations is kept above the average value of approximately 93% and even at the Jhenidha station, the point of minimum value, it is maintained at 87.2%. It is possible to maintain a level above 95% if regulated by LRT.

6-2-3 Power Flow in 1990 Refer to Annexes II-2, II-3.

(1) Power Demand

In 1990, power demand is expected to reach 395MW and the generator output 266MW, resulting in a shortage of approximately 130MW in supply. This difference will be covered by the east-west interconnection.

(2) Normal Conditions Refer to Annex II-2.

a. Power flow
The maximum power flow under normal conditions will occur between Bheramara and Bottail, reaching 66.6MW. There will be no overloading problem.

b. Voltage
The minimum value for busbar voltage at 33kV side is 84% in Bottail, but there is no problem because 10% regulation is possible by means of LRT.

(3) In Case of Interruption   Refer to Annex II-3.

Off in Bheramara-Rajbari section

a. Power flow
The maximum power flow in the Bheramara-Bottail section will be 84.7MW, and there will be no overloading problem.

b. Voltage
Power to the substations of Rajbari, Faridpur and Madaripur is supplied via Goalpara and Barisal, incurring a voltage drop to 75 - 77.8%. Even taking into consideration regulating of 10% by the LRT it is impossible to maintain the target value.

(4) Countermeasures

Capacitor of about six (6) MVAR shall be installed in the substations of Rajbari, Faridpur and Madaripur in order to cope with the voltage drop.

6-2-4 Power Flow in 1992   Refer to Annexes II-4 and II-5.

(1) Hypothesis for Calculations

a. Capacitor of six (6) MVAR have already been installed in the Rajbari, Faridpur and Madaripur substations.

b. Capacitor of 50 MVAR have already been installed in the Goalpara power station, aiming for compensation of the reactive power of that station.

(2) Power Demand and Supply

In 1992 the demand will increase to 486MW, and a capacity of 220 - 230MW will be transferred via the west-east interconnector.

(3) Normal Conditions   Refer to Annex II-4.

a. Power flow
Maximum power flow will occur in the Bheramara-Bottail section, with a value of 104MW, within the capacity of the transmission line.

b. Voltage
In the substations of Jessore and Jhenidha, the voltages will

be reduced to 79.9 - 83%, and it will be impossible to attain the target value even by regulation with LRT.

(4) In Case of Interruption   Refer to Annex II-5.

Off in Bheramara-Rajbari section

a. Power flow
The power flow of the No. 1 line in Bheramara will be 137MW and of the No. 2 circuit 98MW. Even by distributing the loads equally in the two (2) lines, it becomes (137 + 98) ÷ 2 = 118MW, slightly exceeding transmission line capacity.

b. Voltage
The voltages at the substations of Rajbari, Faridpur, Madaripur and Jessore will drop to from 67% to 77% and the target value will not be attained even by regulation with LRT.

(5) Countermeasures

a. Power flow countermeasures
The capacity of the Goalpara power station should be increased by approximately 100MW, aiming at supply of power to the Khulna area, which presents the highest demand density, in order to reduce the power flow in the transmission line.

b. Voltage countermeasures
(i) Capacitor of approx. 10MVAR should be installed in Jessore.
(ii) Capacitor of 50MVAR should be installed in the Goalpara power station, aiming at compensation for the reactive power.
(iii) Duplication of the east circuit
Capacitor of six (6) MVAR will be installed in the substations of Rajbari, Faridpur and Madaripur. However, in case of interruption in the Bheramara-Rajbari section, it will be impossible to maintain the rated voltage if the circuit is not duplicated.

6-2-5 Power Flow in 1995   Refer to Annex II-6.

(1) Hypothesis for Calculation

a. The execution of the following countermeasures, according to items 6-2-3 (4) and 6-2-4 (5) is assumed as hypothesis for calculation.

- Duplication of the east circuit
- Installation of 50MVAR capacitor in the Goalpara power station, six (6) MVAR in the Rajbari, Faridpur and Madaripur substations, and 10 MVAR in Jessore.
- Increase in the capacity of the Goalpara power station to 280MW, with reinforcement of 100MW.

(2) Power Demand and Supply

In 1995 the demand will show a remarkable increase and total demand within the grid will reach 665MW, while the output of the generators is 366MW. The difference is of the order of 300MW and will be supplied by means of the east-west interconnector.

(3) Normal Conditions Refer to Annex II-6.

a. Power flow
Power flow of the No. 1 and No. 2 lines in Bheramara reaches 123MW and 69.3MW respectively. If the loads of the two (2) circuits are distributed evenly, the power flow becomes $(123 + 69.3) \div 2 = 96.2$MW.

b. Voltage
In the substations of Jessore and Jhenidha, the voltage drops to 75% and in almost all other substations the voltage drops to from 77% to 82%. The target value is not attained even by regulation with LRT.

(4) In Case of Interruption Refer to Annex II-7.

Off in Bheramara-Goalpara section

a. Power flow
The power flow of the No. 1 line in Bheramara will be 180MW, with an overload of 160% against the line capacity.

b. Voltage
In Jessore and Jhenidha the voltage drops to 68%. Even in the other substations it drops to from 71% to 76%.

(5) Countermeasures

a. Power flow countermeasures

The capacity of the Goalpara power station should be increased by 100MW to an output of 380MW.

b. Voltage countermeasures

- A capacitor of 50MVAR should be installed at the Goalpara substation, totalling 100MVAR.
- Capacitor of 10MVAR should be installed in the substations of Bagerhat, Jhenidha and Bottail.

6-2-6 Power Flow After Countermeasures in 1995

(1) Normal Condition Refer to Annex II-8.

a. Power flow

- Maximum power flow of the No. 1 and No. 2 lines in Bheramara will be 81MW and 23MW respectively. There will be no problem with line capacity.
- Maximum power flow in the east-west interconnector line will reach 206MW and there will be no problem.

b. Voltage

The voltage drops to 81% in Jessore, 83.5% in Jhenidha, 82.2% in Faridpur, and in other substations it is maintained above 85%. Thus, the target value is attained by regulating with LRT.

(2) In Case of Interruption Refer to Annexes II-9, II-10.

Off in Bheramara-Goalpara section
Off in Bheramara-Barisal section

a. Power flow

In case of interruption on the No. 2 line in Bheramara, the No. 1 circuit in Bheramara reaches 95.5MW as maximum power flow, but there will be no problem with line capacity.

b. Voltage

In Jessore the voltage drops to 78%, but in other substations the voltage is kept to over 80% and the target value is attained by regulating the voltage with LRT.

Countermeasures

The results of the analysis above indicate that all conditions regarding the power flow and voltage can be fulfilled by installing capacitor of about five (5) MVAR in Jessore, Jhenidha and Fairdpur.

6-2-7 Results of Power Flow Analysis

(1) Remarks

a. Capacitor should be installed in the various stations of the grid in order to cope with the voltage drops.

b. In addition to the capacitor mentioned above, circuit duplication of the transmission line in this project should be carried out in the future (about 1992).

c. Reinforcement of power generation capacity of the order of 100MW x 2 is expected to be required in future (1992-1995) in the western zone in order to cope with the increase in demand.

d. As for execution of these plans in future, their magnitude and the time of commissioning should be determined by careful examination of actual demand trends, the conditions of the system and power sources and other related points on each occasion.

(2) Summary of Power Flow Analysis

Summary of Power Flow Analysis

Year	Status of the System when Calculated	Problems	Countermeasures
1986 (Commissioning)	East circuit (one(1) circuit)		
	(1) Under normal conditions	None	
	(2) Under interruption	None	
1990	East circuit (one(1) circuit)		
	(1) Under normal conditions	None	
	(2) Under interruption, Off in Bheramara-Rajbari section	Voltage drop in Rajbari, Faridpur and Madaripur	Capacitor of the order of six (6) MVAR should be installed in the substations shown at left.
1992	- East circuit (one(1) circuit) - Six (6) MVAR capacitor in Rajbari, Faridpur and Madaripur		
	(1) Under normal conditions	Voltage drop in Jessore	Capacitor of the order of 50MVAR should be installed in the Goalpara power station and 10MVAR in Jessore.
	(2) Under interruption		
	a. Off in Bheramara No.1 or No.2 line of west circuit	Overload of approximately 150% in the remaining circuits	Reinforcement of 100MW capacity in the Goalpara power station
	b. Off in Bheramara-Rajbari section of east circuit	Voltage drop in Rajbari, Faridpur and Madaripur	Duplication of the east circuit.

Year	Status of the System when Calculated	Problems	Countermeasures
1995	- Output of Goalpara power station: 280MW - Double circuit of east circuit - Capacitor Goalpara 50MVAR Jessore 10MVAR Rajbari 6MVAR Faridpur 6MVAR Madaripur 6MVAR		
	(1) Under normal conditions	(1) Power flow is within the capacity of the transmission line if the load is evenly distributed in Bheramara No. 1 and No. 2 lines.	
		(2) When one (1) circuit of the east-west interconnector is OFF, the remaining circuit will be overloaded	Additional reinforcement of 100MW in the Goalpara power station for a total of 380MW of output power.
		(3) Voltages at various substations suffer substational drop	Installation and/or reinforcement of capacitors in the following stations. Goalpara power station: 50MVAR reinforcement Jessore, Faridpur, 5MVAR reinforcement Jhenidha, new 15MVAR. Bagerhat, Bottail: new 10MVAR installation
	(2) Under interruption, Off in Bheramara No.1 or No.2 line	The remaining circuits are overloaded 160%.	The same countermeasures as described above solve the problem.

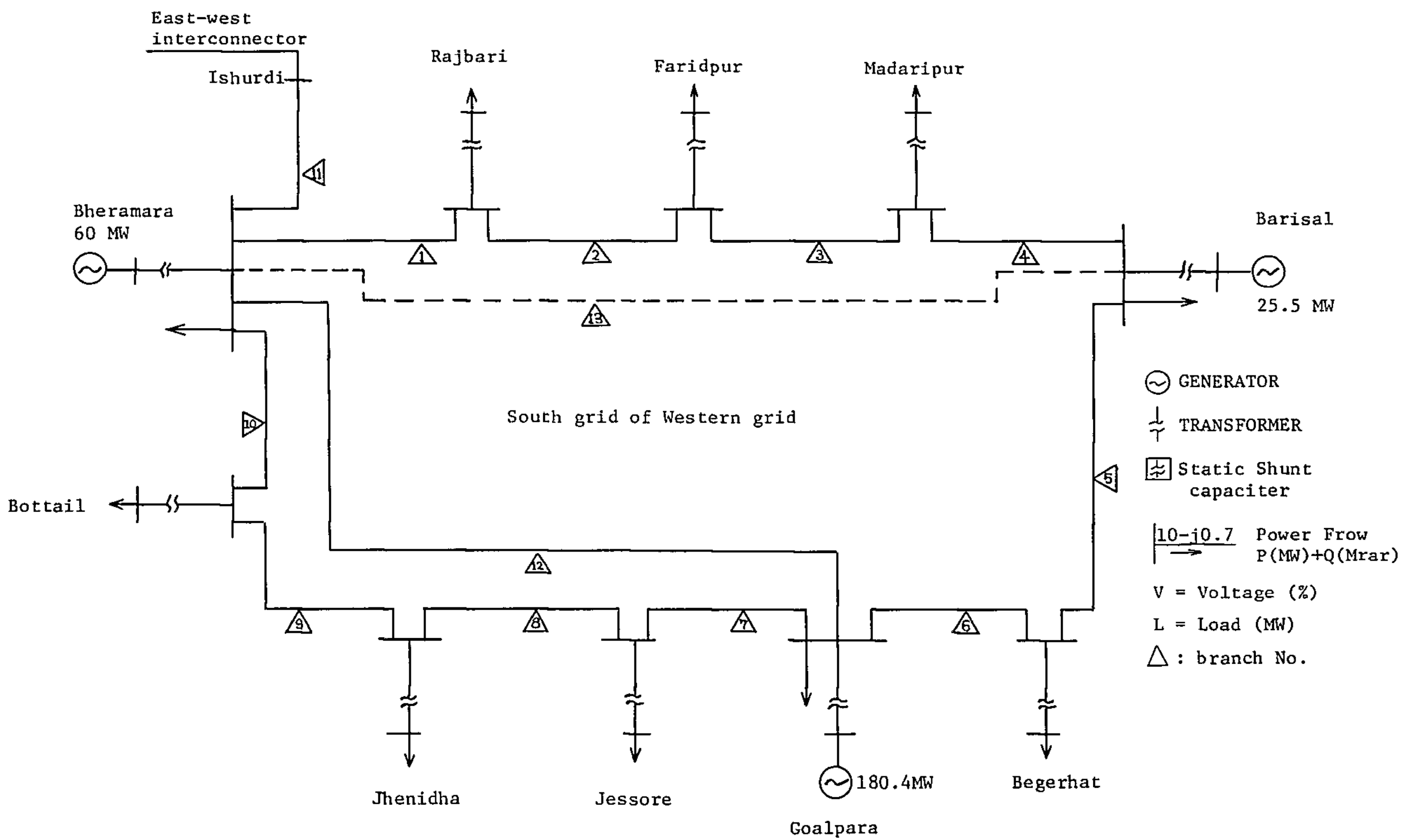
Table 6-1 Transmission System Data of Grid System

Base 132kV

Section		Branch No.	Length (km)	100MVA Base		
				R (%)	X (%)	Y/2 (%)
Bheramara	Rajbari	1	80	6.192	18.32	2.0
Rajbari	Faridpur	2	28	2.167	6.41	0.7
Faridpur	Madaripur	3	64	4.953	14.65	1.6
Madaripur	Barisal	4	58	4.489	13.28	1.45
Barisal	Bagerhat	5	66	5.12	16.28	1.53
Bagerhat	Goalpara	6	43	3.34	10.6	0.99
Goalpara	Jessore	7	49	3.715	10.99	1.2
Jessore	Jhenidha	8	48	3.467	10.26	1.12
Jhenidha	Bottail	9	43	3.343	9.89	1.08
Bottail	Bheramara	10	22	1.733	5.13	0.56
Bheramara	Goalpara	12	162	12.538	37.09	4.05
Bheramara	Barisal	13	230	17,802	52.67	5.76

Note: Existing lines accord with BPDB impedance map.

Fig. 6-1 Power System at Power Flow Analysis



6-3 Transient Stability Calculation

6-3-1 Study Conditions

(1) Calculations of this study refer to the system in 1992.

(2) The configuration of the system is shown in Figure 6-2.
The loop is assumed to be in operation.

(3) Equipment constants are listed in Table 6-2.

(4) Conditions of occurrence of faults

a. Fault type 3LG
(Three (3) phase short-circuit and ground fault

b. Duration of fault 5 cycles

(5) Place of Occurrence of the Fault (Refer to Figure 6-2.)

Case 1 Bheramara-Rajbari section (Branch No. 1)
Case 2 Bheramara-Bottail section (Branch No. 10)
Case 3 Bheramara-Goalpara section (Branch No. 12)
Case 4 Jessore-Goalpara section (Branch No. 7)

6-3-2 Results of Calculations

The results of the calculations are presented in Annexes III-1 through III-4. Results indicate stability in all cases.

Summary

Case	Fault location	Fault type and time	Power flow before fault	Results of cal- culation	Remarks
1	Bheramara-Rajbari	1 circuit 3LG-0 0-0.1 sec	51.6+j 3.3	OK	Annex III-1
2	Bheramara-Bottail	"	103.8+j38.8	OK	Annex III-2
3	Bheramara-Goalpara	"	64.4+j 5.1	OK	Annex III-3
4	Jessore-Goalpara	"	24.2-j 41	OK	Annex III-4

Table 6-2 Generator Constants for Calculation

		MVA	MW	P.F (%)	Unit inertia constant M (sec)	%xd' (Own base)	%xd' (100MVA base)
Bheramara P/S	No. 1	32	25.6	80	7	21.5	67.2
	No. 2	32	25.6	80	7	21.5	67.2
	No. 3	32	25.6	80	7	21.5	67.2
Goalpara P/S	No. 1	75	60	80	7	21.9	29.2
	No. 2	75	60	80	7	21.9	29.2
	No. 3	75	60	80	7	21.9	29.2
Barisal P/A	No. 1	32	25.6	80	7	21.5	67.2
Ishurdi		625	500	80	7	21.5	67.2

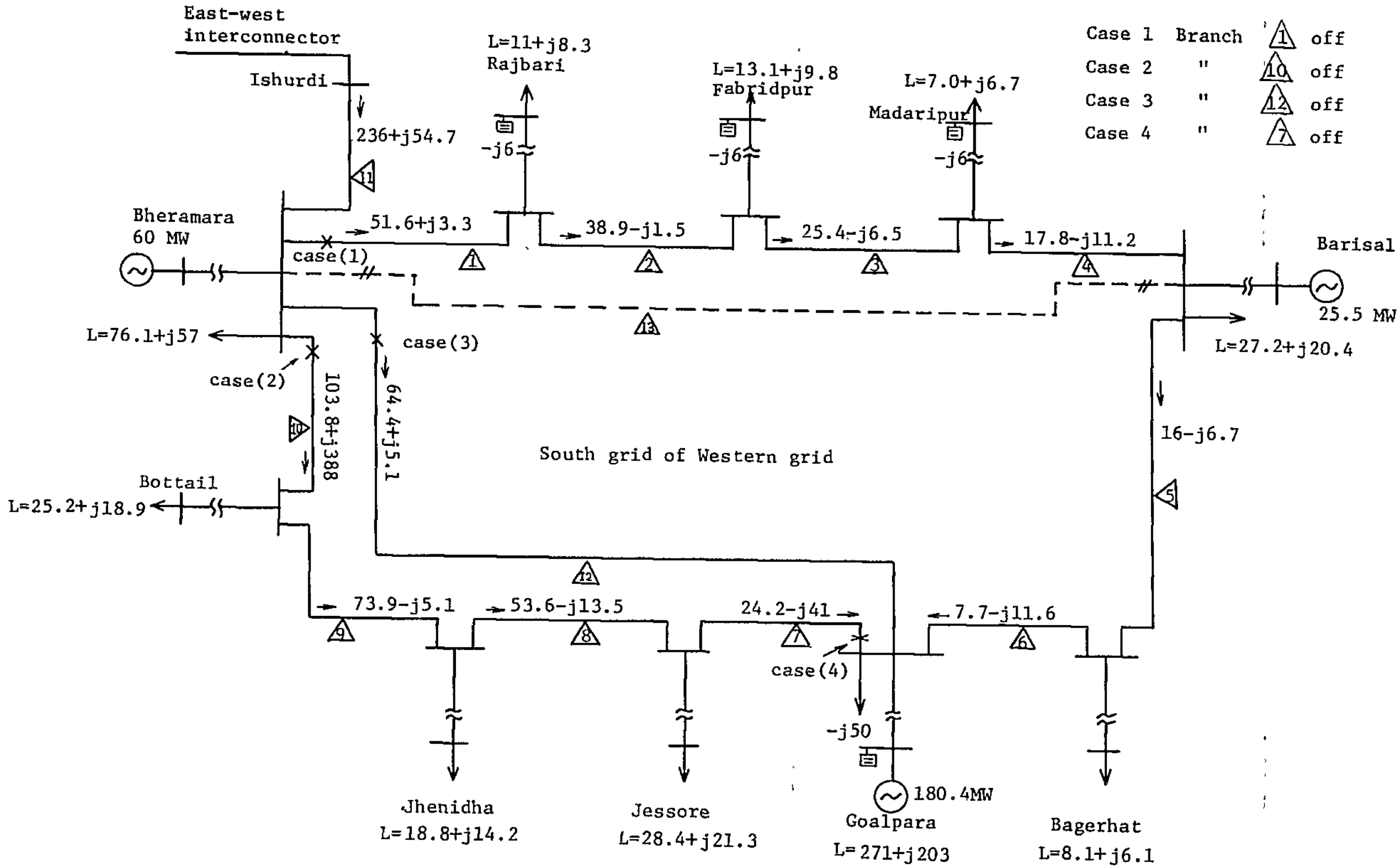
Notes: (1) The %xd' value for Bheramara P/S and Goalpara P/S are obtained from BPDB data.

(2) The %xd' value for Barisal P/S is assumed to be equivalent to that of Bheramara P/S.

(3) The constant of inertia M conforms to the standard value of generators in Japan.

(4) A 500MW power generator is assumed to be connected at Ishurdi, because the constants of the east-west interconnector line are unknown.

Fig. 6-2 Power Flow at Transient Stability Study in 1992



6.4 Transmission Line Scale

(1) The size and Characteristics of the Conductor

Size	ACSR 477MCM (26/7)	
Transmission capacity	(at 132kV, PF = 0.8)	
Continuous	595A	108MW
Short time	670A	122MW

(2) Number of Circuits

The transmission line constructed in 1986 is a single circuit, and duplication will be required in 1992. There are two (2) methods to meet the requirement, that is,

(Case 1)

The towers of the transmission line should be of the double circuit type, but with only one (1) circuit installed in the initial stage. An additional one (1) circuit will be installed in future.

(Case 2)

The towers of the transmission line should be of the single circuit type. Construction of another similar transmission line will be required along different route in future.

Comparison for the above two (2) cases

(Case 1) Double circuit towers

(A) Total construction cost of a transmission line by 1985 (excluding interest during construction) $365,840 \times 10^3$ TK

(B) Cost for stringing one (1) additional circuit in 1992/93 $84,930 \times 10^3$ TK

Present value at 1984/85 = A + B x *0.3269 = $393,427 \times 10^3$ TK

(Case 2) Single circuit towers

(A) Total construction cost of a transmission line by 1985 (excluding interest during construction $302,943 \times 10^3$ TK

(B) Cost for construction of a line along another route in 1992 $302,943 \times 10^3$ TK

Present value at 1984/85 = A + B x *0.3269 = $401,975 \times 10^3$ TK

The comparison presented above suggests that case 1 is more advantageous.

*Discount rate 15%

A breakdown of the transmission line construction costs is presented below.

[Case 1]

(1) Transmission Line Construction Cost

(One (1) circuit on double circuit towers)

Item	Foreign currency		Local currency	Total
	¥ (1000)	TK (1000)	TK (1000)	TK (1000)
Transmission line	1,922,616	144,557	156,767	301,324
Equipment	1,779,732	133,814	40,144	173,958
Tools and vehicles	142,884	10,743	3,223	13,966
Construction costs	-	-	113,400	113,490
Land purchase cost and compensation for right-of-way	-	-	1,150	1,150
Route survey costs	-	-	2,721	2,721
(1) Total of direct construction costs	1,922,616	144,557	160,638	305,195
Site supervising and overhead cost (7%)	-	-	11,245	11,245
Contingency (10%)	192,261	14,456	16,064	30,520
Engineering fee	201,250	15,130	3,750	18,880
(2) Total of indirect construction costs	393,512	29,586	31,059	60,645
Grand Total (1) + (2)	2,316,128	174,143	191,697	365,840

Interest during construction not included.

(2) Cost for Stringing One (1) Additional Circuit

Item	Foreign currency		Local currency	Total
	¥ (1000)	TK (1000)	TK (1000)	TK (1000)
Equipment	704,862	52,997	15,899	68,896
Construction costs	-	-	3,168	3,168
(1) Total of direct construction costs	704,862	52,997	19,067	72,064
Site supervising and overhead cost (7%)	-	-	1,335	1,335
Contingency (10%)	70,486	5,300	1,907	7,207
Engineering fee	46,005	3,459	865	4,324
(2) Total of indirect construction costs	116,491	8,759	4,107	12,866
Grand Total (1) + (2)	821,353	61,756	23,174	84,930

Interest during construction not included.

[Case 2]

Transmission Line Construction Cost (Single circuit towers)

Item	Foreign currency		Local currency	Total
	¥ (1000)	TK (1000)	TK (1000)	TK (1000)
Transmission line	1,797,543	135,153	114,963	250,116
Equipment	1,654,659	124,410	37,323	161,733
Tools and vehicles	142,884	10,743	3,223	13,966
Construction costs	-	-	74,417	74,417
Land purchase cost and compensation for right-of-way	-	-	1,150	1,150
Route survey costs	-	-	2,721	2,721
(1) Total of direct construction costs	1,797,543	135,153	118,834	253,987
Site supervising and overhead cost (7%)	-	-	8,318	8,318
Contingency (10%)	179,754	13,515	11,883	25,398
Engineering fee	162,140	12,191	3,048	15,239
(2) Total of indirect construction costs	341,894	25,706	23,250	48,956
Grand Total (1) + (2)	2,139,437	160,859	142,084	302,943

Interest during construction not included.

6-5 System Operation

6-5-1 Basic Criteria for Operation

(1) In the initial of commercial operation of the western loop system in 1986, demand will be small, and supply has a sufficient margin. The roop operation is advantageous from the point of view of no-stoppage supply of power, and voltage countermeasure.

(2) The following matters shall be carefully considered in the loop system operation when power demand increases to some extent in future.

Under normal conditions the loop system may present high stability. However, in case of fault condition it may extend and give a severe influence to the entire system if the system is not adequately protected.

Therefore, after 1992, when overload and over power flow operation is expected, inspection and maintenance of the protection equipment will be utmost importance, and also a reserve in power supply capacity should be taken into due consideration when studying the system operation.

6-5-2 Voltage Regulation

(1) When the load power factor changes, voltage drop of the transmission line changes even when the effective power of the line remains constant. Under heavy load operation, the voltage may drop to a point where it becomes very difficult to keep the busbar voltage in the extent of the target value exclusively by means of LRT regulation.

Thus, the use of capacitors combined with the LRT must be used as a method for voltage regulation. Gradual connection of capacitors concurrent with load increase is considered as the most economical metod.

The time and installation place of the capacitors should be determined taking into account the evolution of demand of entire system and each individual substation.

(2) The maximum demand within the grid system area occurs in the Khulna area. In 1986 it is expected to exceed the output power of the Goalpara power station, and the power will be transmitted by means of the

east-west interconnector via Bheramara power station but concurrent with the increase in load and power flow, the voltage drops remarkably.

As a countermeasure, capacitor of the order of 50MVAR-100MVAR will be required in 1990 - 1995 in the Goalpara power station, to be used as reactive power supply source for the Khulna area.

6-5-3 Ferranti Effect

When voltage is applied on an unloaded transmission line a charging current will flow in the line. The value of this charging current is determined by the value of the electrostatic capacity of the transmission line. Due to the presence of this lead current, the voltage at the receiving end becomes higher than at the transmitting end.

In case of unloaded transmission from Bheramara to Barisal, via Rajbari, Faridpur and Madaripur, the receiving end voltage will be as follows:

Transmission line distance 230 km

$r = 0.135$ Ω/km

$x = 0.3991$ Ω/km

$y = 2.876 \times 10^{-6}$ ℧/km

$Vs = (\cosh \sqrt{Z \cdot Y})\ Vr$

Vs: sending end voltage

Vr: receiving end voltage

$Z = 31.05 + j91.793$ (Ω)

$\dot{Y} = j0.66148 \times 10^{-3}$ (℧)

$\dot{Z} \cdot \dot{Y} = -0.0607 + j0.0205$

$(\dot{Z} \cdot \dot{Y})^2 = 0.00326 - j0.0025$

$$\mathrm{Cosh}\ \sqrt{\dot{Z} \cdot \dot{Y}} = 1 + \frac{\dot{Z} \cdot \dot{Y}}{1} + \frac{(\dot{Z} \cdot \dot{Y})^2}{24}$$

$$= 1 + \frac{-0.0607 + j0.0205}{2} + \frac{0.00326 - j0.0025}{24}$$

$$= 1 - 0.03035 + 0.000136 + j0.01025 - j0.0001$$

$$= 0.96951 + j0.01015$$

$$= 0.9695$$

$Vs = 0.9695\ Vr$

The receiving end voltage rises to 103% of the sending end voltage.

6-5-4 Charging Capacity of Noloaded Transmission Line

The following is a study intended to verify if it is possible to charge the 230km transmission line between Bheramara-Barisal with one(1) generator in Bheramara without causing self-excitation.

In order to make the charging without self-excitation of the generator, the short-circuit ratio of the generator should be larger than the Ks given by the following expression.

$$Ks \geqq \frac{Q'}{Q}\left(\frac{V}{V'}\right)^2(1+\delta)$$

V': Charging voltage
132kV x 0.9695 ≒ 128kV taking into account the Ferranti effect

V : Voltage rating of the generator 132kV

Q : Output rating of the generator 25MVA

Q': Charging capacity of transmission line for charging voltage V'

Ks: Short circuit ratio 0.6 (Data of the BPDB)

δ : Saturation ratio of the generator 0.1 is assumed

$$Q' = 3 \times 2\pi fc\ E^2$$

$$= 3 \times 2\pi \times 50 \times 0.00915 \times \left(\frac{128}{\sqrt{3}}\right)^2 \times 230 \times 10^{-3}$$

$$= 10.8\ (\text{MVA})$$

$$Ks \geqq \frac{10.8}{25} \times \left(\frac{132}{128}\right)^2 \times (1 + 0.1)$$

$$0.6 \geqq 0.505$$

The obtained values indicate that for the short circuit ratio 0.6 of the generator, the calculated value is 0.5, suggesting therefore that charging only with the Bheramara power station is possible.

6-6 Protection Relay System (Refer to Annex XII, drawing No. 8003.)

The protection system for the 132kV transmission line, transformer and busbar is presented below.

6-6-1 132kV Transmission Line

The Bheramara-Faridpur-Madaripur-Barisal 132kV transmission line to be constructed under this project will be interconnected with the west circuit between Bheramara-Goalpara-Barisal, making loop operation possible.

The protection system to be adopted for the system should make possible loop transmission system and shown as below.

(1) Main Protection

Directional distance comparison relaying system

(2) Back-up Protection

Short circuit	Overcurrent relay
Ground fault	Ground fault overcurrent relay

(3) Transmission Circuit

Power line carrier circuit

(4) Reclosing System

Medium speed three (3) phase reclosing system

6-6-2 Transformer

(1) Main Protection

Ratio differential relay

(2) Back-up Protection

Overcurrent relay
Ground fault overcurrent relay

6-6-3 Busbar Protection

Ratio differential relay
Low voltage relay

CHAPTER 7

CONSTRUCTION OF TRANSMISSION LINE

CHAPTER 7 CONSTRUCTION OF TRANSMISSION LINE

7-1 Selection of Transmission Line Route

Selection of the Bheramara-Faridpur-Barisal transmission line route is based upon data obtained from aerial surveys, field survey by vehicle and examination of maps.

7-1-1 Faridpur-Madaripur-Barisal Section

The length of this section is approximately 143km (road distance), and there is a paved road with a width of approximately six (6) meters. The route of the transmission line can be selected to closely parallel this road.

In this section there are three (3) rivers which must be crossed, the maximum span being approximately 320 meters. Consequently, there are no problems regarding the construction of this section of transmission line.

7-1-2 Faridpur-Bheramara Section

For determining the route for the transmission line over this section, five (5) cases presented below are comparatively analyzed, taking into consideration the actual conditions of roads, railways, existing transmission lines, river crossings and other local factors. (Refer to Figure 7-1.)

Plan 1 Bheramara - Kushtia - Rajbari - Faridpur (106km)

Plan 2 Bheramara - Jhenidha (57km): Utilization of existing transmission line
Jhenidha - Faridpur (75km): Construction of a new transmission line

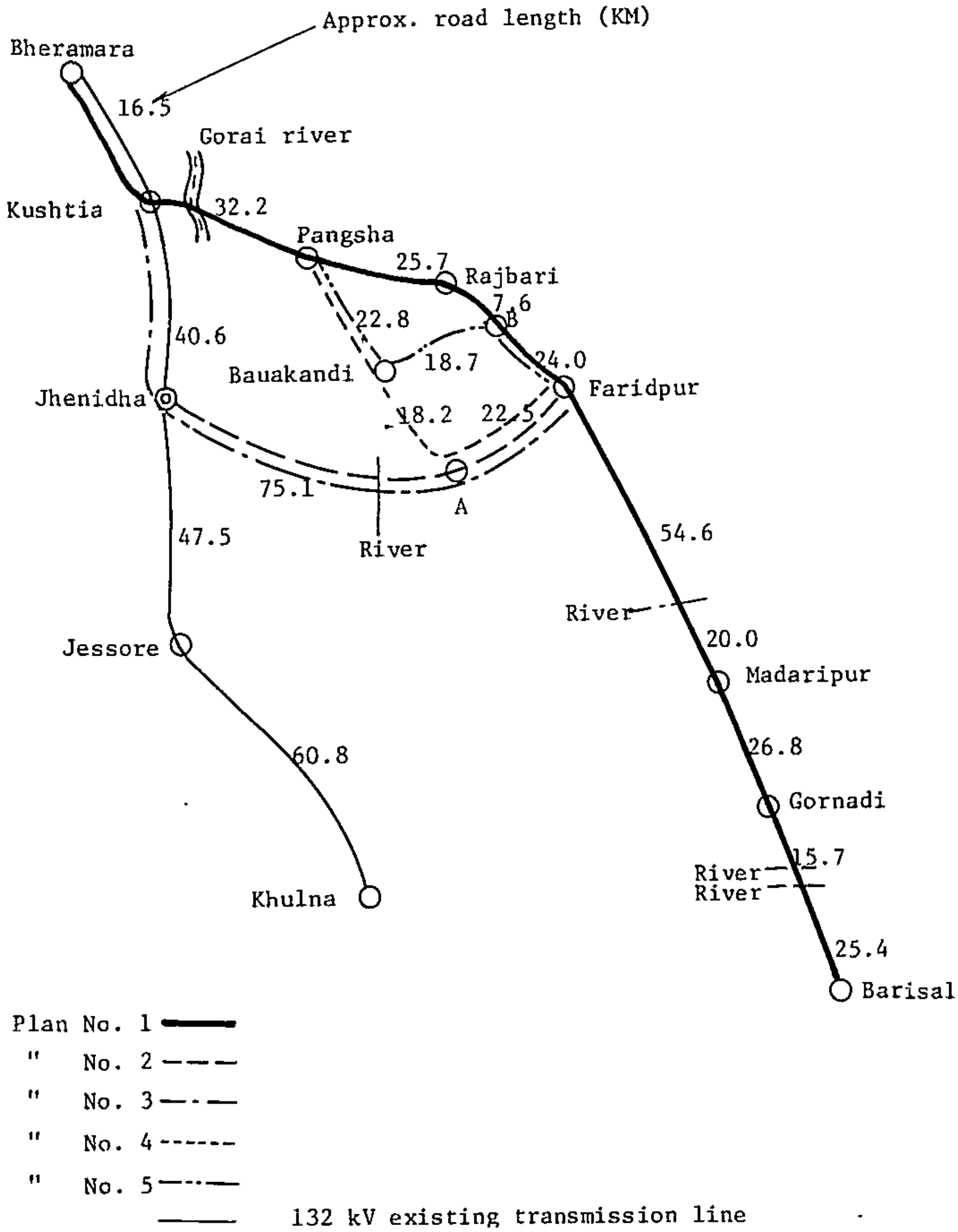
Plan 3 Bheramara - Jhenidha - Faridpur (132km)

Plan 4 Bheramara - Kushtia - Pangsha - Bauakandi - (A) - Faridpur (112km)

Plan 5 Bheramara - Kushtia - Pangsha - Bauakandi - (B) - Faridpur (114km)

Note: (A) and (B) are points indicated in Figure 7-1.

Fig. 7-1 Plans of Transmission Line Route



7-1-3 Comparative Study

A comparative study of the five (5) plans are as follows:

Plan 1: The Pangsha - Rajbari section of approximately 26km on this route is not provided with roads and the transportation of materials, tools, etc., will depend exclusively on the railway.

Plan 2: Under this plan the length of newly constructed transmission line is the shortest of all plans but the capacity of the existing transmission line does not have sufficient margin.

Plan 3: The entire route in this plan follows paved roads and there are no apparent construction problems. However, the length of the transmission line becomes 20 - 28km longer compared with other plans. In addition, if a substation is constructed in the neighbouring of Rajbari in the future, a new transmission line extension of about 30km will be required. Consequently, this plan is not advantageous from the economic point of view.

Plan 4: The entire route in this plan follows roads but in the (A)-Bauakandi - Pangsha section of approximately 66km the road is not paved, and its surface is rough. This road section should undergo considerable repairs in order to make transportation of materials and tools required for the construction possible.

Plan 5: The entire route in this plan follows roads but in the (B)-Bauakandi - Pangsha section of approximately 64km the road requires extensive repairs, as in Plan 4.

7-1-4 Results of Comparative Study

Results recommend adoption of Plan 1 in view of the following facts. Plans 2 and 3 present demerits in view of the power transmission capacity and economical aspect, respectively. Plans 3 and 4 are disadvantageous because the roads along the selected routes are poor, requiring extensive repair, and in addition power line distances are six (6) to eight (8) kilometers longer than under Plan 1, imposing economic disadvantage. In the Plan 1 route there is a section of 26km

where there is no road but utilization of the railway makes possible the construction of the transmission line with major advantages.
Among five(5) plans above, Plan 1 is the most feasible judging by economy, easiness of erection and other points of view.

7-1-5 Remarks on Transmission Line Route

(1) Determination of Route

The route of the transmission line parallels the left side of the road (partially railway) from Barisal to Bheramara. Since the road and railway are constructed at a level higher than the surrounding terrain, it is assumed that they will serve as protection embankments in case of overflow of the nearby river. The route is positioned on the side of the road opposite of the Jamna River.

(2) Crossing the Gorai River

The transmission line crosses the Gorai River between Kushtia and Pangsha. The span at the crossing point is approximately 420 meters. There will be no problem with construction work. The river crossing point is selected approximately 330m from the existing telecommunication line running along the railway bridge (according to regulations of the BPDB).

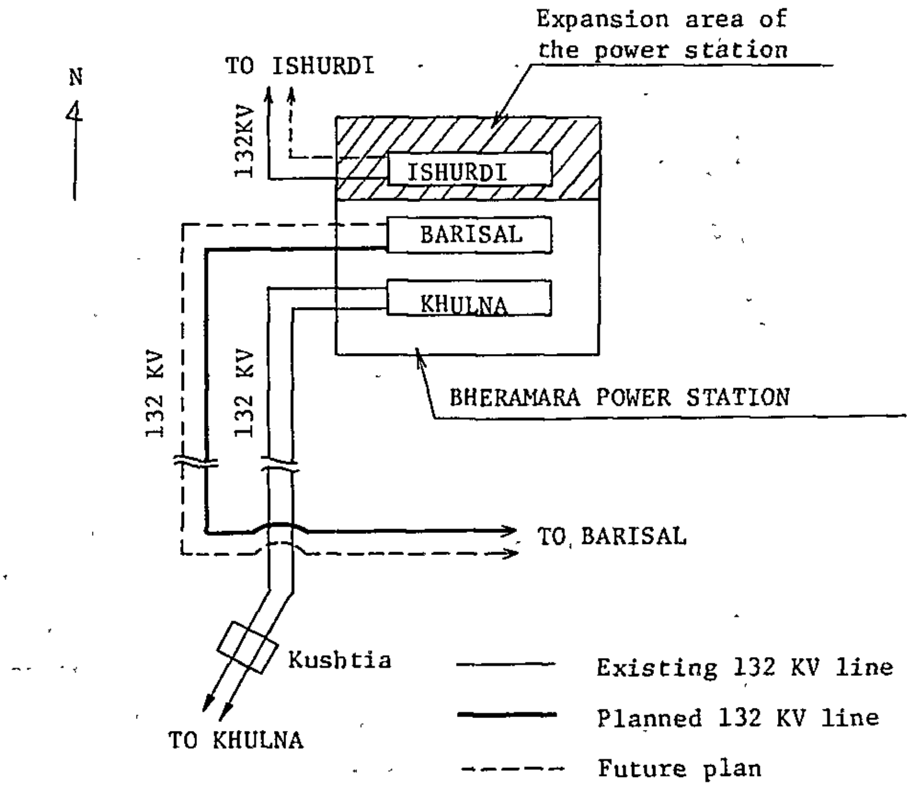
(3) Routé of the Bheramara-Kushtia Section

a. In view of the relationship with an existing 132kV transmission line, two (2) plans, described below, were taken into account when studying the route of the transmission line in the Bheramara-Kushtia section.

[Plan 1]

A route is selected to the west of the existing 132kV transmission line (Bheramara-Khulna). It crosses above the existing line at a point before Kushtia, as shown in the illustration below.

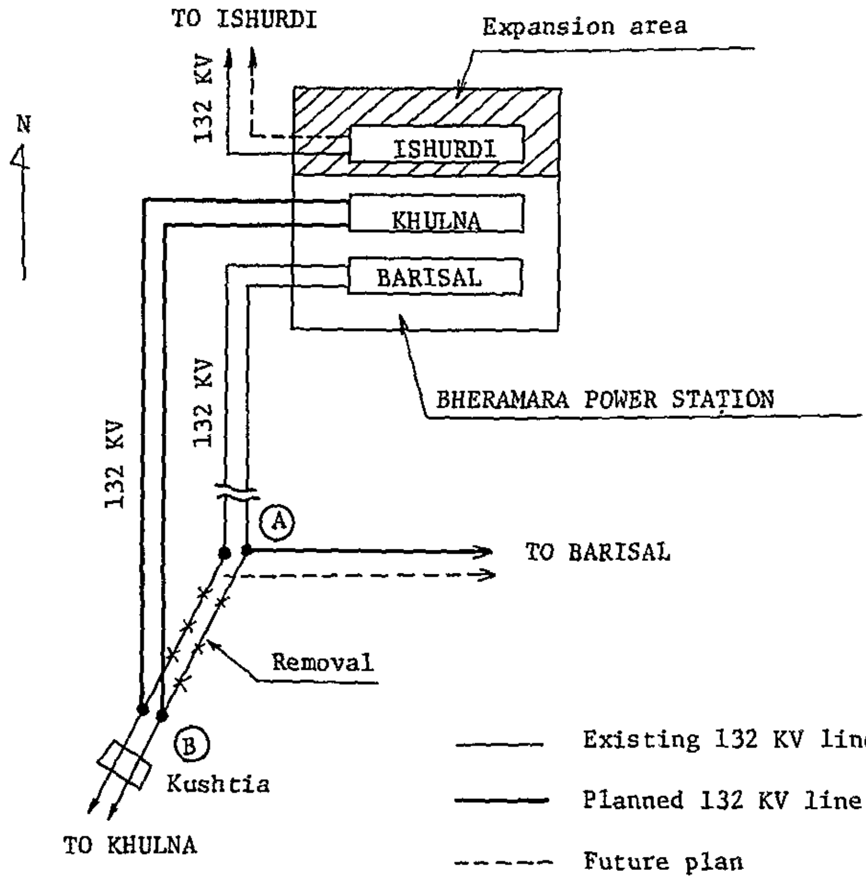
At the entrance of the transmission lines into Bheramara power station, the Ishurdi line should be moved toward the north, and consequently, the area of the power station should be expanded as shown in the illustration.



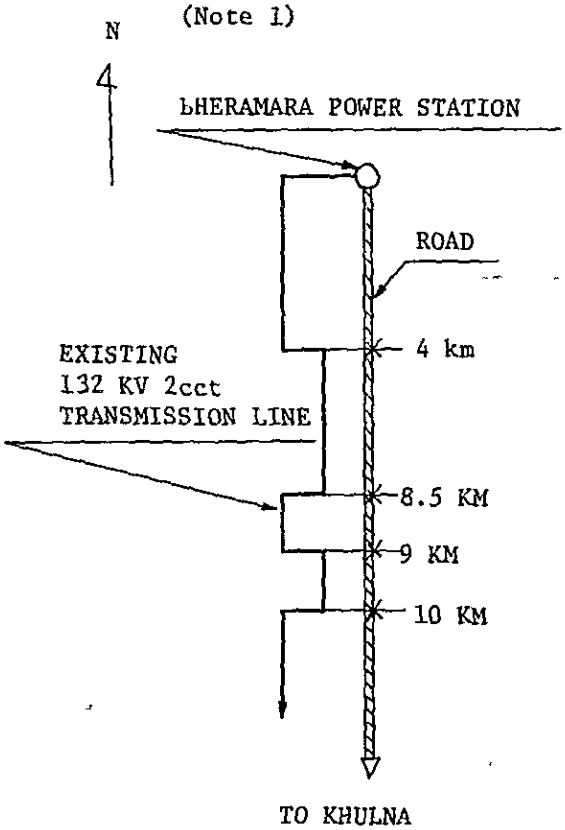
[Plan 2]

Under this plan the new transmission line is connected to the existing transmission line at a point before Kushtia (Point B), and the (A)-(B) section is disconnected. And the Bheramara-(A) section of the existing line is used as the transmission line for this project.

As a consequence of this plan, the configuration of the transmission lines connected to the Bheramara power station will be arranged as shown below.



(Note 1)



As shown in the figure at left, the existing 132kV transmission line comes very close to the Bheramara-Kushtia road along a section of 4.5km, starting from a point 4km from Bheramara, and along a section of 1km starting from a point 9km from Bheramara. In these sections it is therefore impossible to construct a new transmission line between the road and the existing line.
In addition, the area to the right of the road is an inundatible region unsuited for construction of a transmission line. In view of these facts, a route

for construction of the new transmission line to the west of the existing transmission line has been selected.

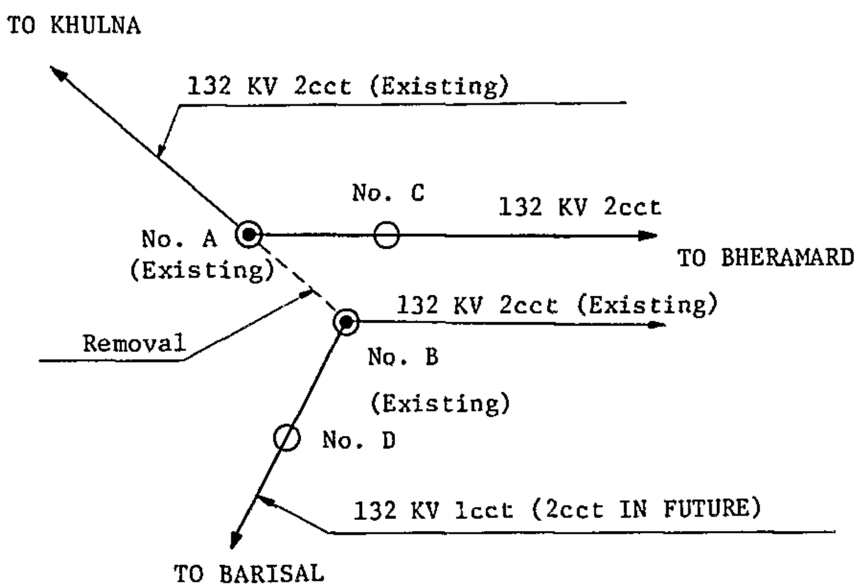
b. Technical considerations

[Plan 1]

In this plan, the new transmission line must cross above the existing 132kV line but this poses no problems in construction.

[Plan 2]

Since this plan implies utilization of part of the existing power transmission facilities, the following points should be studied in detail.



(i) Strength of the existing towers

In view of the change in loading conditions, the strength of the existing towers No.A and No.B should be checked in detail. In case of insufficient strength, the towers should be reconstructed.

(ii) Transfer work method

In the transfer work, provisional stay cables should be installed on the No.A and No.B towers. After this, the tension on the conductors of the existing transmission line, installed between towers No.A and No.B should be gradually loosened, beginning from the upper conductors, and the conductors should be removed.

Simultaneously, the conductors between towers No.A and No.C should be tensioned at tower No.A. In addition, the conductors between towers No.B and No.D should be tensioned at tower No.B. Consequently the amount of work required is large. In addition, although reinforced with stay cables, utmost care is required in order to maintain tensions balance, otherwise the crossarms of towers No.A and No.B may be broken.

c. Results of study

As described above, Plan 2 requires detailed checks of the strength of existing towers and in addition, installation of the conductors is highly complicated, and has some safety problems. Thus, Plan 1, with a more simple construction procedure, is adopted for this project.

7-2 Geological Features

7-2-1 Geologically, the terrain of Bangladesh can be classified as follows:

(1) Hilly accumulations of the tertiary era
(2) Protruded bench accumulations
(3) Inundated alluvial plains and alluvial accumulations at the feet of mountains.

In Bangladesh, 70% of the flat area of the country is composed of alluvial accumulations.

The Bheramara-Faridpur-Barisal area along the Ganges River is an inundation area of the Ganges, Jamuna, and Meghna River. The ground of this area is composed mainly of new accumulations of the quaternary era carried down by these rivers. These accumulations are chiefly composed of sand, silt and clay.

7-2-2 Analysis of geological data obtained by the field survey and in borings (Annex V) give the following results. Initially, the planned route has been divided into five (5) blocks. (Refer to Figure 7-2.)

Block No. 1: Bheramara-Kushtia
Block No. 2: Kushtia-Rajbari
Block No. 3: Rajbari-Bansagari
Block No. 4: Bansagari-Gaurnadi
Block No. 5: Gaurnadi-Barisal

The following are geological features observed in the five (5) blocks.

(1) Block No. 1

Up to depth of 30 meters, the various layers are arranged as follows:

- Surface layer of black humus.
- Second layer of fine sand containing small fragments of mica.
- Third layer of brown sandy soil and silty loam.
- Fourth layer of gray silt and clay with relatively high plasticity.
- Final layer of gray silty sand.

The value of N obtained by the standard penetration test is of the order of three (3) through seven (7) to a depth of eight (8) meters. At depths exceeding that value, N increases gradually up to a maximum of 58.

From the considerations above, the following values are assumed as typical geological constants for the soil of block No. 1.

- Cohesive strength	0.6 t/m^2
- Internal friction angle	25°
- Unit volume weight	1.5 t/m^3

(2) Block No. 2

Up to a depth of 50 meters, the various layers are arranged as follows:

- Surface layer of brown-gray colored hard silt containing fine sand.
- Second layer of light brown silty fine sand.
- Final layer, with a thickness of 41 meter, of uniform brown fine sand with traces of silt.

The value of N is of the order of six (6) through 12 to a depth of five (5) meters from the surface, increasing gradually up to a maximum of 39.

The typical values of the geological constants for the soil of block No. 2 are assumed as follows:

- Cohesive strength	0.6 t/m^2
- Internal friction angle	27°
- Unit volume weight	1.6 t/m^3

(3) Block No. 3

The layers of this block are arranged to a depth of 50 meters as follows:

- Surface layer of light brown loose silt and sand.
- Second layer, 45 meters in thickness, of uniform fine sand and medium sand, with traces of silt and gray color.

The value of N in this block is nine (9) through 11 to a depth of five (5) meters, increasing gradually to a maximum of 61.

The typical values of the geological constants for the soil of block No. 3 are assumed as follows:

- Cohesive strength 0.6 t/m^2
- Internal friction angle 27°
- Unit volume weight 1.6 t/m^3

(4) Block No. 4

The various layers of block No. 3 are arranged as follows to a depth of 30 meters from the surface:

- Surface layer of gray colored silty fine sand, sandy silt or brown clay.
- Second layer of gray colored silty clay, with places containing fine sand.
- Third layer of gray colored silt, containing clay and fine sand.
- Fourth layer of line and medium sand, with small quantities of silt, presenting gray color.
- Final layer of fine and medium sand, containing silt and pieces of mica. The color of this final layer is gray.

The value of N is of the order of three (3) through 15 to a depth of nine (9) meters, approximately 21 at a depth of 20 meters, with a gradual increase up to a maximum of 63.

The typical values of the geological constants for the soil of block No. 4 are assumed as follows:

- Cohesive strength 1.0 t/m^2
- Internal friction angle 15°
- Unit volume weight 1.6 t/m^3

(5) Block No. 5

In block No. 5 the various layers are arranged as follows to a depth of 30 meters from the surface:

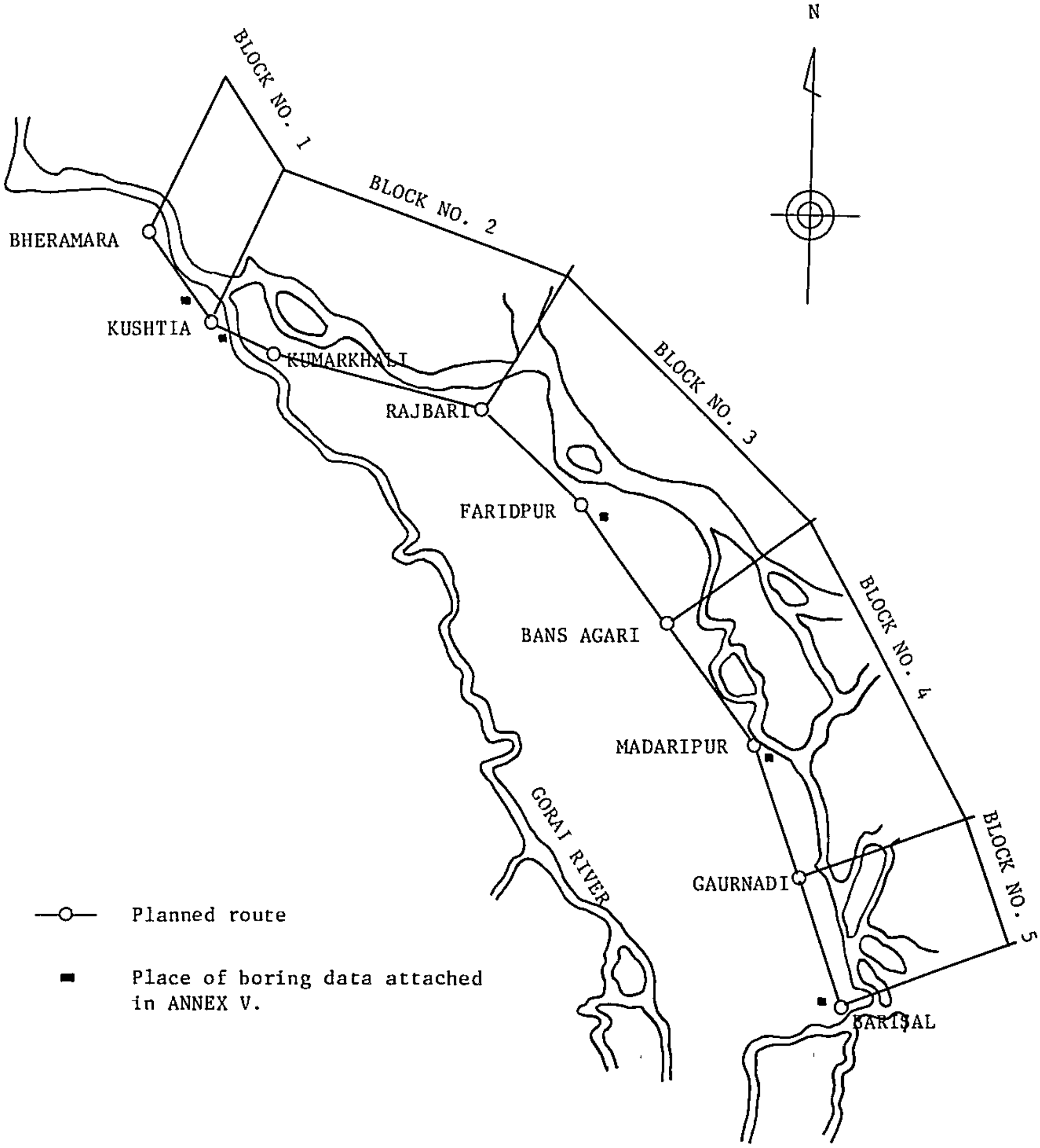
- Gray silt up a depth of 18 meters from the surface, containing clay and fine sand.
- The layer beyond that depth is composed of gray silt and fine sand.

The value of N is of the order of four (4) through 11 to a depth of 15 meters from the surface. At a depth of 15 meters there are places with N of the order of five (5) but in general it increases gradually to a maximum of 30.

The typical values of the geological constants of the soil of block No. 5 are assumed as follows:

- Cohesive strength 1.5 t/m^2
- Internal friction angle 10°
- Unit volume weight 1.6 t/m^3

Fig. 7-2 Regional blocks for Geological study



7-3 Conditions of Design

7-3-1 Design of Towers

(1) Design Criteria

The criteria for design of the towers takes into account the following factors:

- Local meteorological conditions.
- Design criteria of the BPDB.
- Design conditions of existing transmission lines and those under construction.
- Design criteria prevailing in Japan.

Tower design is based upon these criteria, the weight of the towers and the stresses acting upon the foundations.

(2) Design Conditions

a. Conductors

The conductor selected for the transmission line is the Aluminum Conductor Steel Reinforced (ACSR) 477MCM (26/7), conforming to ASTM B232. This conductor is widely used as a standard in Bangladesh and has been selected by taking into consideration the interchangeability of accessories in case of faults, repairs, etc.

For the overhead ground wire Galvanized Steel Wire (GSC) of $55mm^2$ (7/3.2mm), conforming to JIS G-3537 and widely used in Bangladesh has been selected.

b. Selection of insulators

The selected insulator is the ball and socket type 250mm suspension insulator conforming to BS-137. This insulator is widely used in Bangladesh as a standard product. The quantity to be used has been determined in accordance with the design guidelines of the BPDB, i.e., 10 units of 1,500 lb (6,800kg) when used as suspension insulator and 11 units of 25,000 lb (11,400kg) when used as tension insulator.

In this project insulators made of porcelain containing alumina will be used because they exhibit excellent arc withstanding characteristics in addition to superior resistance to mechanical shock loads.

c. Design of towers

The design guidelines prevailing in Bangladesh and the design conditions of existing transmission lines and those under construction have been adopted as fundamental design conditions such as wind pressure and the safety factor of the towers. However, details other than those mentioned above have been designed according to JEC 127.

The criteria adopted in the design of the 132kV Goalpara-Barisal transmission line, adjacent to the subject of the present project, have been studied carefully, aiming at harmonizing the designs of both lines.

(i) Type of tower, number of circuits

The design is for double circuit, because duplication of circuits is expected in near future.
Following four (4) standard types have been assumed in the design of the towers.

Type A (up to 3°),
Type B (up to 15°),
Type C (up to 30°) and
Type D (up to 60° or anchor).

Type A is of the suspension type while all others are of the tension type.

In the route of the project, the only point with special characteristics is the crossing of the Gorai River.
At this point the span is of the order of 430-450 meters, and the required tower height will be of the order of 60 meters. Strength is examined by increasing the value of the assumed wind pressure to 340 kg/m^2. In view of these conditions, suspension towers which pose standard type of B (called BA type) to be installed at both sides of the river have been selected.

(ii) Wind load

The following wind loads same as the design condition of the transmission line under construction are adopted in the design of this project, since the area of this project are relatively close to the site where the transmission towers being constructed.

Maximum wind speed:	100 mph (44.4 m/s)
Wind pressure:	300 kg/m^2 (tower)
	125 kg/m^2 (conductor, ground wire and insulator)

Safety factors are based upon the same criteria adopted for the transmission lines under construction and have the following values.

Towers:	2.0 - normal conditions
	1.2 - abnormal conditions (rupture of conductor)
Conductors:	2.0
Ground wire:	2.3
Insulators:	2.3 or more

(iii) Height above ground

According to design criteria of the BPDB, in normal areas the clearance between conductor and the ground level is 6.71 meters (at conductor temperature of 65.6°C). Since the area concerned is normally flooded (one (1) meter of water) in the rainy season, traffic is in many cases by means of boat and temporary bridge. The effects of inundations in the rainy season are taken into account in determining the height of the conductors.

Table 7-1 Basic Design of Transmission Line

Item	Design Criteria	Remarks
Section	Bheramara-Barisal approximately 230km via Faridpur, Madaripur	
Voltage	132kV	
Conductor	477MCM 26/7, ACSR Code Name "Hawk"	Same as existing transmission line
Number of Circuits	Single circuit	
Overhead Ground Wire	Galvanized steel wire 55mm^2 (tensile strength 4.66 ton)	IKL 60
Insulator	Ball and socket type 250mm suspension insulator (Porcelain containing alumina)	
	10 units: (15,000 lbs - 6,800 kg system) - Used as suspension insulator	Same as transmission line now under construction (Goalpara-Barisal section)
	11 units: (25,000 lbs - 11,400 kg system) - Used as tension insulator	According to criteria of the BPDB S.F. 2.3 (suspension) 2.7 (tension)
Accessories	Span connection - Compression type joint sleeve For conductor repair - Compression type repair sleeve Protection against lightning Arc horn (Rod shaped double end type) Suppression of overhead line vibration Conductor - Double torsional damper No. 12 Ground wire - Double torsional damper No. 3 Span distance 150-300m 2 units " 300-350m 4 units	

Item	Design Criteria	Remarks
	Suspension connection - Performed armor rods Clamp Tension - Compression type (for conductor) - Zinc plated bolt type (for ground wire) Suspension - Aluminum alloy suspension clamp (for conductor) - Zinc plated suspension clamp (for ground wire)	
Others	Climbing steps - Mounted on two (2) diagonally opposite legs	
	Grounding rod - Drive 1.5m long rod for each independent four (4) legs	
	Anti-climbing facilities - All towers should be protected against access by unauthorized persons, by means of barbed wire to three (3) meters above ground level. A pad-locked gate should be provided to maintenance personnel	According to existing transmission lines
	Accessories - Warning plates, sense plates, number plates, line name plates	Warning plates - along roads adjacent to residential areas Sense plates - Close to the substations, power stations, transmission line branches, etc.
	Countermeasures against floods - The towers should be protected with anti-rust painting up to 1.5m above GL.	Protection of all towers against corrosion due to inundation.

Table 7-2 Tower Design Conditions

Item	Design Criteria	Remarks
Number of Circuits	Two (2) circuits at final stage but one (1) circuit installed at this initial stage.	
Tower Type	Four (4) types: A, B, C and D. Designed for height progressions of three (3) meters from 12 meters through 30 meters from lowest arm to ground level. For the Gorai River crossing, B type towers will be used as suspension type towers. (called BA type)	Vertical configulation, so as to facilitate future stringing of additional circuit. A type Horizontal angle 3° max B type Horizontal angle 15° max C type Horizontal angle 30° max D type Horizontal angle 60° max 0° (anchor)
Wind Velocity	Conductor, overhead ground wire, insulators 125 kg/m^2 Towers 300 kg/m^2	Average maximum wind speed 100 mph (44.4 m/s) BA type towers are checked with 340 kg/m^2 and as a result B type tower may be used as BA type tower.
Maximum Tensile Strength	Conductor 4,200 kg Overhead ground wire 1,950 kg	S.F. 2.09 S.F. 2.39
Shielding Angle of Overhead Ground Wire	+15°	
Clearance Design (Insulation Distance)	(1) Suspension tower Without wind pressure 145cm At 20° lateral swing 145cm At 40° lateral swing 115cm At 60° lateral swing 85cm (2) Tension tower Jumper distance 200cm Without wind pressure 160cm At 15° lateral swing 160cm At 40° lateral swing 85cm	

Item	Design Criteria	Remarks
Safety Factor of Tower Material	Normal conditions: S.F. 2.0 with regard to yield point Abnormal conditions: S.F. 1.2 with regard to yield point (in case of rupture)	
Shape of Tower Material	Symmetrical angle steel	
Material	Tower material: SS 41, 50, 55 Bolts and nuts: SS 41, 50, SCR 4	JIS G 3101 JIS G 4104
Clearance Above Ground Level	Minimum clearance above ground level 6.71m (in case of 65.6°C) Minimum clearance from other obstacles Roads 7.93m (in case of 74°C) River (general) 7.62m (") River (Gorai) 15.2m (") Railroad 3.81m (") Residential: In principle crossing over residential buildings is not allowed. However, under unavoidable circumstances height of 5.18m (in case of 74°C) should be guaranteed.	Design criteria of the BPDB Clearance above ground level shall be from the water surface because the transportation by means of boat is done during inundated season. The inundation level is assumed to be +1 meter based on the survey.

d. Tower design results

The results of the design, according to the tower design conditions described above, are summarized in Table 7-3. Structural drawings of the towers are shown in Annex VI.

Table 7-3 List of the Foundation Reactions and the Tower Weight

(Unit: kg)

Tower Type	Design Conditions	Body Extension 3.0m (7.7m above ground level)*2					Body Extension 6.0m (10.4m above ground level)*3				
		Tower*1 Weight	Foundation Reaction*5				Tower*1 Weight	Foundation Reaction*5			
			Com-pressive Load	Tensile Load	Horizontal Load	Horizontal Load on Members		Com-pressive Load	Tensile Load	Horizontal Load	Horizontal Load on members
A	Horizontal angle 3°, tower wind pressure 300 kg/m² (common to types B-D)	5,929	22,650	18,960	2,980	920*6	6,739	23,680	19,620	3,140	930*6
B	Horizontal angle 15°	8,273	34,960	30,080	4,710	1,130*6	9,299	35,870	30,510	4,880	1,130*6
C	Horizontal angle 30°	8,910	46,590	41,320	6,750	1,230*6	10,195	47,920	42,050	6,940	1,230*6
D	Horizontal angle 60° or horizontal angle 0° (anchor)	12,344	64,400	57,450	10,660	2,330	14,396	66,160	58,260	10,900	2,260
BA *4	Horizontal angle 3°, tower wind pressure 340 kg/m²	Body extension 24m (required clearance: 15.2m)									
		17,788	42,720	33,430	6,040	1,150					

Notes: *1 Including weight of foundation material

*2 The height of the conductors above ground level is determined according to design guidelines of the BPDB (6.71m at 65.6°C). Inundation factor of one (1) meter during the rainy season is included.

*3 Towers for crossing over roads, medium scale rivers, canals, power lines and communication lines are taken into consideration. Tower type is determined taking into consideration roads, which are the element to be crossed most commonly, as examples. (Banked road height of approximately 2.5m. Clearance according to the guideline is 7.93m at 74°C).

*4 Designed with Gorai River as a reference.

*5 The foundation stress is actual stress.

*6 Stress in abnormal case.

No mark = Normal condition

7-3-2 Foundation Design

(1) Design Guidelines

Factors taken into special consideration in the design:

a. The route along which the transmission line is planned is completely inundated during the rain season.

b. For foundations requiring piling work, domestically manufactured concrete piles should be used, in view of the high cost of steel materials.

c. The period of construction should be restricted to the dry season.

d. The design is based upon JEC (Standards of Japanese Electro-Mechanical Committee) and applicable standards and codes.

e. As for the co-efficient of soil condition, the following values are adopted, based upon Table 7-2.

Co-efficient of Soil Condition

Item		Unit	Block 1	Block 2	Block 3	Block 4	Block 5
Internal Friction Angle		Degree	25	27	27	15	10
Cohesive Strength		ton/m^3	0.6	0.6	0.6	1.0	1.5
Unit Volume Weight	Normal	ton/m^3	1.5	1.6	1.6	1.6	1.6
	Under-water	ton/m^3	0.5	0.6	0.6	0.6	0.6

(2) Material

a. Concrete

Weight of reinforced concrete	Normal	2.4 ton/m^3
	Underwater	1.4 ton/m^3
Designed standard strength of concrete		180 kg/cm^2

b. Piles

Designed standard strength of concrete pile	240 kg/cm^2
Designed standard strength of cast-in-place concrete pile	300 kg/cm^2

c. Reinforcing steel bar

Normal steel bar (SK25)	Tension	1,600 kg/cm^2
	Compression	1,600 kg/cm^2

(3) Safety Factor

Normal	2.0 or more
Abnormal	1.33 or more

(4) Design Formula

a. Spread foundations

Yield compressive bearing power (Qcy)

$$Qcy = \frac{1}{1.5} (\alpha \cdot C \cdot Nc + \beta \cdot \gamma_{s1} \cdot B \cdot Nr + \gamma_{s2} \cdot Df \cdot Nq)$$

Where:
- α : Base plate shape coefficient 1.3
- β : Base plate shape coefficient 0.4
- C : Cohesive strength of soil under base plate (ton/m^2)
- γ_{s1}: Average unit volume weight of soil under base plate (ton/m^3) (Buoyancy should be considered when under water level.)
- γ_{s2}: Average unit volume weight of soil above base plate (ton/m^3) (Buoyancy should be considered when under water level)
- Df : Depth from ground surface to base plate (m)
- Nc,Nr,Nq: Bearing power coefficient due to internal friction angle φ of soil

b. Yield bearing power for pulling out (Qry)

$$Qry = Wc + Ws + \frac{1}{1.5} \cdot L \cdot Df \left(c + \frac{1}{2} \cdot \gamma_{s2} \cdot Df \frac{\tan \phi}{1 + \sin\phi}\right)$$

Where:
- L : Perimeter of base plate
- C : Average cohesive strength of soil above base plate (ton/m^2)
- φ : Internal friction angle of soil above base plate (degree)
- Wc: Weight of foundation (ton) (Buoyancy should be considered when under water level)
- Ws: Weight of soil on the base plate (ton) (Buoyancy should be considered when under water level)

(5) Pile Foundation

a. Yield compressive bearing power

(i) Compressive bearing power of single pile

1) Driving pile (precast concrete pile)

$$Qcy = \frac{1}{1.5}\{30\eta\cdot\overline{N}\cdot Ap + (\frac{Ns\cdot \ell s}{5} + \frac{qu\cdot \ell c}{2})\pi\cdot D\} - 2Wp$$

2) Cast-in-place pile

$$Qcy = \frac{1}{1.5}\{15\overline{N}\cdot Ap + (\frac{Ns\cdot \ell s}{5} + \frac{qu\cdot \ell c}{2})\pi\cdot D\} - 2Wp$$

Where: Qcy: Yield compressive bearing power as single pile or grouped pile (ton/pile)

η : Pile end blocking effect

$\overline{N}$: Pile end design N value

N_1 : Average N value within a distance of 1xD (D: outer diameter of pile) under pile end

N_2 : Average N value within a distance of 4xD above the pile end

Ap : Pile end area (m^2)

D : Pile diameter (m)

$\overline{Ns}$: Average N value of sandy soil ($\leqq 15$)

qu : Single axis compression strength of clayed soil

ℓs : Thickness of sandy soil (m)

ℓc : Thickness of clayed soil (m)

Wp : Weight of pile (ton/pile)

b. Yield bearing power for pulling out

(i) Driving pile and cast-in-place pile

1) Bearing power for pulling out of single pile

$$Qty = \frac{1}{1.5}\{(\frac{\overline{Ns}\cdot \ell s}{5} + \frac{qu\cdot \ell c}{2})\pi\cdot D + 1.5Wp\}$$

(6) Design Results

The results of design under the above-mentioned criteria give consideration to economy and safety as per the following table:

Spread foundation: 563 units (80%)

Pile foundation: 142 units (20%)

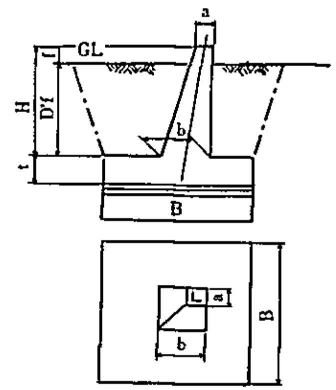
Of the pile foundations, 139 units use present concrete piles, and 3 units use cast-in-place piles:

Table 7-4
List of Transmission tower Foundation

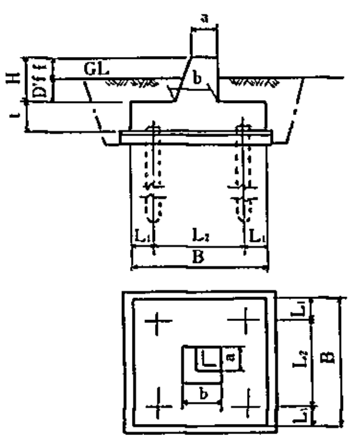
Note: Type of foundation S : Spread foundations P: Pile foundetion
Kind of pile C·P : Cast-in-place concrete pile P·P : Present pile

	Regional block	Block No.1				Block No.2				Block No.3				Block No 4				Block No.5		
	Type of tower	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	D
	Number in each tower	42	12	2	5	134	38	2	12	134	25	6	8	159	19	6	4	82	12	3
	Type of foundation	S	S	P	P	S	S	P	P	S	S	P	P	S	S	P	P	P	P	P
Coefficient of soil condition	Cohesion C (t/m²)	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0 60	0.60	0.60	0.60	0.60	1.00	1.00	1. 00	1 00	1.50	1 50	1.50
	Internal friction angle Ø(°C)	25°	25°	25°	25°	27°	27°	27°	27°	27°	27°	27°	27°	15°	15°	15°	15°	10°	10°	10°
	Unit weight by volume γ_s(t/m³)	1.5	1.5	1.5	1.5	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Loading condition	Compression load (t)	23.68	35.87	47.92	66.16	23.68	35.87	47.92	66.16	23 68	35.87	47.92	66 16	23.68	35.87	47.92	66.16	23.68	35.87	66.16
	Tensile load (t)	19.62	30.51	42.05	58.26	19.62	30.51	42.05	58.26	19 62	30 51	42.05	58.26	19.62	30.51	42.05	58.26	19.62	30.51	58.26
	Horizontal load (t)	1.80	2.20	2.40	4.47	1.80	2.20	2.40	4.47	1.80	2.20	2.40	4.47	1.80	2.20	2.40	4.47	1.80	2.20	4.47
Dimension	a (m)	0.50	0.50	0.50	0.55	0.50	0.50	0.50	0 55	0.50	0.50	0.50	0.55	0.50	0.50	0.50	0.55	0.50	0.50	0.55
	b (m)	1.16	1.35	0.77	0.90	1.13	1.35	0.77	0.90	1.13	1.35	0.77	0.90	1.13	1.40	0.77	0.90	0.74	0.77	0.90
	f (m)	0.45	0.45	0 45	0.45	0.45	0.45	0.45	0 45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0 45	0.45	0.45	0.45
	H (m)	2.65	3.05	0.95	0.95	2.55	3.05	0.95	0 95	2.55	3.05	0.95	0 95	2.55	3.05	0.95	0.95	0.95	0.95	0.95
	D'f (m)	2.20	2.60	0.50	0.50	2.10	2.60	0.50	0.50	2.10	2.60	0.50	0.50	2.10	2.60	0.50	0.50	0.50	0.50	0.50
	B (m)	3.80	4.10	3.50	4.00	3.60	4.10	3.50	4.00	3.60	4.10	3.50	4.00	3.50	3.80	3.50	4.00	1.80	2.10	3.20
	t (m)	0.70	0.80	1.00	1.10	0.70	0.80	1.00	1.00	0.70	0.80	1.00	1.00	0.60	0.80	1.00	1.00	0.60	0.60	1.00
	L_1 (m	—	—	0.50	0.50	—	—	0.50	0.50	—	—	0.50	0.50	—	—	0.50	0.50	0 50	0.50	0.80
	L_2 (m)	—	—	2.50	3.00	—	—	2.50	3.00	—	—	2.50	3.00	—	—	2.50	3.00	0.80	1.10	1.60
	Sectional area of pile (ft×ft×ft)	—	—	1×1×45	1×1×45	—	—	1×1×45	1×1×45	—	—	1×1×45	1×1×45	—	—	1×1×45	1×1×45	1×1×45	1×1×45	60×23 5
	Number of pile	—	—	16	20	—	—	16	20	—	—	16	20	—	—	16	20	16	20	16
	Nature of pile	—	—	P·P	P·P	—	—	P·P	P·P	—	—	P·P	P·P	—	—	P·P	P·P	P·P	P·P	C·P
Quantity	Excavation (m³)	234	324	184	237	204	324	184	222	204	324	184	222	189	284	184	222	59	70	180
	Back filling (m³)	169	239	116	142	145	239	116	133	145	239	116	133	138	209	116	133	44	51	122
	Excavated soil (m³)	65	85	68	95	59	85	68	89	59	85	68	89	51	75	68	89	15	19	58
	Gravel filling (m³)	12	14	12	16	11	14	12	16	11	14	12	16	10	12	12	16	4	5	11
	Concrete (m³)	48	65	51	75	44	65	51	66	44	65	51	66	37	58	51	66	9	12	43
	Lean concrete (m³)	6	7	6	8	5	7	6	8	5	7	6	8	5	6	6	8	2	3	5
	Forming work (m²)	36	46	66	82	34	46	66	76	34	46	66	76	34	48	66	76	27	30	63
	Reinforcing bar (kg)	3534	4048	2868	3638	3259	4048	2868	3534	3259	4048	2868	3534	3096	3868	2868	3534	931	1036	2467
	Length of pile (ft)	—	—	720	900	—	—	720	900	—	—	720	900	—	—	720	900	720	900	376

Spread foundation



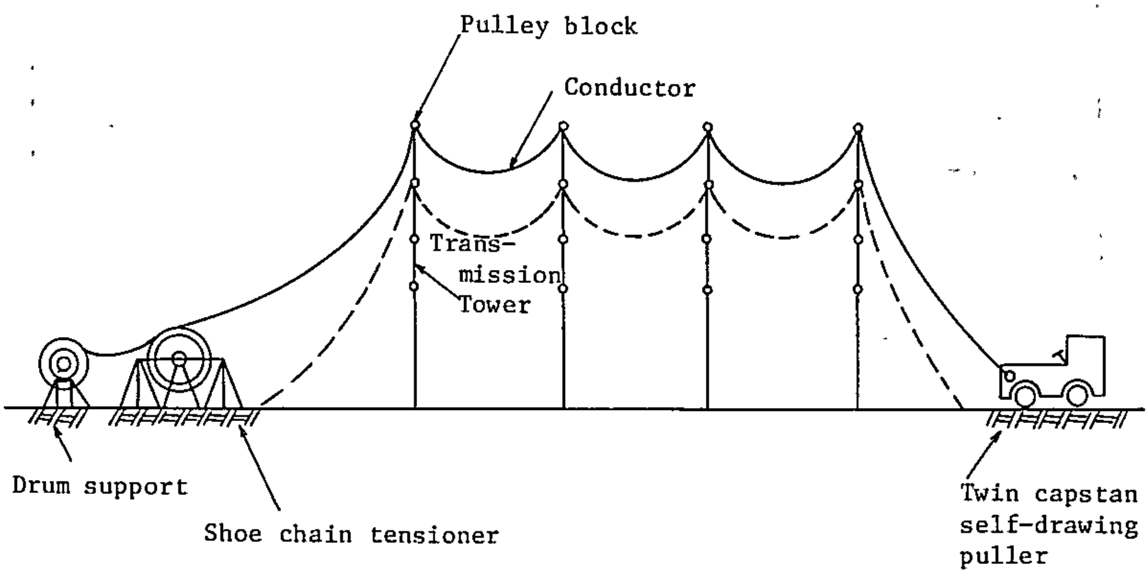
Pile foundation



7-4 Stringing Method

Presently the BPDB's stringing method depends mainly on man's power and oxcarts. In view of protection of the conductors, safety, and efficiency of work, survey team recommend the adoption of the "non-stop stringing" method in the construction of this transmission line.

Figure 7-3 Stringing Method



7-5 Required Material

7-5-1 Main Material

Calculation of the main material, takes into consideration the route selected and the design conditions. Details are listed below:

Main Material

Name	Specifications	Unit	Total Quantity
Tower		ton	4,800
Conductor	ACSR 477MCM	km	712
Overhead ground wire	GSC 55 mm^2	km	236
Insulators and hardware	Single suspension strings, with clamp and horn	Sets	1,840
"	Single tension strings	"	948
Hardware for ground wire	Suspension, with clamp	"	570
"	Tension, with clamp and clip	"	320
Joint sleeve	ACSR 477MCM	Units	360
"	GSC 55 mm^2	"	120
Jumper sleeve	ACSR 477MCM	"	60
"	GSC 55 mm^2	"	20
Conductor repair sleeve	ACSR 477MCM	"	20
Pre-formed armor rods	ACSR 477MCM	Sets	1,700
Double torsional damper	ACSR 477MCM No. 12	Units	4,320
"	GSC 55 mm^2 No. 3	"	1,440

7-5-2 Tools and Vehicles

Tools required for construction of the transmission line should be selected and supplied taking into consideration the method of construction and maintenance. Vehicles required for supervision of construction and maintenance of the transmission line should also be supplied.

(1) Tools for Stringing Work

a. Guidelines for calculation of required quantity

Initially the quantity of tools required for one (1) stringing job is calculated. The total quantity of tools required is calculated for 12 contractors.

Calculations are based upon the following hypothesis.

(i) One (1) stringing section has a length of five (5) km with 15 towers consisting of 12 suspension and three (3) tension towers.

$$230\text{km} \div 4 \div 12 = 5\text{km}$$

(ii) The tools used on one (1) stringing section can be shared by two (2) contractors because a time lag on construction work will come about. Forty (40) days have been allowed for one (1) stringing job in each section.

The BPDB possesses a some quantity of construction tools, now being used on transmission lines under construction. The quantity of tools to be provided for this project is the total required quantity minus the quantity possessed by the BPDB.

b. Required quantity

The required quantity of tools are shown in Table 7-5.

(2) Vehicles

The following vehicles should be provided, for supervision of the construction work and for maintenance.

a.	Truck	6 ton	2 units
b.	Light van	Class 1,200-1,300cc	4 units
c.	Jeep		2 units
d.	Micro bus		1 units

Table 7-5 List of the Required Quantity of Tools

Name	Specifications	Unit	Quantity required for one(1) stringing job (1)	(1) x 6 (2)	Possessed by the PBDB (3)	Spares (4)	Quantity to be provided (5)
Shoe chain tensioner	12m	Unit	2	12	4	2	10
Twin capstan self-drawing puller		Unit	2	12	4	2	10
Hydraulic compressor with accessories	100 tons	Set	2	12	10	4	6
Stringing clamp and accessories	For conductors	Set	6	36	20	6	22
Come along clamp and accessories		Set	12	72	40	12	44
"		Set	4	24	20	6	10
Swivel		Unit	2	12	-	6	12
Counter weight for running board	Automatic passing type	Set	2	12	-	2	14
Wire connector	Double pulling type	Unit	130	780	300	20	500
Pulley blocks	Urethane lining 300ϕ	Unit	45	270	200	30	100
"	Pressed steel plate 200ϕ	Unit	15	90	130	-	-
Snatch blocks	5-ton one wheeled pulley 150mmϕ	Unit	20	120	70	10	60
Joint protector	For conductors	Set	4	24	15	6	15
Drum support with drum jack		Set	4	24	8	2	18
Hand winch	1 ton	Unit	4	24	10	6	20
Conductor hook		Unit	3	18	15	3	6
Insulator changer	For 254mm	Unit	2	12	-	3	15
Turnbuckle	Hook type No.3	Unit	8	48	20	12	40
"	Hook type No.2	Unit	6	36	20	6	22
Level hoist	1.5-ton 3-ton	Unit	3	18	30	-	-

7-6 Material Transportation Method

In the western zone the roads and railroads are not as developed as in the eastern zone. Thus, transportation by means of barges has developed in the western zone.

Consequently, transportation of materials for this project by barge seems to be most advantageous. The port with the best conditions for unloading is Chalna port.

(1) Merits of Transportation by Means of Barge

- Economy (The cost is reduced to approximately 60% compared with railroad and truck means).
- Ultra-heavy equipment (transformers, etc.) can be transported only by means of barge.
- Barges are the most advantageous means of transportation during the rainy season.

(2) Transportation Route

Routes of transportation for this project are shown in Figure 7-4.

Fig. 7-4 Transportation Route