Table 3-9 Luzon Grid KWH Balance (1979-2000)

Unit: 10^6 KWH

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
HYDRO	2050	2050	2098	2098	3201	3201	3201	3201	3201	4354	4354	4354	4354	5511	5511	6315	8102	9152	9679	10637	11052	12435
PUMP HYDRO				275	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
GEOTHERMAL	959	2283	3176	3671	3970	3970	9748	10542	10542	11336	11336	12130	12130	12924	12924	13718	13718	14512	14512	15306	15306	15306
COAL FIRED THERMAL						1989	3978	3978	3978	3978	3978	3978	3978	3978	5967	5967	5967	5967	7956	7956	11934	11934
NUCLEAR							1684	3367	3639	3856	3910	3910	3910	3910	3910	3910	3910	3910	3910	3910	3910	3910
OIL FIRED THERMAL	13871	13571	13571	14769	14769	14769	14769	14769	14769	14769	14769	14769	14769	14769	14769	14769	14769	14769	14769	14769	14769	14769
TOTAL	16880	17904	18845	20813	22240	24229	33680	36157	36439	38593	38647	39441	39441	41392	43381	44979	46766	48610	51126	52878	57271	58654
REQUIRED ENERGY	12010	12850	13750	14710	15740	16840	18020	19280	20630	22075	23620	25275	26920	28670	30530	32515	34630	36705	38910	41245	43720	46340
PUMPING ENERGY				370	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
SURPLUS	4870	5054	5095	5733	6100	6989	15260	16477	15399	16118	14627	13766	12121	12322	12451	12064	11736	11505	11816	11233	13151	11914

Table 3-10 Luzon Grid
Average 30 Yrs Hydrologic Data
of Existing and Proposed Hydro Projects
(Source: Project Development)

	QUARTERLY CAP. (MW)				CAPABILITY (MW)		DEPENDABLE CAPACITY (MW)
NAME OF PLANT	1ST	2ND	3RD	4TH	MAX./1	MIN./2	
Caliraya (32)	32.3	32.1	32.1	32.3	32.3	32.1	32.1
Ambuklao (75)	64.3	50.9	57.3	67.3	67.3	50.9	50.9
Binga (100)	90.0	85.1	87.0	90.0	90.0	85.1	85.1
Angat (218)	188.3	157.7	150.0	176.9	188.3	150.0	150.0
Pantabangan (100)	77.6	67.4	75.7	87.3	87.3	67.4	67.4
Botocan (17)	15.3	15.3	15.3	15.3	15.3	15.3	15.3
Masiway (12)	10.8	10.8	10.8	10.8	10.8	10.8	10.8
Magat (360)	313.7	270.6	307.9	315.0	315.0	270.6	270.6
Magat (180)							180.0
San Roque (260)	219.2	191.6	197.6	228.1	228.1	191.6	191.6
San Roque (130)							130.0
Gened (600)	528.3	487.8	461.7	490.5	528.3	461.7	461.7
Kanan (280)	250.0	240.0	221.9	231.5	250.0	221.9	221.9
Chico IV (360)	321.4	290.6	305.2	349.5	349.5	290.6	290.6
Chico II (250)	216.1	197.0	204.7	220.3	220.3	197.0	197.0
Tabu (110)	99.0	92.6	77.3	99.0	99.0	77.3	77.3
Cabingatan (140)	123.1	112.6	112.2	121.9	123.1	112.6	112.6
Chico III (120)	108.0	103.1	78.7	89.2	108.0	78.7	78.7
Abuan (100)	87.9	82.8	78.4	83.1	87.9	78.4	78.4
Dakgan (120)	100.3	100.9	100.7	106.8	106.8	100.3	100.3
Amburayan (100)	82.4	75.6	81.5	88.7	88.7	75.6	75.6
Ilagan (210)	183.2	175.9	168.9	175.5	183.2	168.9	168.9
Gadeng (150)	132.2	116.2	116.1	130.0	132.2	116.1	116.1
Tanudan (140)	119.1	110.3	114.6	125.7	125.7	110.3	110.3
Diduyon (350)	-	-	-	-	-	-	220.0

NOTE: The above are Synthetic Data generated by Lahmeyer as there is no available data for planning purposes.

/1 Max. capability for hydro means capacity the plant can deliver at high or favorable reservoir condition.

/2 Minimum capability means capacity the plant can deliver at low or worst reservoir condition defined as dependable capacity.

Table 3-11 Thermal Plants
Plant Capacity Data

NAME OF PLANT	NO. OF SETS	INSTALLED CAPACITY (MW)	CAPABILITY MAX.	(MW) MIN.	DEPENDABLE CAPACITY (MW)
Rockwell 1-5	5	125	75	25	75
Rockwell 6-8	3	180	150	54	150
Tegen 1 & 2	2	200	190	60	190
Bataan 1	1	75	72	22	72
Bataan 2	1	150	143	45	143
Gardner 1	1	150	140	45	140
Gardner 2	1	200	180	60	180
Snyder 1	1	200	190	60	190
Snyder 2	1	300	290	90	290
Malaya 1	1	300	290	90	290
Malaya 2	1	350	340	105	340
		GEOTHERMAL			
Tiwi 1-6	6	330	300	270	300
Geo. 1 x 55	1	55	50	45	50
		NUCLEAR			
PNPP 1	1	620	590	197	590
		COAL			
Coal Thermal I	1	300	270	90	270
		PUMPED HYDRO			
Kalayaan 1 & 2	2	300	300	300	300

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* Maximum and Minimum capability is the operating level at which the plant can be operated economically for thermal plant max. capability is the dependable capacity.

Table 3-12 Existing EHV System and 2nd Voltage in World

unit : kV

Nations	EHV (A)	2nd Voltage (B)	Ratio (A)/(B)	Note
U.S.A.	345	138 154	2.5 2.24	
	500	220	2.27	
	765	345	2.22	
Canada	730 *1	220	3.32	*1 Very long transmission line (> 600 km)
	500	220	2.27	
U.K.	400	275	1.45	
France	730 *2	220	3.32	*2 Future Surround Paris planning
	400	220	1.82	
Other European	400	220	1.82	
Japan	500	275 220	1.82 2.27	

Table 3-13 Main Characteristics of Transmission Lines

(for System Analysis)

(per circuit)

Voltage (kV)	No. of Circuits	Line Size (MCM)	Max. Current (Amp.)	Max. Capacity (MVA)	Kvarc per km	% for km on 100 MVA base positive sequence	
						Resistance	Reactance
230	1	1 - 795	900	358.5	168.28	0.01619	0.09679
230	2	1 - 795	900	358.5	175.10	0.01619	0.09314
230	2	2 - 795	1,800	717.0	227.30	0.00809	0.07093
230	2	4 - 795	3,600	1,434.1	269.64	0.00405	0.05927
500	2	4 - 795	3,600	3,117.6	1,197.22	0.00086	0.01334
115	1	1 - 795	900	179.3	45.78	0.06474	0.35676 *1
115	1	1 - 795	900	179.3	47.67	0.06474	0.3431 *2
115	1	2 - 795	1,800	358.5	64.45	0.03237	0.2428 *2

Note: *1. Tower
*2. Pole

Table 3-14 Main Characteristics of Generators and Step-up Transformers

Existing Plants

Name	MW	MVA	X'd(%)	X"d(%)	H	TrB.MVA	TrB.Imp. (%)	Note
Mak-Ban	55.0	69.0	24.00	18.00	4.0	68.75	15.83	% value means per unit own base
Tiwi	55.0	69.0	26.86	21.02	4.0	41.4	10.10	
Malaya	650.0	828.0	29.49	23.47	2.8	812.0	24.31 10.38 12.69	21 kV - 230 kV 117 kV - 230 kV 21 kV - 117 kV
Gardner	350.0	433.0	25.78	18.71	3.5	362.0	9.42	
Snyder	500.0	615.0	32.22	23.02	3.5	602.0	13.44	Geothermal MW means unit capacity.
Tegen	200.0	256.0	19.00	15.00	3.4	250.0	9.90	
Bataan	225.0	281.0	23.40	18.10	3.45	300.0	9.50	Other plant MW means its total capacity,
Pantabangan	100.0	111.0	27.00	20.00	3.4	128.0	13.63	
Ambuklao	75.0	83.4	31.00	22.00	3.2	64.0	16.97	
Binga	100.0	112.2	31.00	21.60	2.9	132.0	13.60	
Angat	200.0	222.0	22.00	15.50	2.9	244.0	29.68	

Table 3-15 Main Characteristics of Generators and Step-up Transformers

Future Plants

Name	MW	MVA	X'D (%)	X"D (%)	H	Tr.B MVA	Tr.B Imp.(%)	Note
Geothermal	55.0	69.0	26.86	21.02	4.0	41.4	10.1	The same value as Tiwi
C F T H	300.0	370.0	32.00	24.00	3.0	400.0	15.0	
P N P P	620.0	800.0	39.33	28.22	4.5	768.0	15.0	
Kalayaan	300.0	333.0	30.00	22.00	4.0	340.0	15.0	
Magat	540.0	600.0	30.00	22.00	4.0	690.0	15.0	
Gened	600.0	690.0	30.00	22.00	4.5	768.0	15.0	
San Roque	390.0	433.0	30.00	22.00	4.0	500.0	15.0	
Chico IV	360.0	400.0	30.00	22.00	4.0	460.0	15.0	
Agos Kanan	280.0	311.0	30.00	22.00	4.0	360.0	15.0	
Chico II	250.0	278.0	30.00	22.00	4.0	320.0	15.0	
Other Future Hydro	-	MW÷0.9	30.00	22.00	4.0	MW÷0.9 x 1.15	15.0	

Table 3-16 Main Characteristics of Step-down Transformers

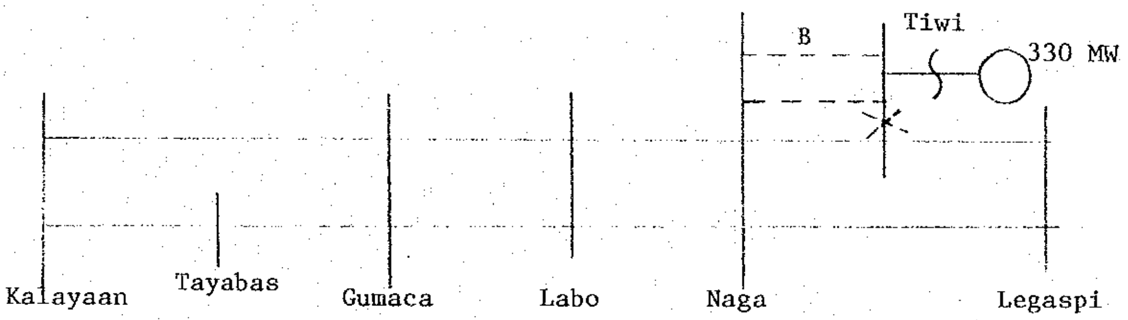
Voltage	Capacity	Impedance
230 kV/115 kV	300 MVA	11.5%
230 kV/115 kV	100 MVA	11.3%
500 kV/230 kV	300 MVA	14%
500 kV/230 kV	150 MVA	14%
500 kV/115 kV	300 MVA	16%

Table 3-17 Result of Transient Stability Calculation

(Year 1982)

Case	Fault Point	Opened line	Max. ∠δ & time	Max. ∠δ point	Judgement
A	Tiwi	Naga - Tiwi	>180° 45∿	Tiwi	unstable
	Naga	Naga - Labo 1 cct	92.6° 27∿	Tiwi	stable
	Gumaca	Gumaca - Tayabas	79.6° 24∿	Tiwi	stable
B	Tiwi	Nage - Tiwi 1 cct	85.5° 24∿	Tiwi	stable

System Outline



———— Case A Tiwi 330 MW

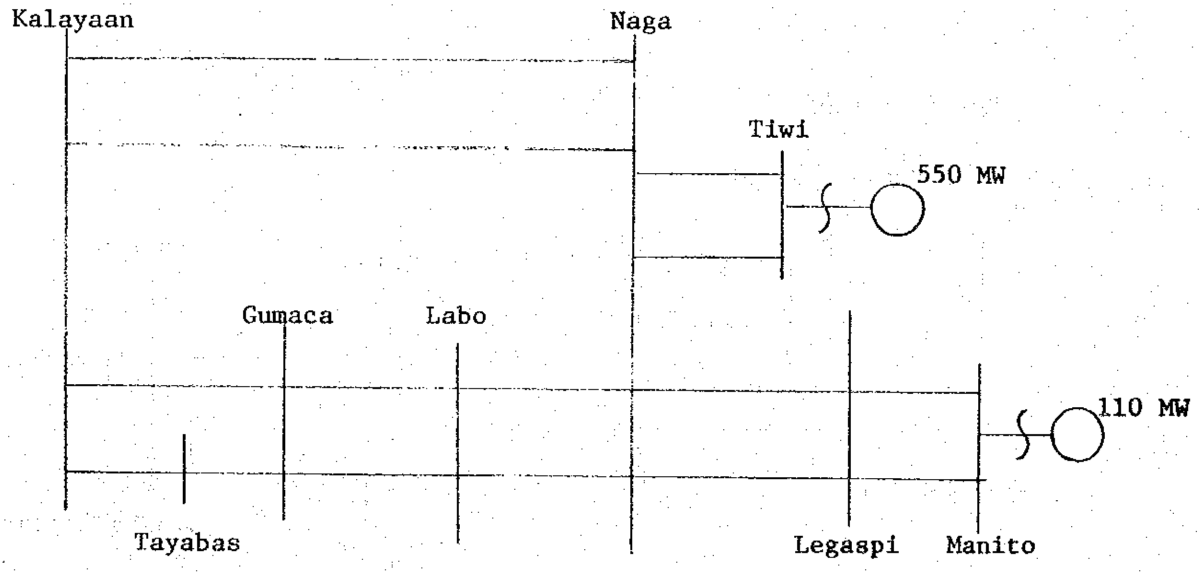
— — — — Case B (additional to Case A) Tiwi 330 MW

Table 3-18 Result of Transient Stability Calculation

(Year 1985)

Case	Fault Point	Opened line	Max. $\angle\delta$ & time	Max. $\angle\delta$ Point	Judgement
C	Naga	Naga - Kalayaan 1 cct	68.2° 24∿	Tiwi	stable

System Outline



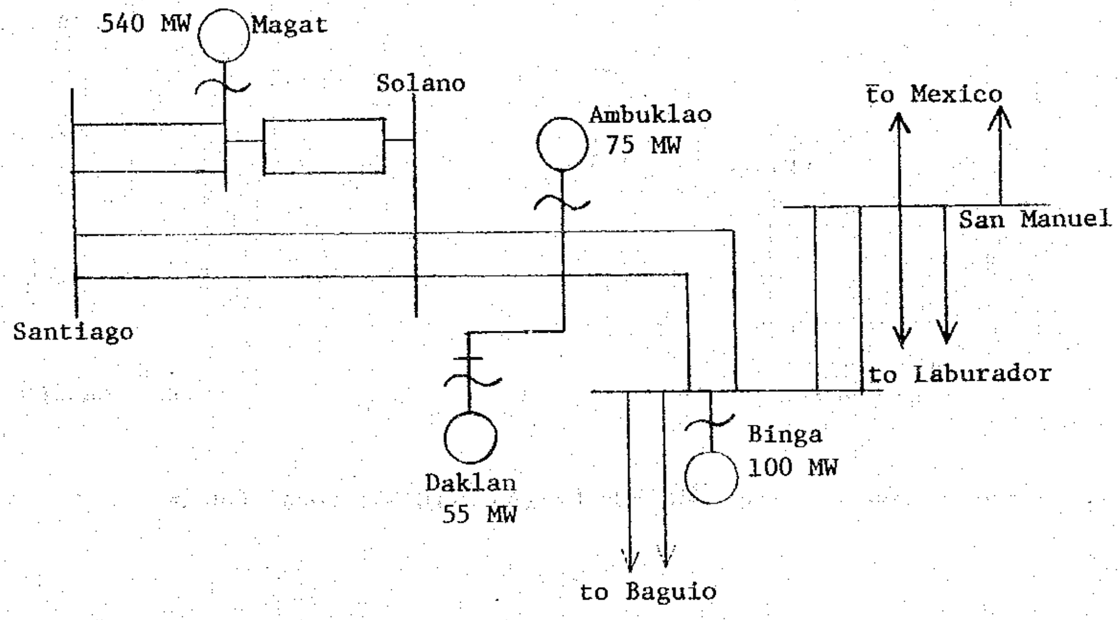
—— Case C Tiwi 550 MW, Manito 110 MW; total 660 MW

Table 3-19 Result of Transient Stability Calculation

(Year 1985)

Case	Fault Point	Opened line	Max. ∠δ & time	Max. ∠δ point	Judgement
D	Solano	Solano - Ambuklao 1 cct	113.3° 36∿	Magat	stable
	Ambuklao	ditto	118.1° 42∿	Magat	stable
	ditto	Ambuklao - Binga 1 cct	93.1° 27∿	Magat	stable
	Binga	ditto	92.8° 27∿	Magat	stable
	Magat	Magat - Solano	105.3° 27∿	Magat	stable

System Outline



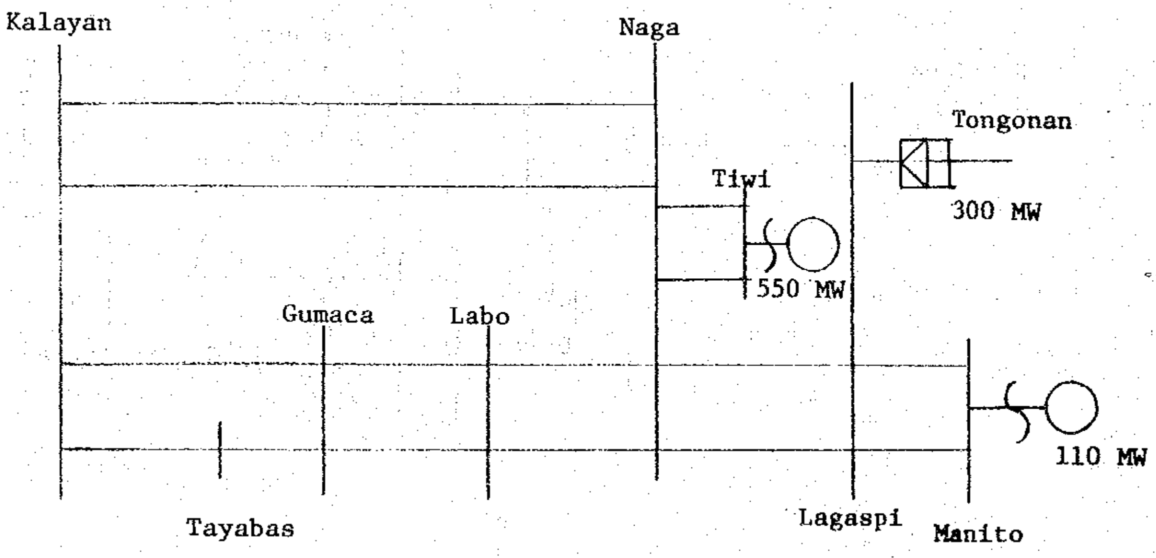
Case D Magat 540 MW, Ambuklao 75 MW, Binga 100 MW, Daklan 55 MW; total 770 MW

Table 3-20 Result of Transient Stability Calculation

(Year 1986)

Case	Fault Point	Opened line	Max. $\angle\delta$ & time	Max. $\angle\delta$ point	Judgement
E	Naga	Naga - Kalayaan 1 cct	99.6° 33∿	Tiwi	stable

System Outline



—— Case E Tiwi 550 MW, Manito 110 MW

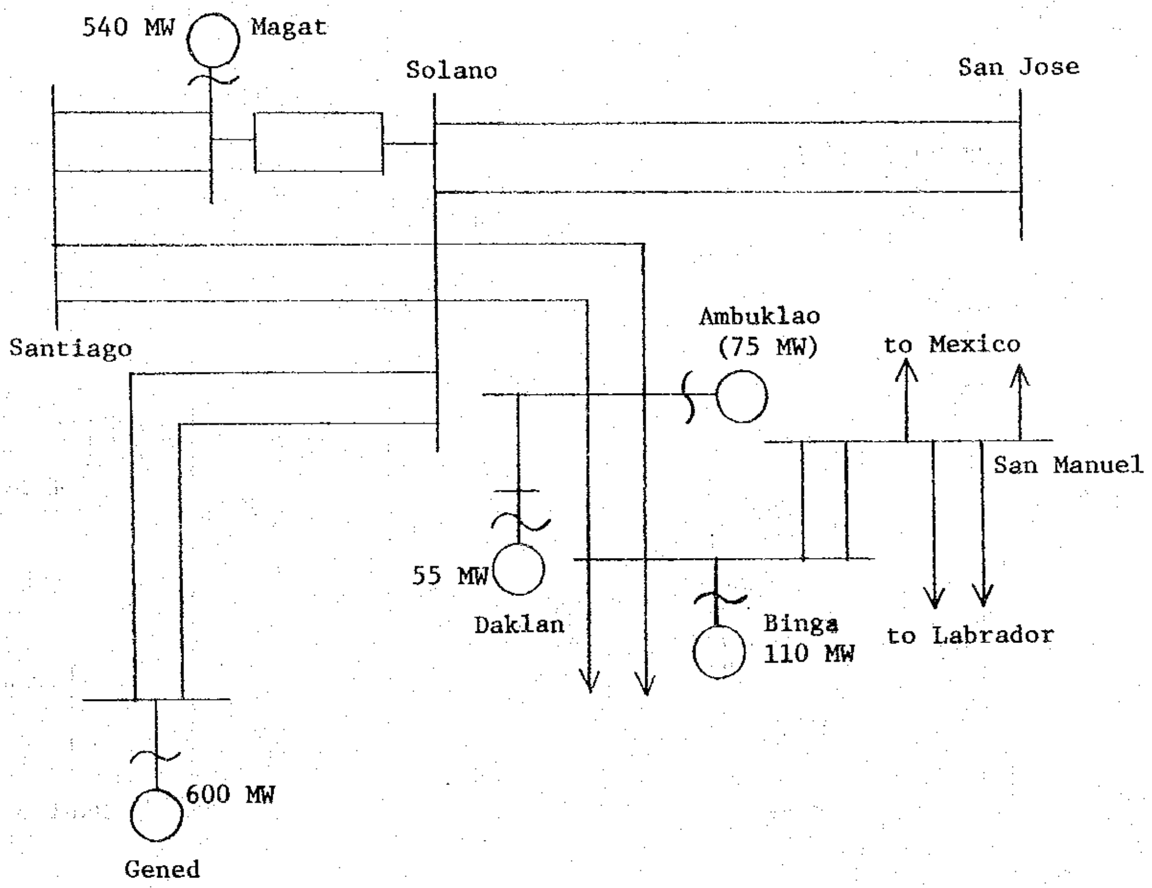
Tongonan 300 MW; total 960 MW

Table 3-21 Result of Transient Stability Calculation

(Year 1988)

Case	Fault Point	Opened line	Max. $\angle\delta$ & time	Max. $\angle\delta$ point	Judgement
F	Gened	Gened - Solano 1 cct	>180° 33~	Gened	unstable

System Outline

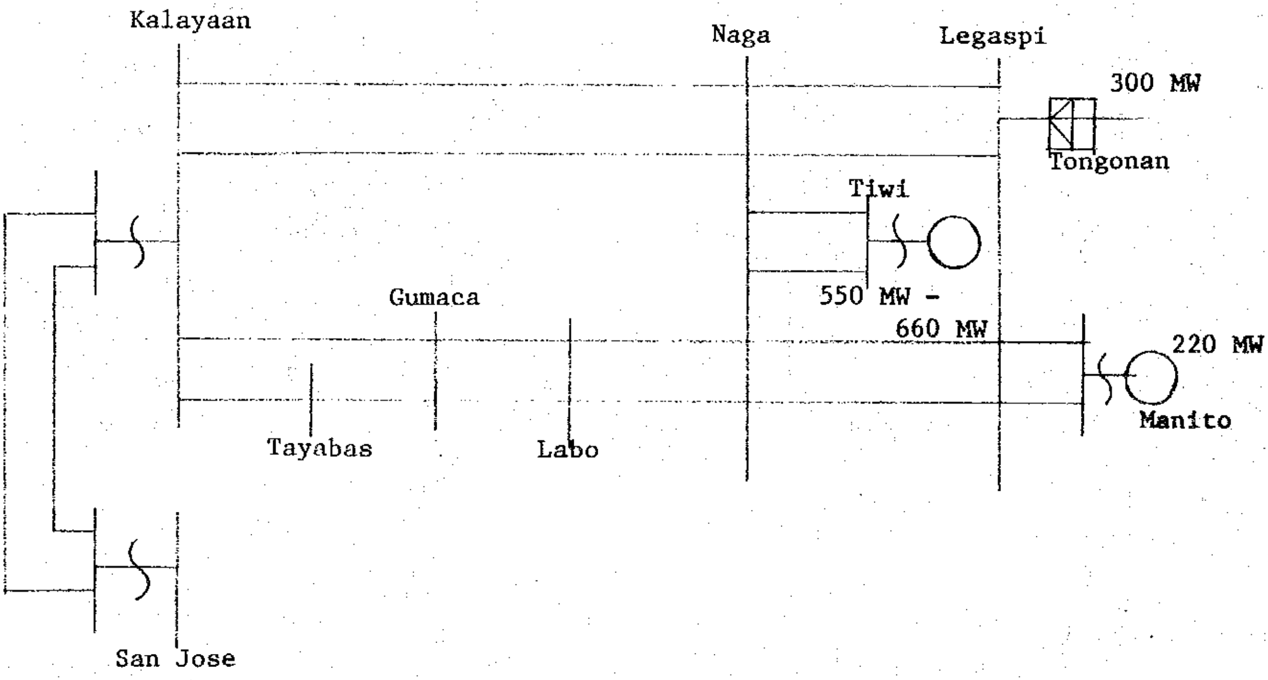


——— Case F Magat 540 MW, Ambuklao 75 MW, Bingu 100 MW, Daklan 55 MW, Gened 600 MW; total 1,370 MW

Table 3-22 Result of Transient Stability Calculation
(Year 1991, 1992)

Case	Fault Point	Opened line	Max. $\angle\delta$ & time	Max. $\angle\delta$ point	Judgement
G-I	Naga	Kalayaan - Naga 1 cct	97.1° 33∿	Tiwi	stable
G-II	ditto	ditto	>180° 57∿	Tiwi	unstable

System Outline



Case G-I (1991) Tiwi 550 MW, Manito 220 MW, Tongonan 300 MW; Total 1,070 MW

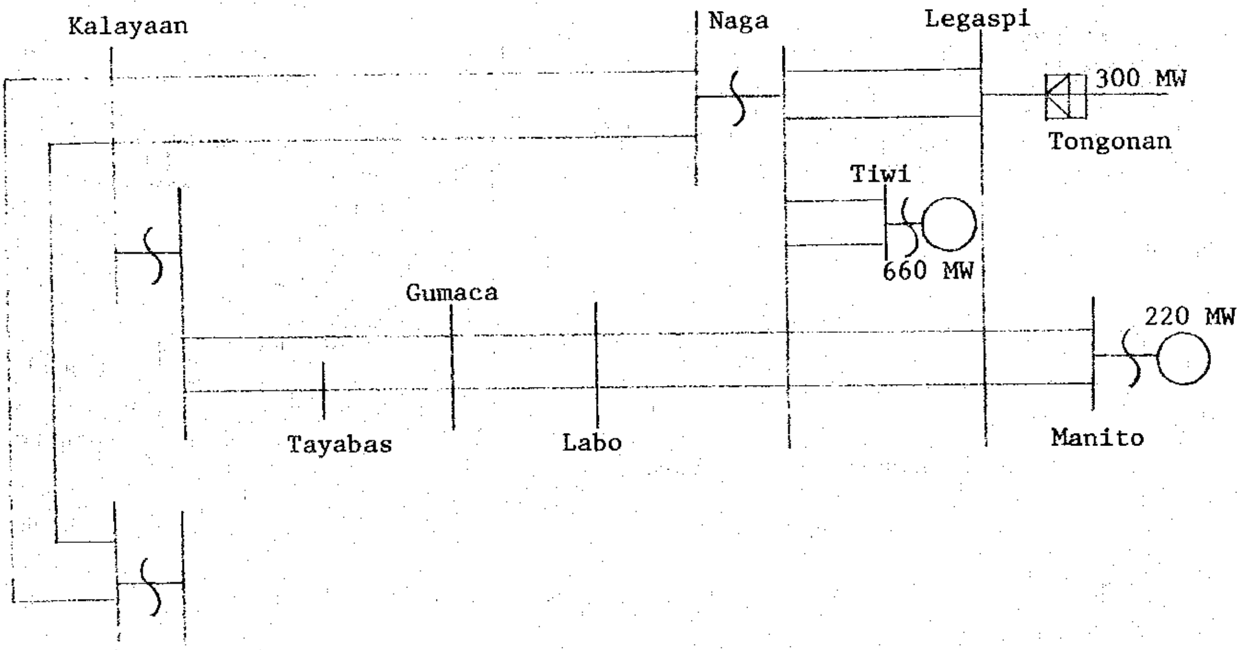
Case G-II (1992) Tiwi 660 MW, Manito 220 MW, Tongonan 300 MW; Total 1,180 MW

Table 3-23 **Result of Transient Stability Calculation**

(Year 1995)

Case	Fault point	Opened line	Max. δ & time	Max. δ point	Judgement
H	Naga	Kalayaan - Naga 1 cct	58.8° 18∿	Tiwi	stable
	Kalayaan	ditto	51.7° 15∿	Tiwi	stable

System Outline



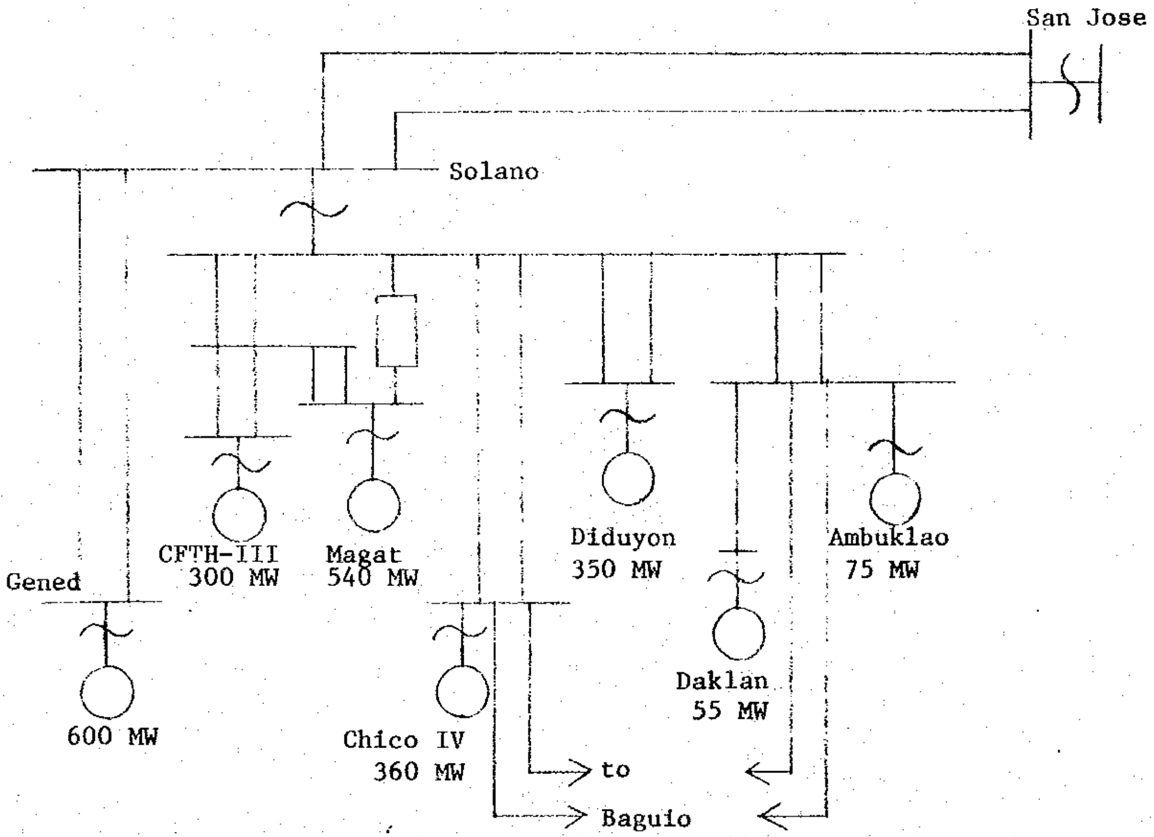
——— Case H Tiwi 660 MW, Manito 220 MW, Tongonan 300 MW;
Total 1,180 MW

Table 3-24 Result of Transient Stability Calculation

(Year 1995)

Case	Fault point	Opened line	Max. ∠δ & time	Max. ∠δ point	Judgement
K-I	Solano	Solano - San Jose 1 cct	95.1° 30∿	Magat	stable
K-II	Gened	Gened - Solano 1 cct	67.7° 21∿	Gened	stable
	Solano	ditto	72.7° 24∿	Magat	stable
	ditto	Solano - San Jose 1 cct	101.5° 45∿	CFTH-III	stable

System Outline



—— Case K - I Southern Luzon 500 kV operation

Case K-II Southern Luzon 230 kV operation

Gened 600 MW, CFTH-III 300 MW, Chico IV 360 MW, Magat 540 MW, Diduyon 350 MW, Daklan 55 MW, Ambuklao 75 MW; Total 2,280 MW

Table 3-25 Luzon EHV Expansion Schedule

Year of Comm.	Northern System		Southern System			
	Transmission Lines	Substations	Transmission Lines		Substations	
1982			Naga - Tiwi (60 km) : 230kV 2 x 2 - 795 MCM	Malaya-Kalayaan (27 km): 230 kV 2 x 4 - 795 MCM		245kV PCB : Naga 3 units
1985	Ambuklao-Daklan (17km): 230 kV 2 x 2 - 795 MCM	245 kV PCB : Ambuklao 1 unit Daklan 1 unit	Kalayaan-Naga (237 km) : 500kV design 2x4-795MCM Legaspi-Manito (43 km) : 230kV 2 x 2 - 795 MCM		245 kV PCB : Kalayaan 3 units	245 kV PCB : Naga 3 units Legaspi 3 " Manito 3 "
1986			Naga - Legaspi (76 km) : 500kV design 2x4-795MCM	San Jose-Kalayaan(76 km): 500 kV design 2x4-795MCM	245 kV PCB : San Jose 3 units Kalayaan 3 units	245 kV PCB : Naga 3 units Legaspi 3 "
1988	Gened-Solano-San Jose (423 km) : 500kV 2x4-795 MCM	525KV/230KV 300MVA TrB : Solano 2 units 550kV PCB : Gened 3 units, Solano 9units 245kV PCB : Solano 3 units ShR: Solano 700 MVAR	Kalayaan-Naga(238 km) : 500KV Operation	San Jose-Kalayaan(76km): 500 kV Operation	525kV/230kV 300 MVA TrB : San Jose 2 units, Kalayaan 1 unit 525kV/115kV 300 MVA TrB : San Jose 1 unit 550kV PCB : San Jose 8 units,Kalayaan 8 units 245kV PCB : San Jose 1 unit 115kV PCB : San Jose 2 units ShR : Kalayaan 550 MVAR	525kV/230kV 300MVA TrB: Naga 3 units 550 kV PCB : Naga 8 units 245 kV PCB : Naga 2 units
					(Relation for Northern System) 525kV/230kV 300 MVA TrB : San Jose 1 unit, Kalayaan 1 unit 525kV/115kV 300 MVA TrB : San Jose 1 unit 550kV PCB : San Jose 6 units,Kalayaan 1 unit 115kV PCB : San Jose 1 unit 245 kV PCB: San Jose 1 unit ShR : San Jose 180 MVAR	
1990						525kV/230kV 300MVA TrB: Naga 1 unit 550kV PCB : Naga 1 unit 245kV PCB : Naga 1 unit
1992	San Roque-San Manuel (9km) 230kV 2 x 1 - 795 MCM	245 kV PCB : San Roque 3 units San Manuel 3 units				
1993	CFTH-III-Santiago(36km) 230kV 2 x 2 - 795 MCM	245 kV PCB : CFTH-III 3 units Santiago 3 units				

Table 3-25

Year of Comm.	Northern System		Southern System	
	Transmission lines	Substations	Transmission Lines	Substations
1994	Chico IV-Solano (107 km) 230 kV 2 x 2 - 795 MCM	525kV/230kV 300 MVA TrB : Solano 1 unit 550kV PCB : Solano 2 units 245 kV PCB : Solano 5 units Chico IV 3 units		525kV/115kV 300MVA TrB : San Jose 1 unit 550kV PCB : San Jose 1 unit 115 kV PCB : San Jose 2 units
1995	Diduyon-Solano (45 km) 230kV 2 x 1 - 795 MCM	525kV/230kV 300 MVA TrB : Solano 1 unit 550 kV PCB : Solano 1 unit 245 kV PCB : Diduyon 5 units Chico IV 3 units		

Fig.3-1 LUZON GRID 230 KV SYSTEM SINGLE LINE DIAGRAM

(AS OF THE END OF 1979)

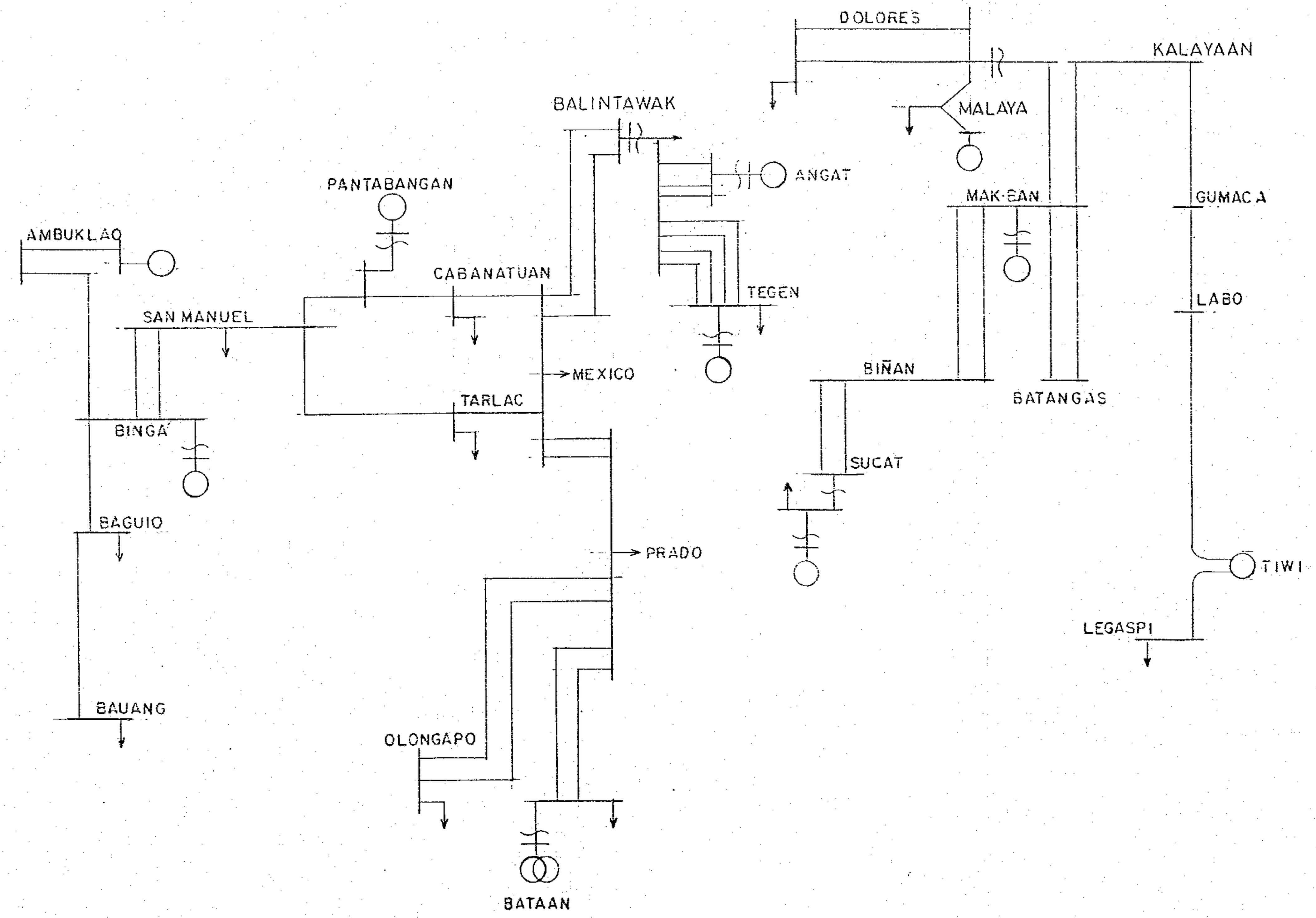


Fig. 3-2 Daily Load Curve Weekdays 1979 Luzon Grid

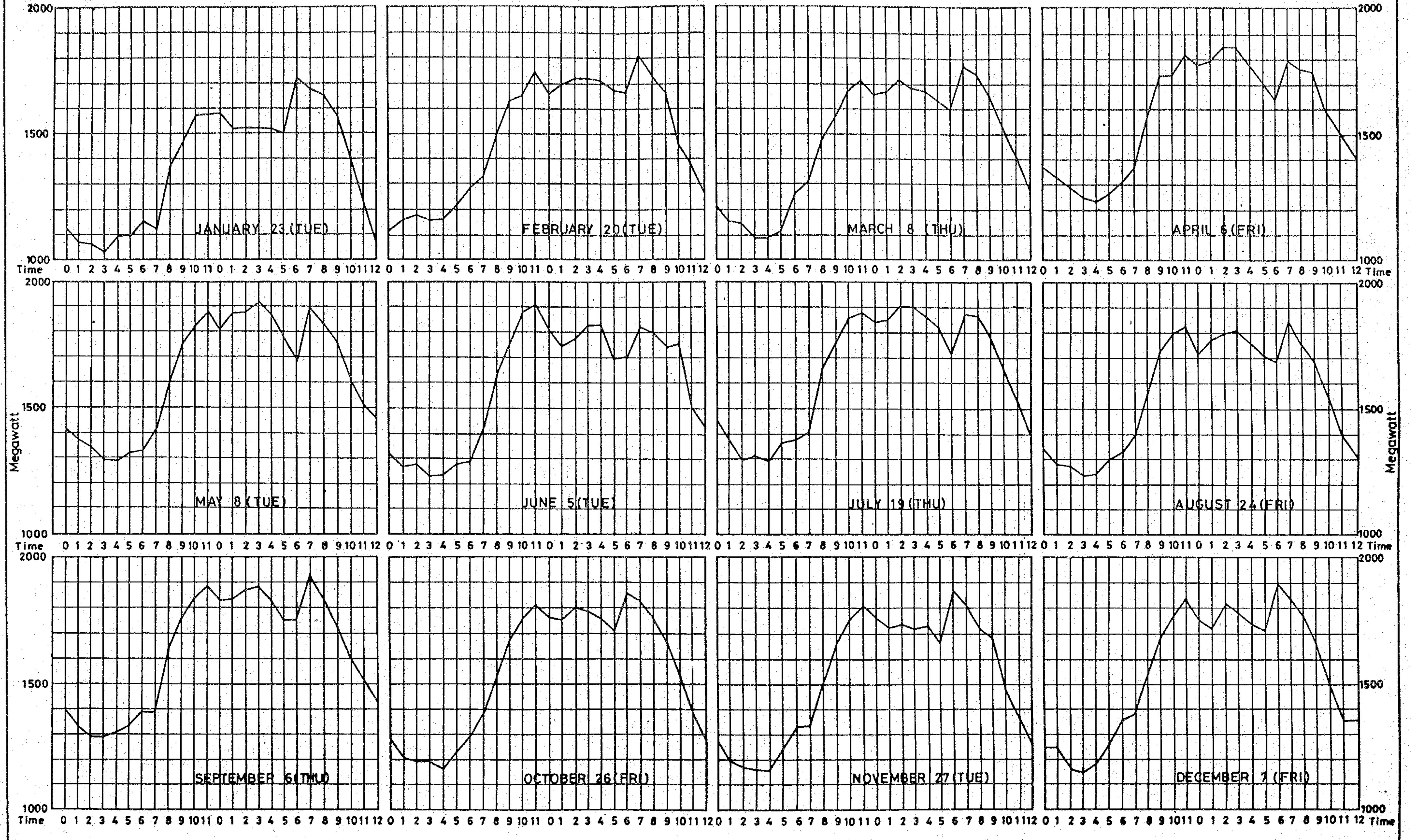
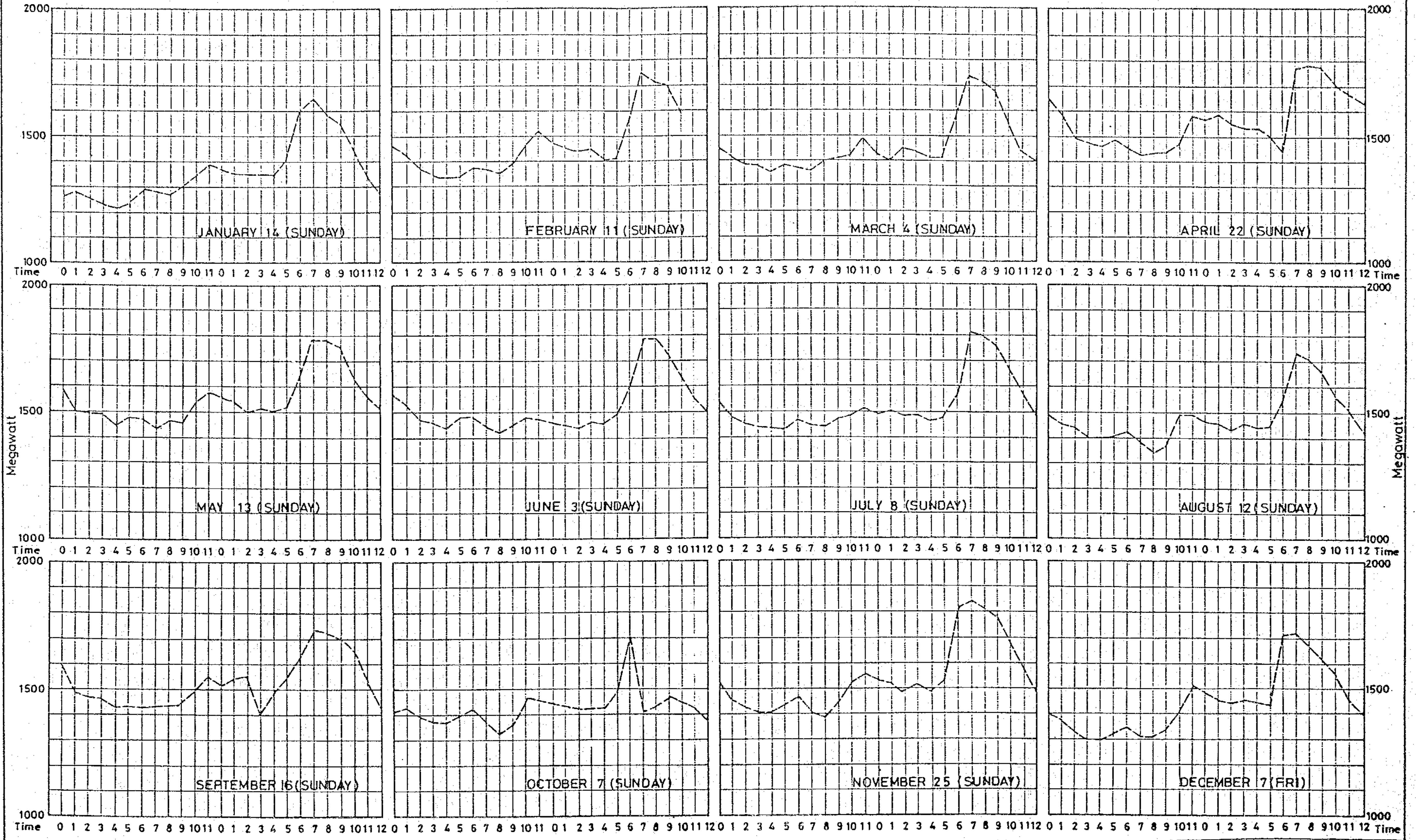


Fig. 3-3 Daily Load Curve Holidays 1979 Luzon Grid



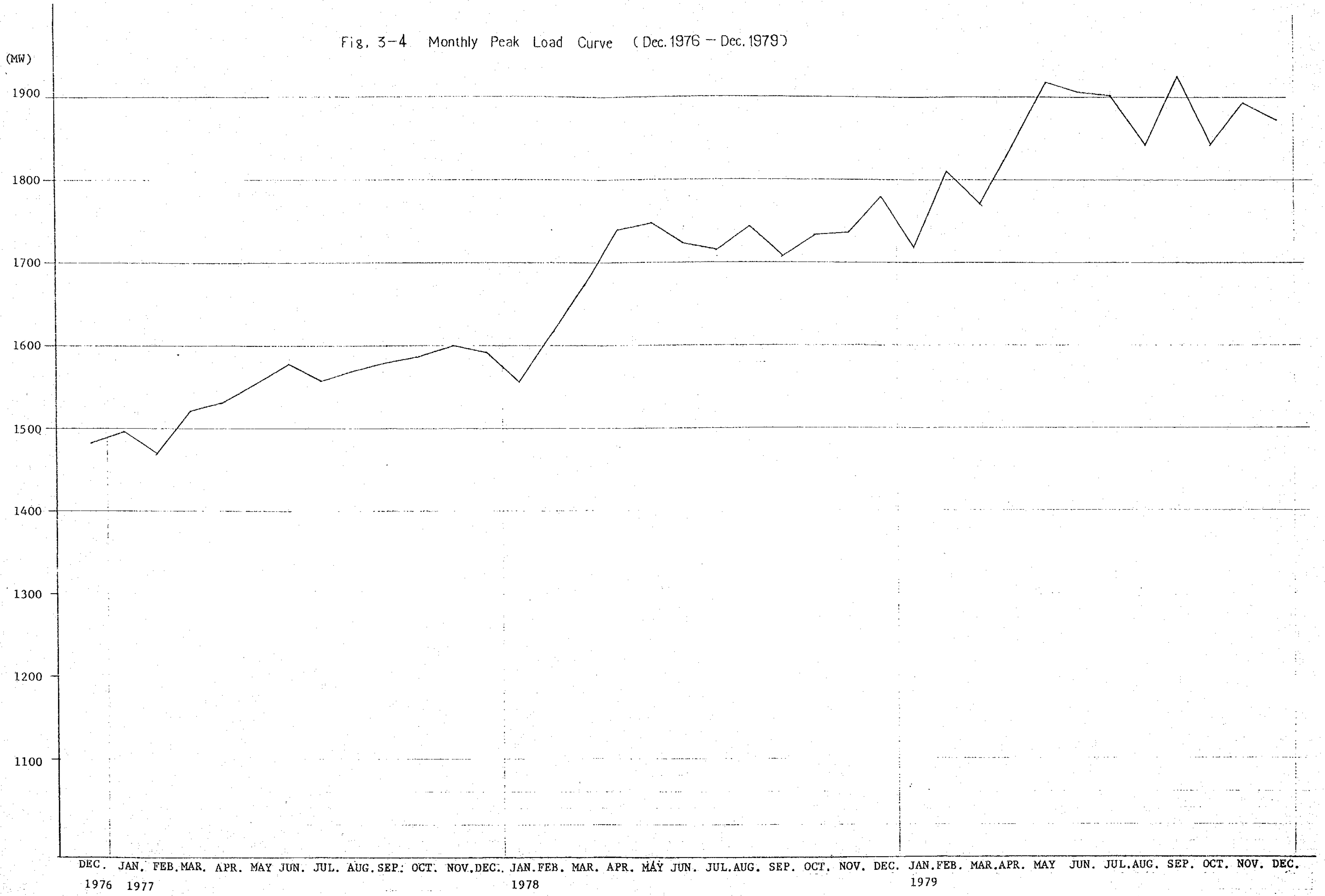


Fig. 3-4 Monthly Peak Load Curve (Dec.1976 – Dec.1979)

Fig. 3-5 Correlation between Electricity Consumption and GDP, per capita, as seen in the World

Source: Statistical Year Book, U.N., 1975

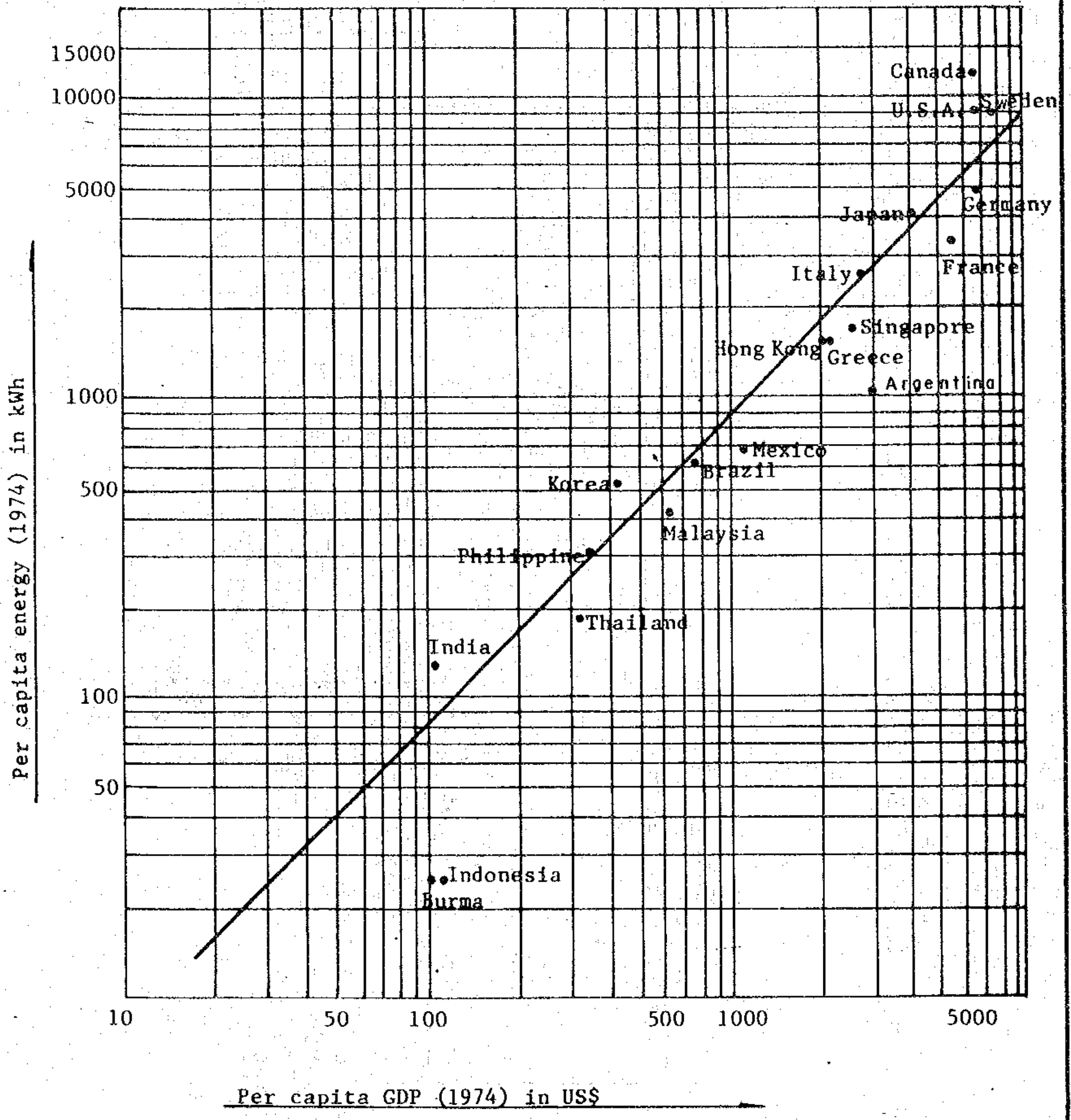


Fig 3-6 Existing Luzon Grid Outline (End of 1979)

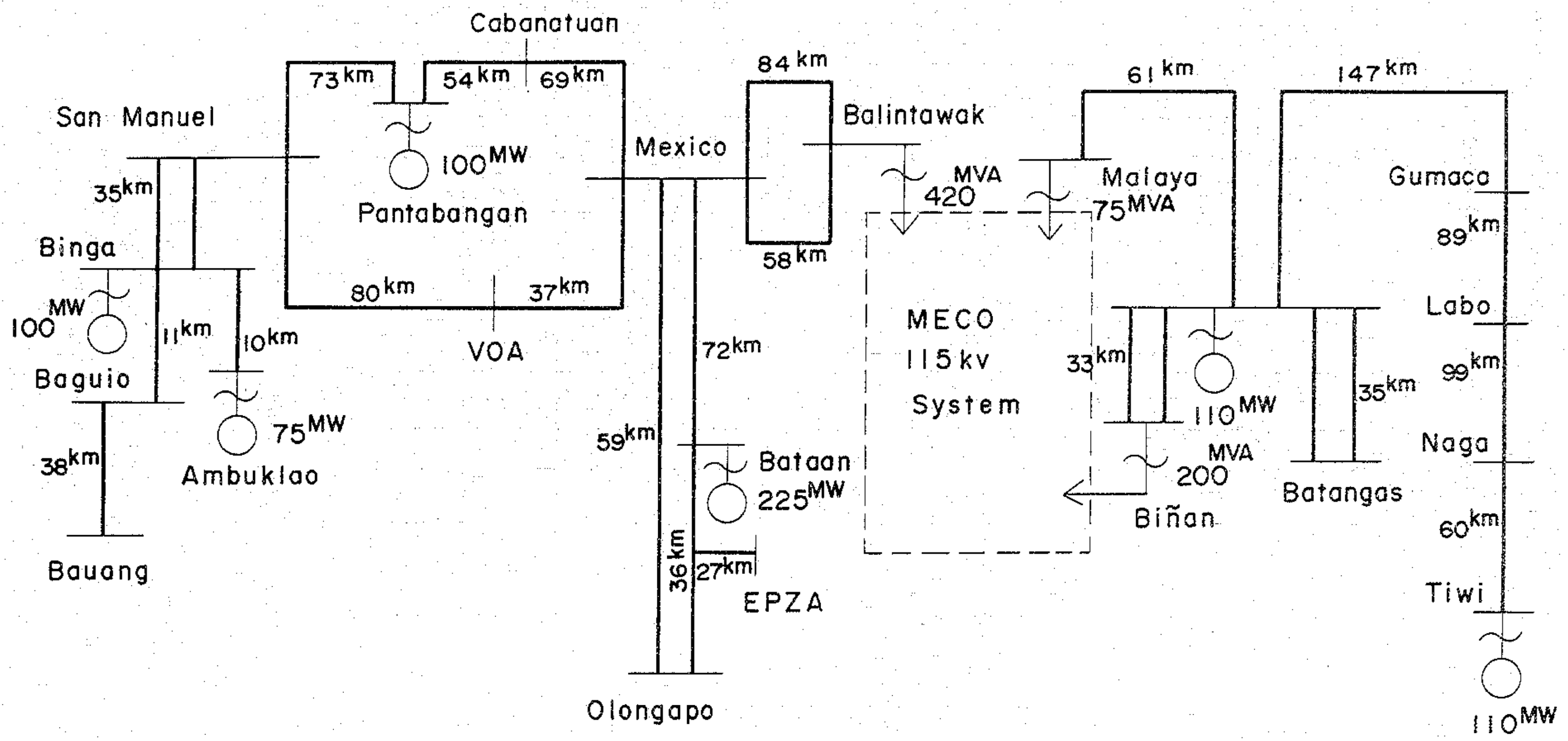


Fig 3-7 Luzon Grid Single Line Diagram

Initial Expansion Program

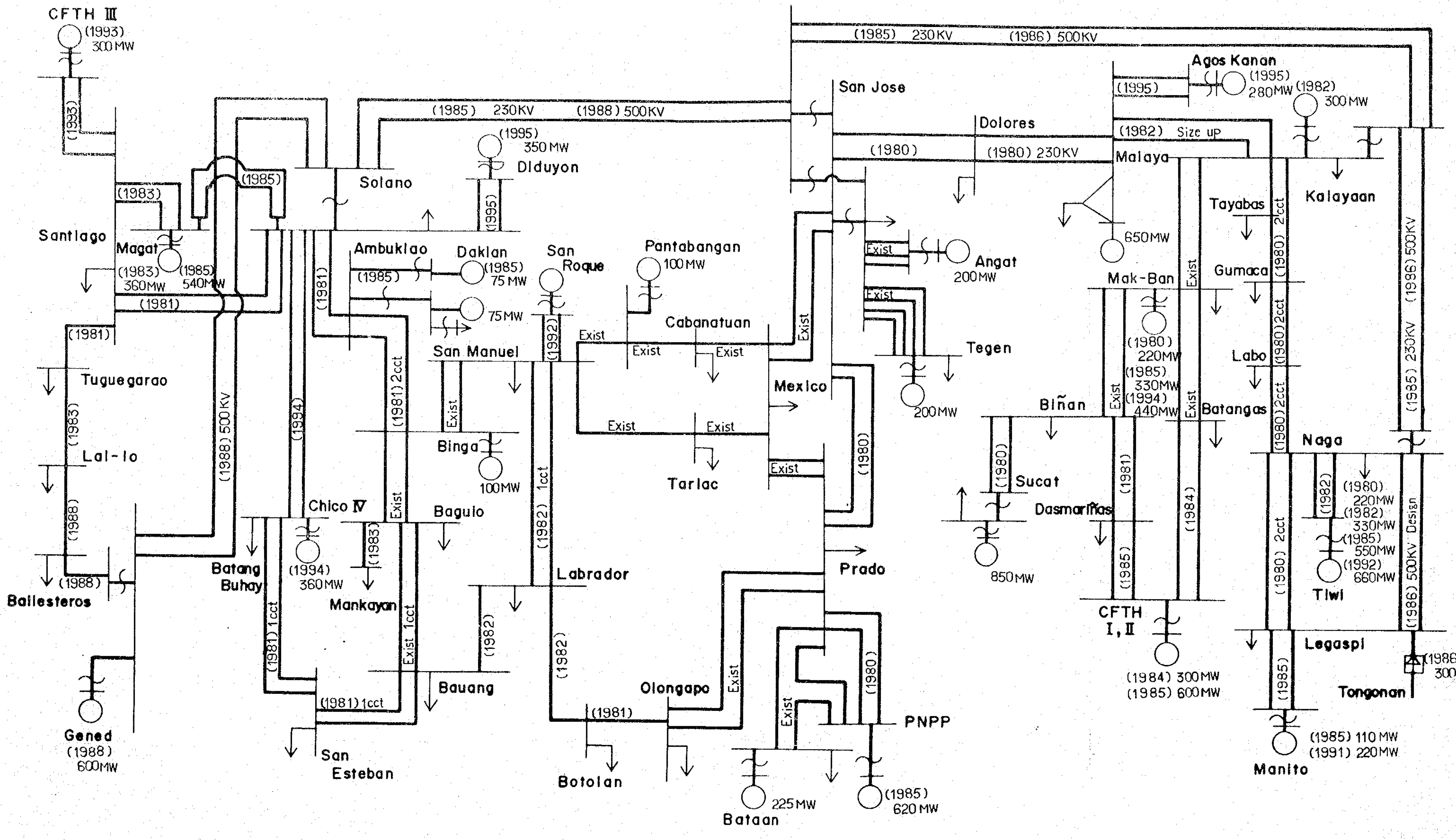


Fig 3-8 Luzon Grid Single Line Diagram

Generator, Transformer Capacity, Line Length, Conductor Size, Node Number

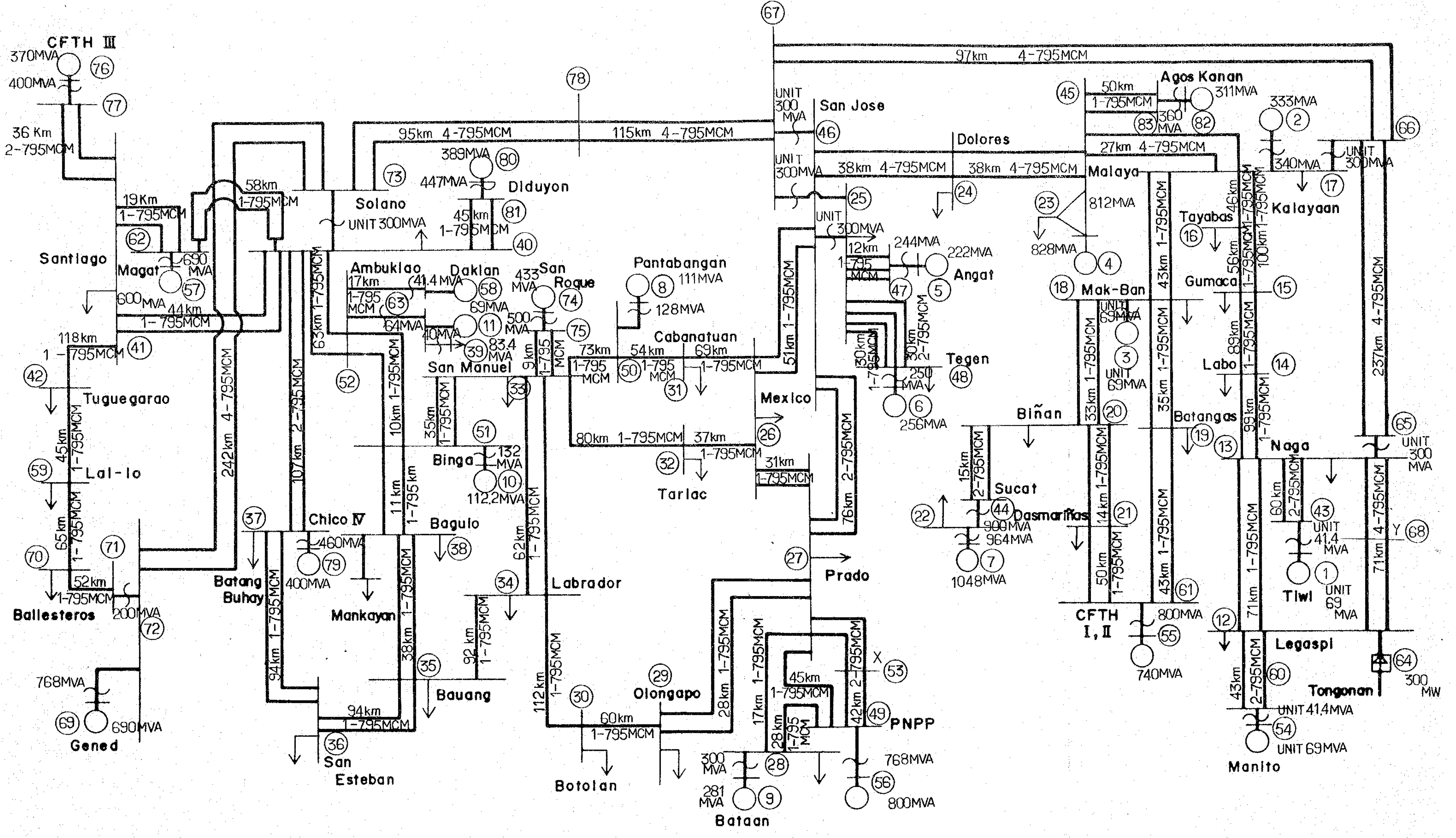


Fig 3-9 Luzon Grid Single Line Diagram

Impedance Map

Note:

$\frac{R+jx}{Y/2 \times 2}$: on 100MVA Basis

H, x'd, x''d : on Own Basis

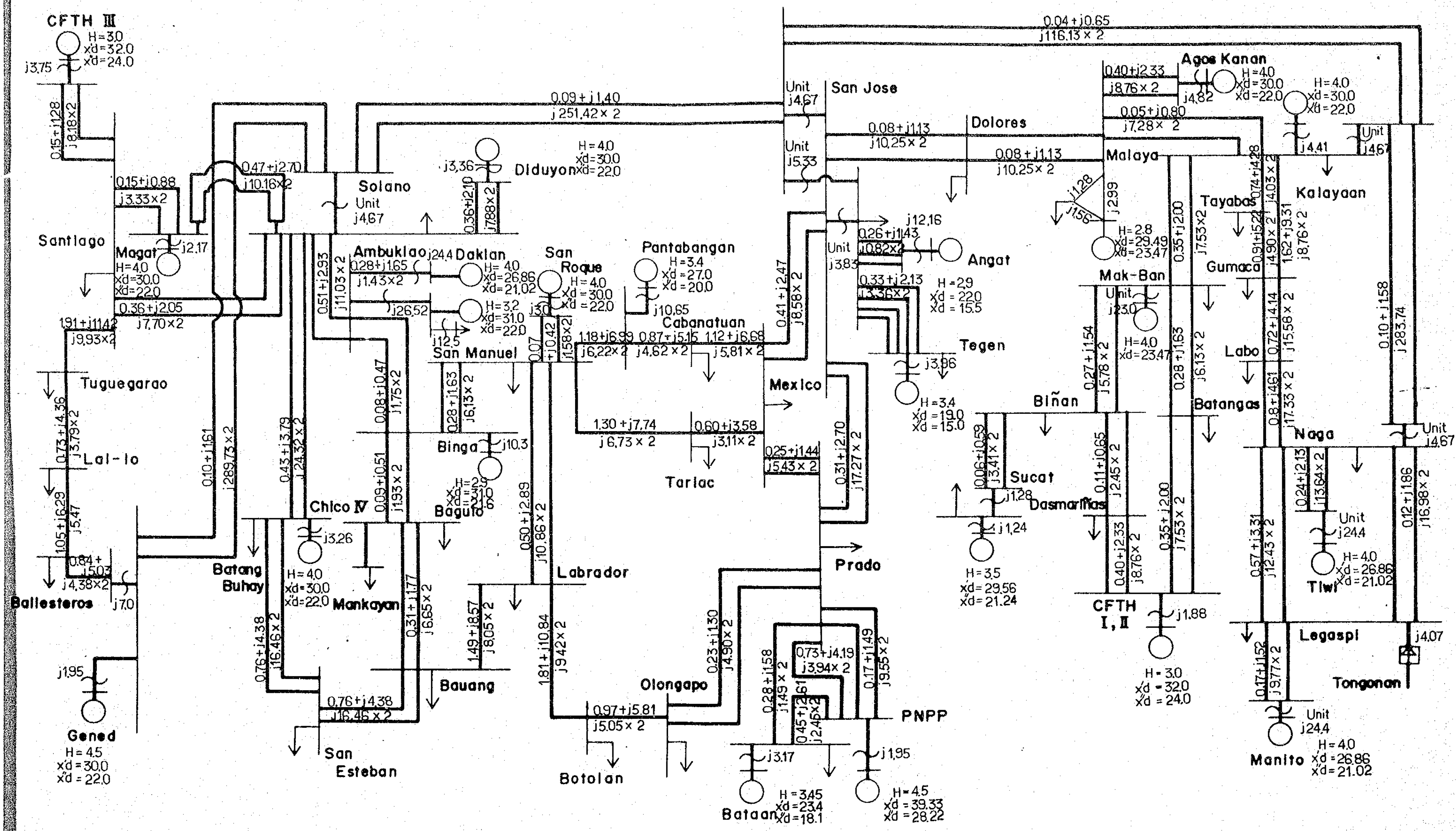


Fig 3-10 Luzon Grid Single Line Diagram

Case A

1982 Peak Power Flow

X : Not Completed

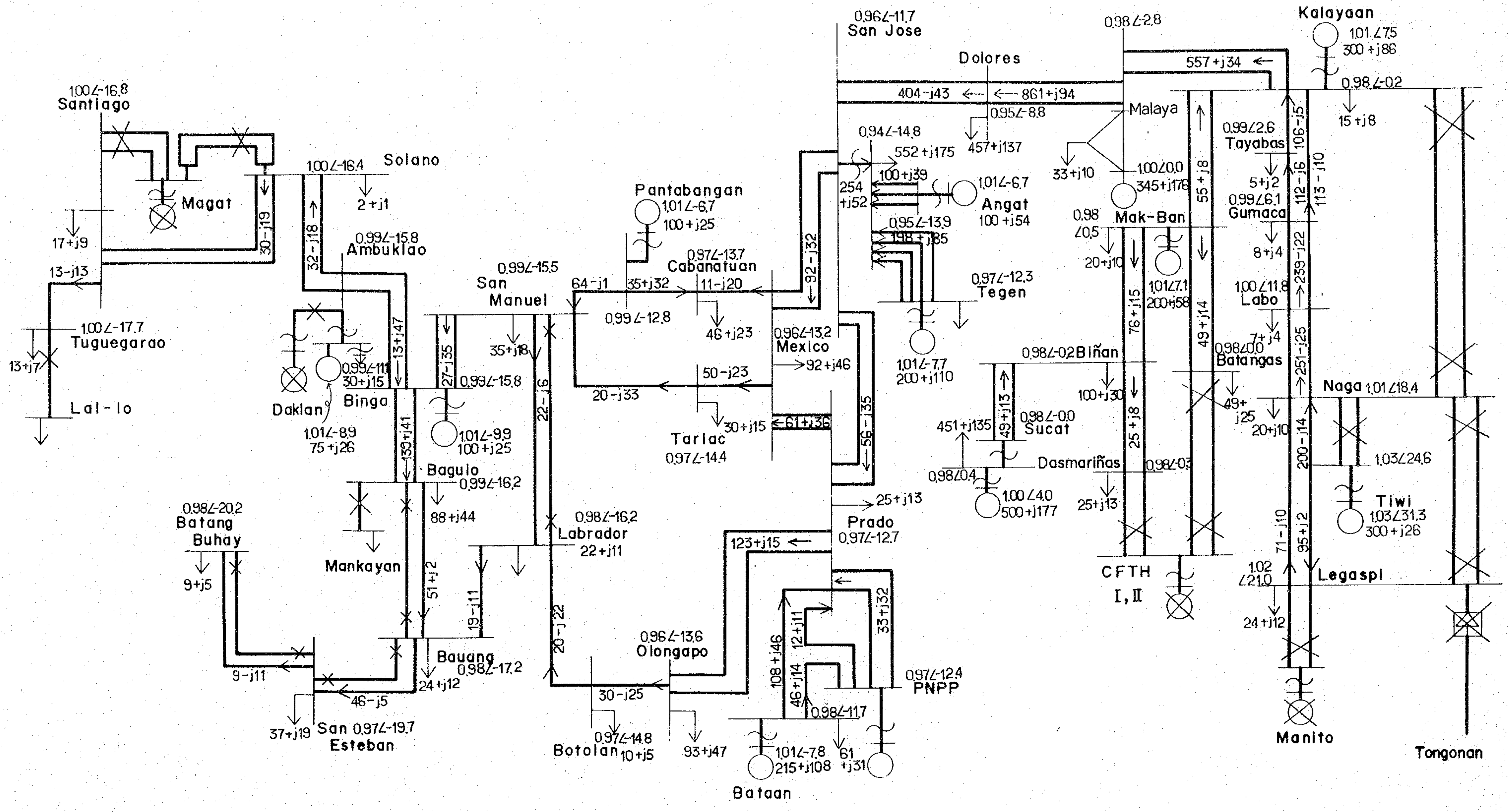


Fig 3-11 Luzon Grid Single Line Diagram

Case B

1982 Peak Power Flow

X : Not Completed

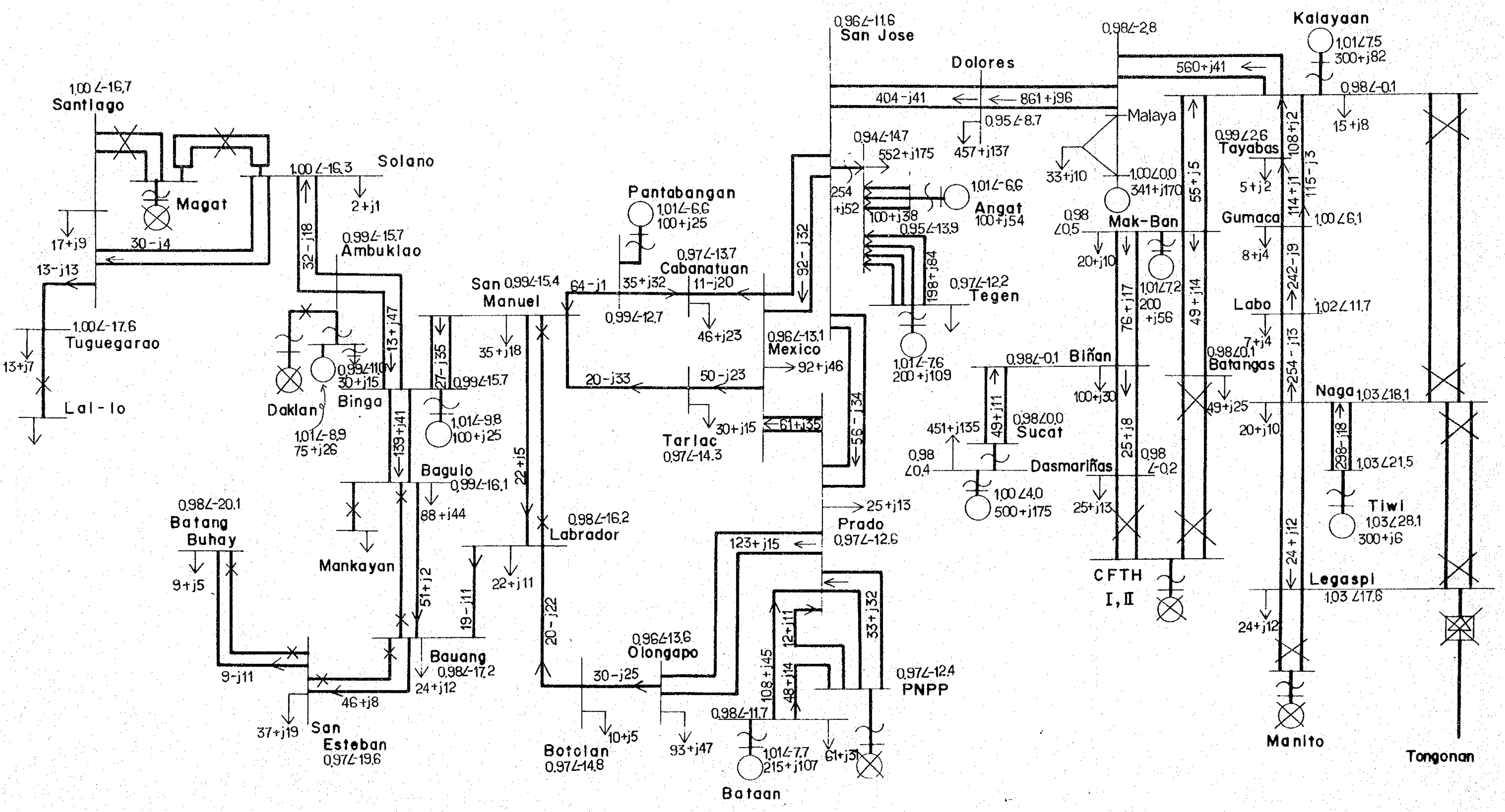


Fig 3-12 Luzon Grid Single Line Diagram

Case C, D 1985 Peak Power Flow

× : Not Commissioned

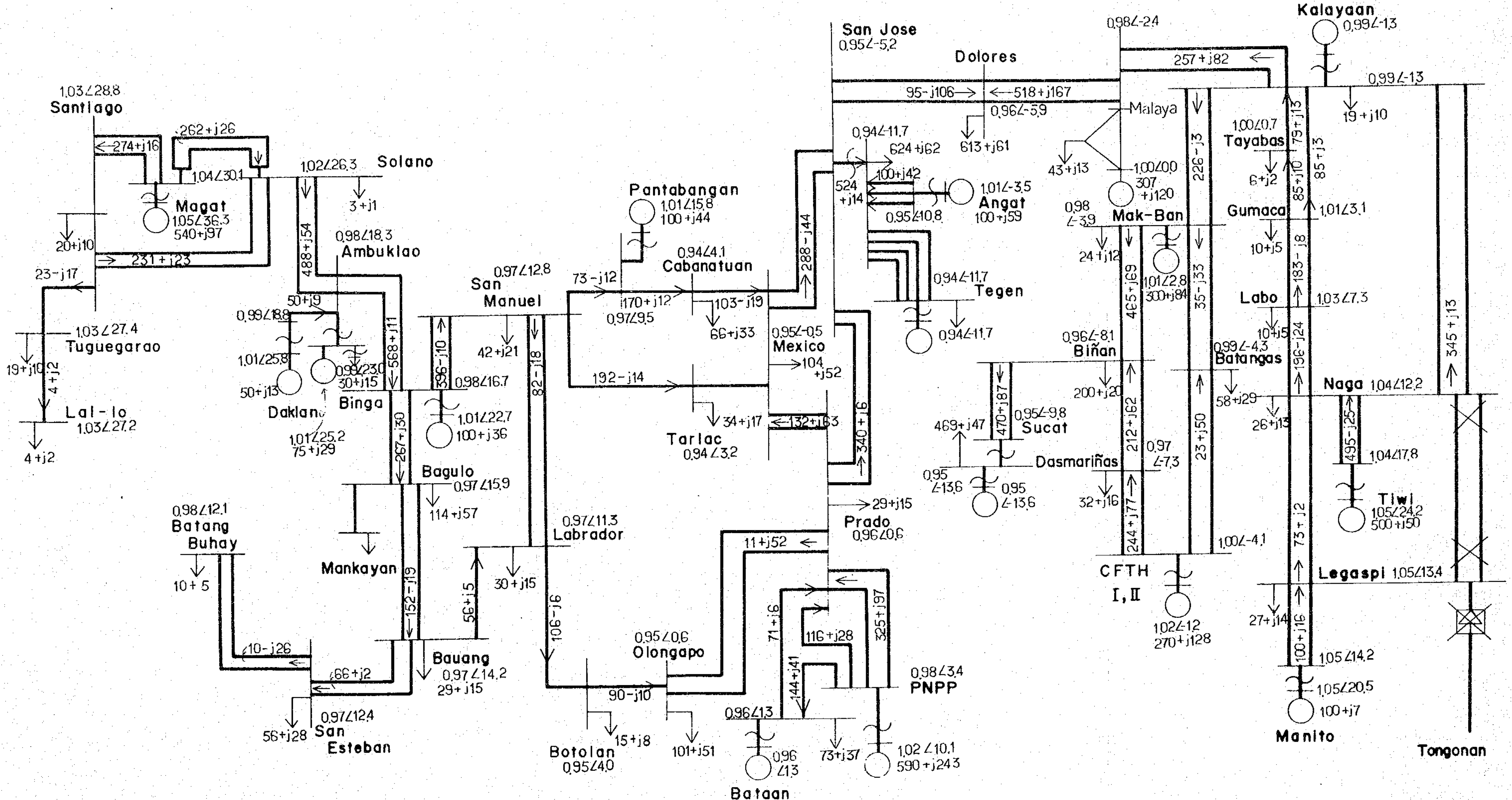


Fig 3-13 Luzon Grid Single Line Diagram

Case E 1986 Peak Power Flow

⨯: Normal open

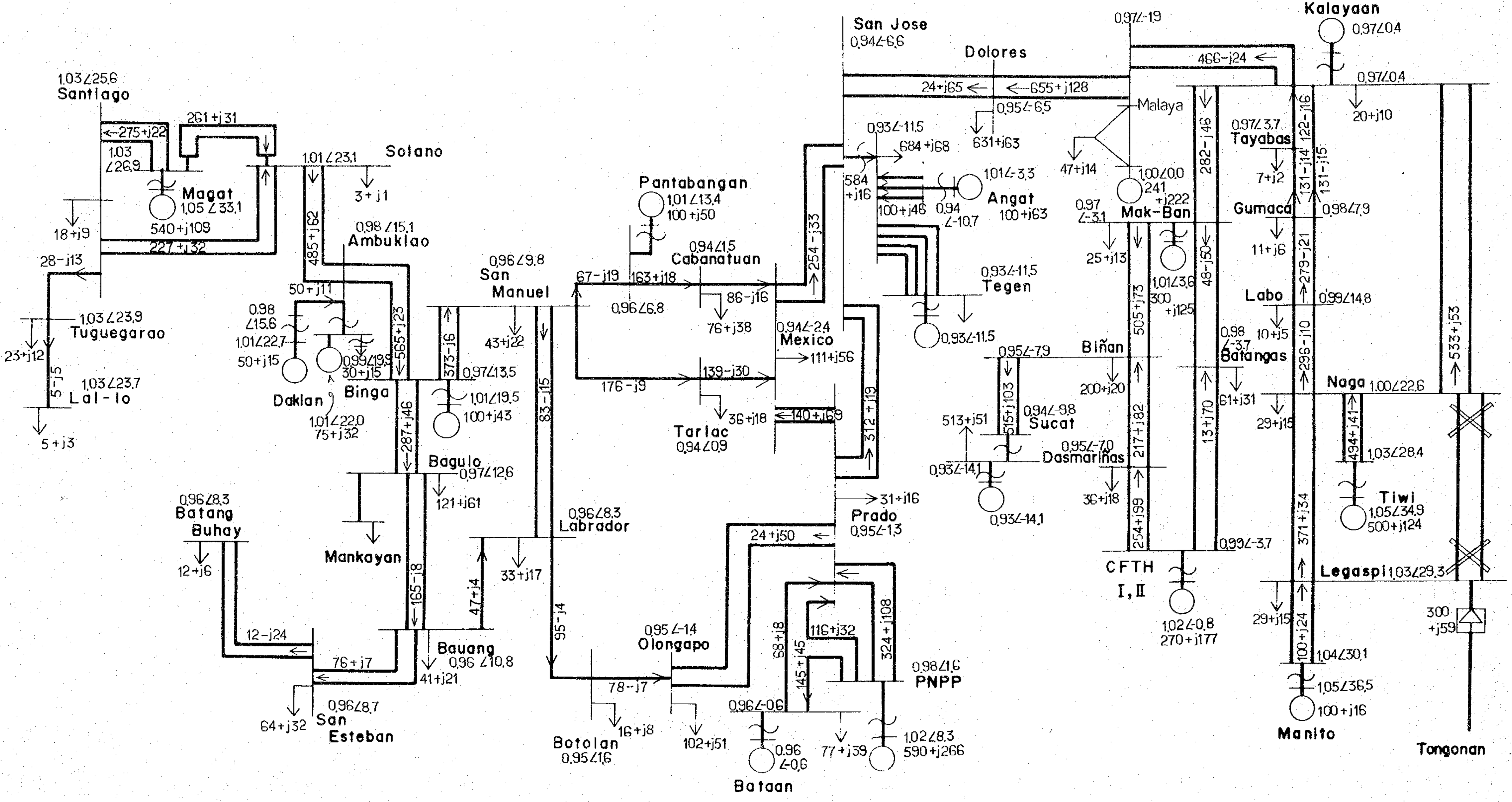


Fig 3-14 Luzon Grid Single Line Diagram

Case F 1988 Peak Power Flow

╳ : Normal open

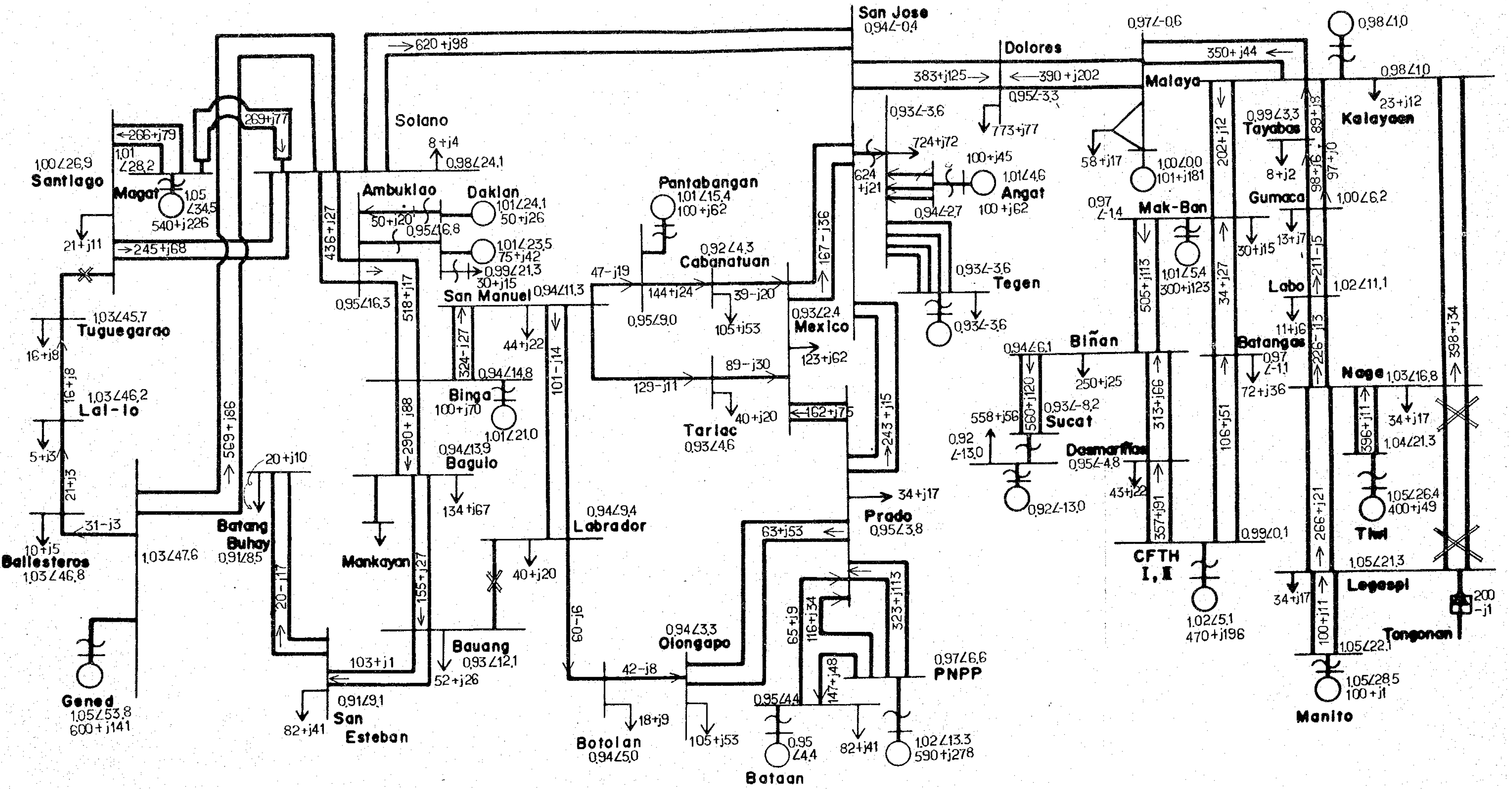
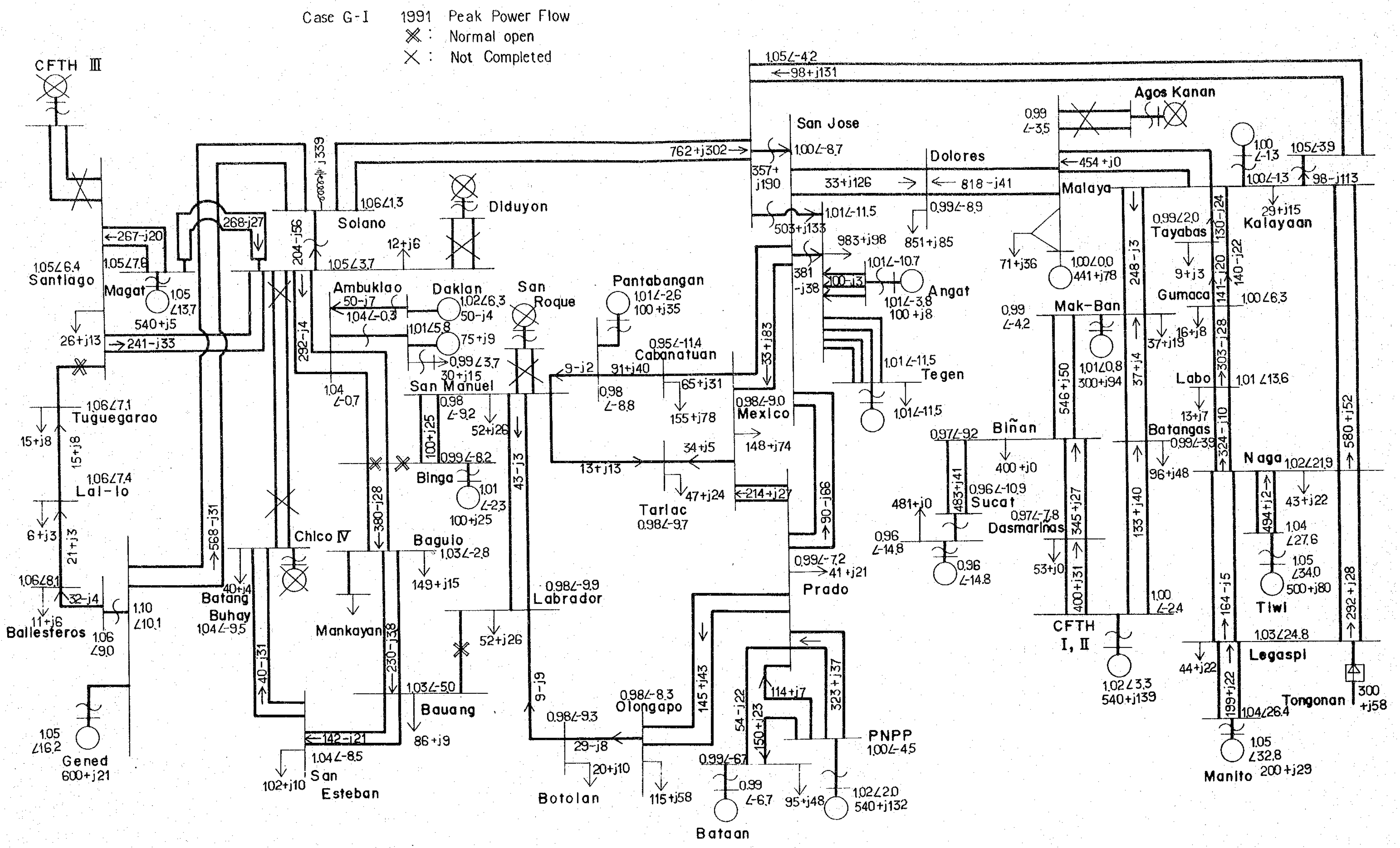


Fig 3-15 Luzon Grid Single Line Diagram



Case G-I 1991 Peak Power Flow

⊗ : Normal open

× : Not Completed

Fig 3-16 Luzon Grid Single Line Diagram

Case G-II 1992 Peak Power Flow

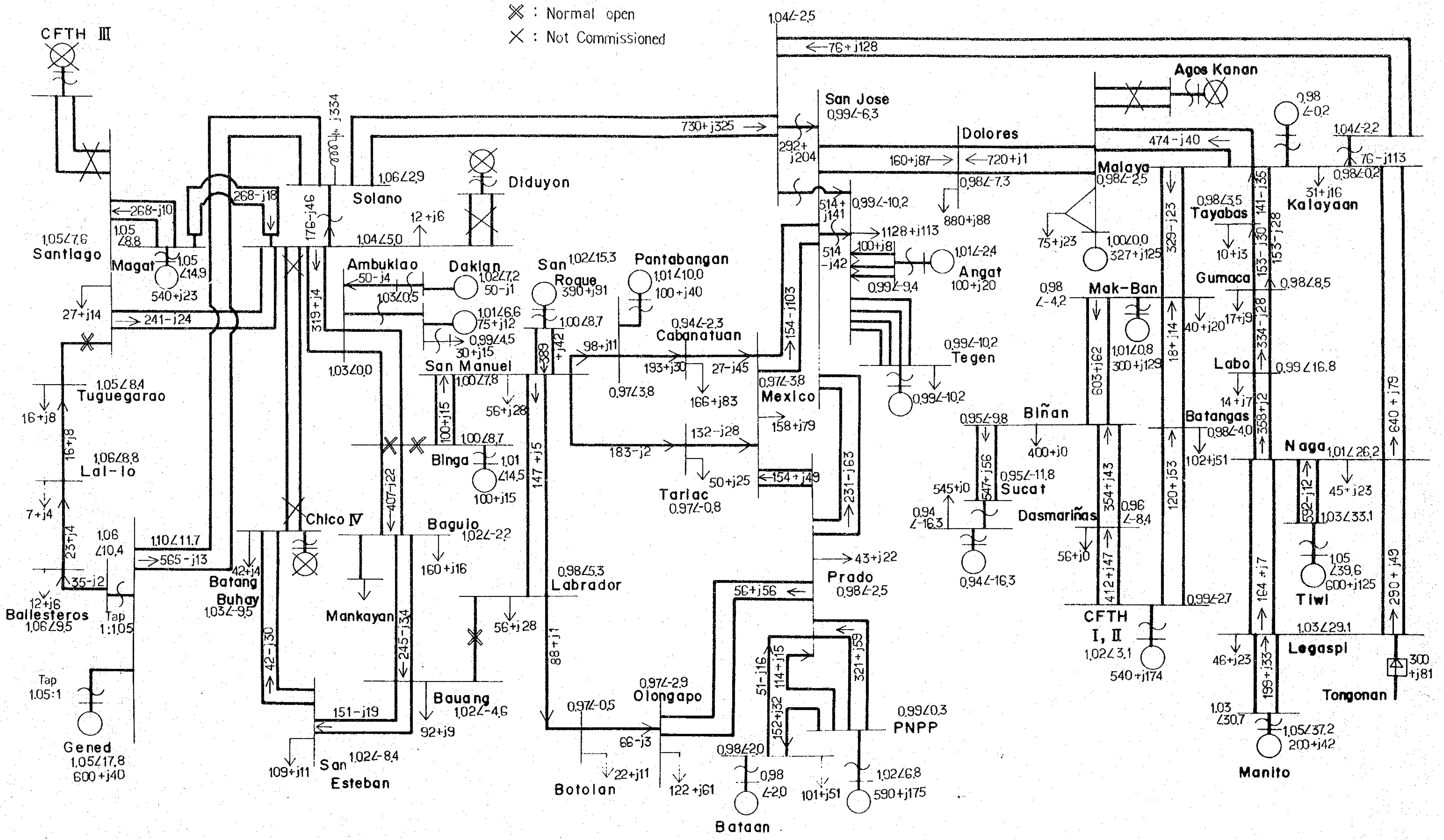


Fig 3-17 Luzon Grid Single Line Diagram

Case H, K-1 1995 Peak Power Flow

※ : Normal Open

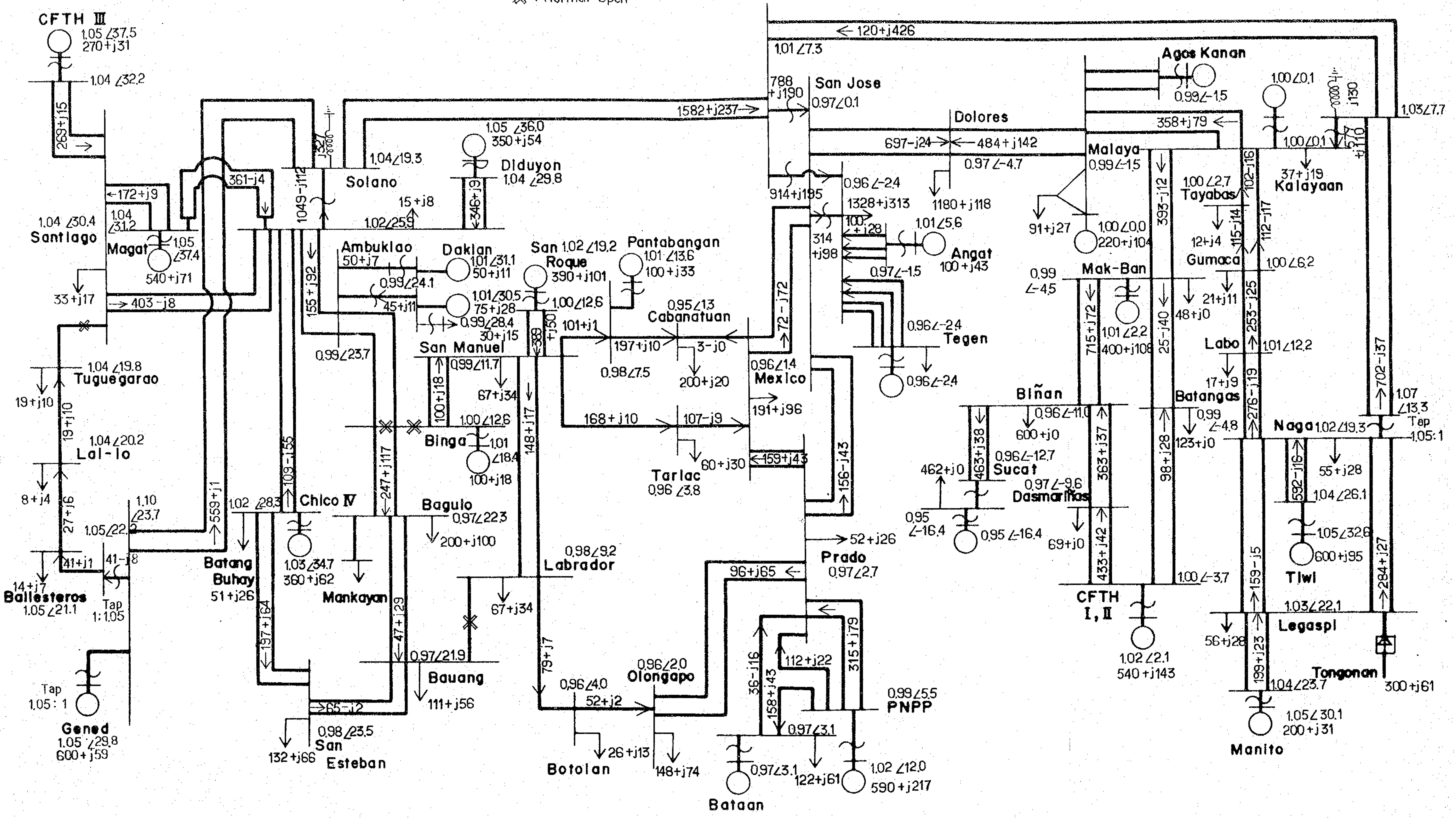


Fig 3-18 Luzon Grid Single Line Diagram

1995 Night Power Flow

※ : Normal open

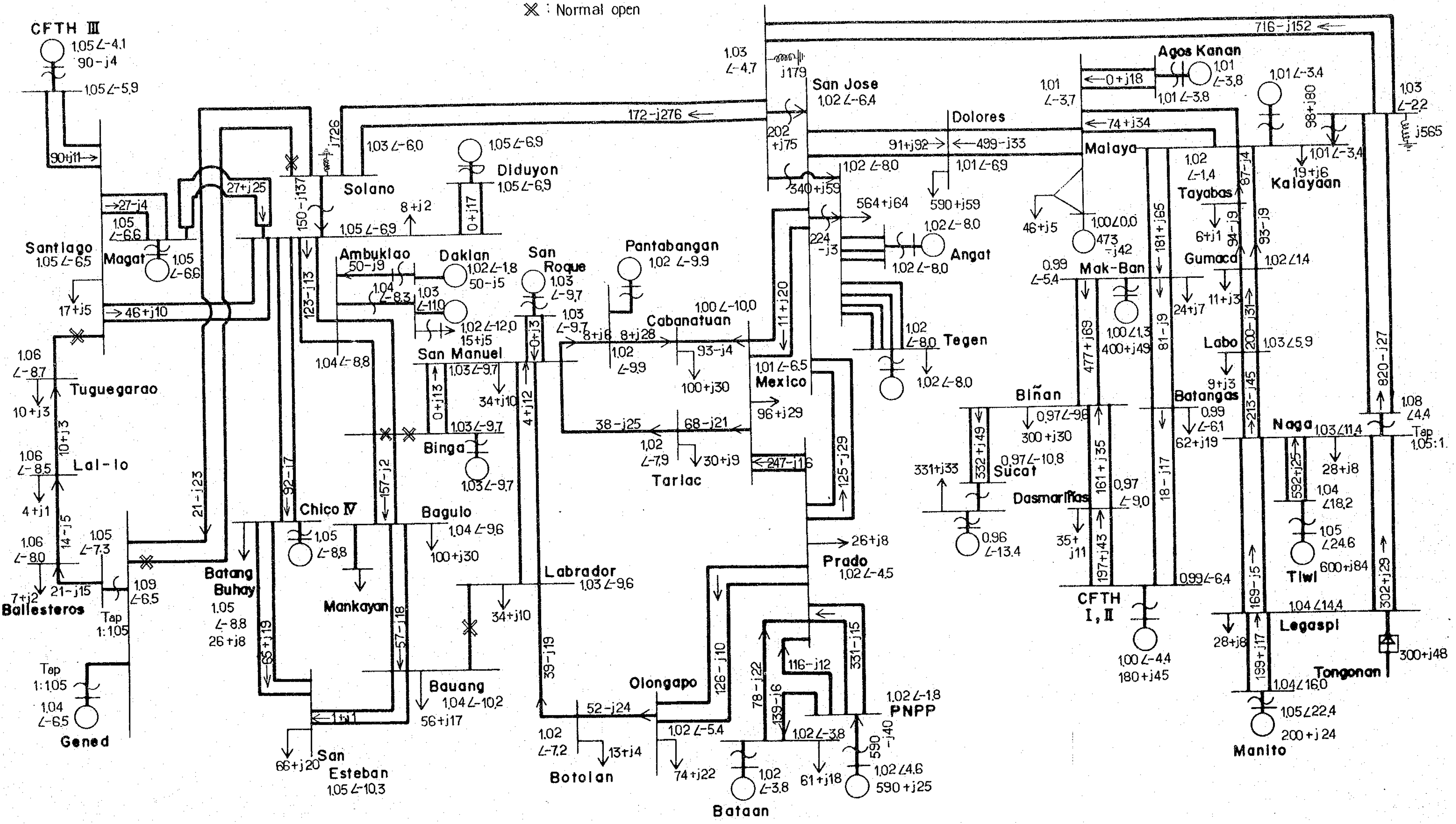


Fig 3-19 Luzon Grid Single Line Diagram

(Unit MVA)

1995 Fault Level

╳ : Normal open

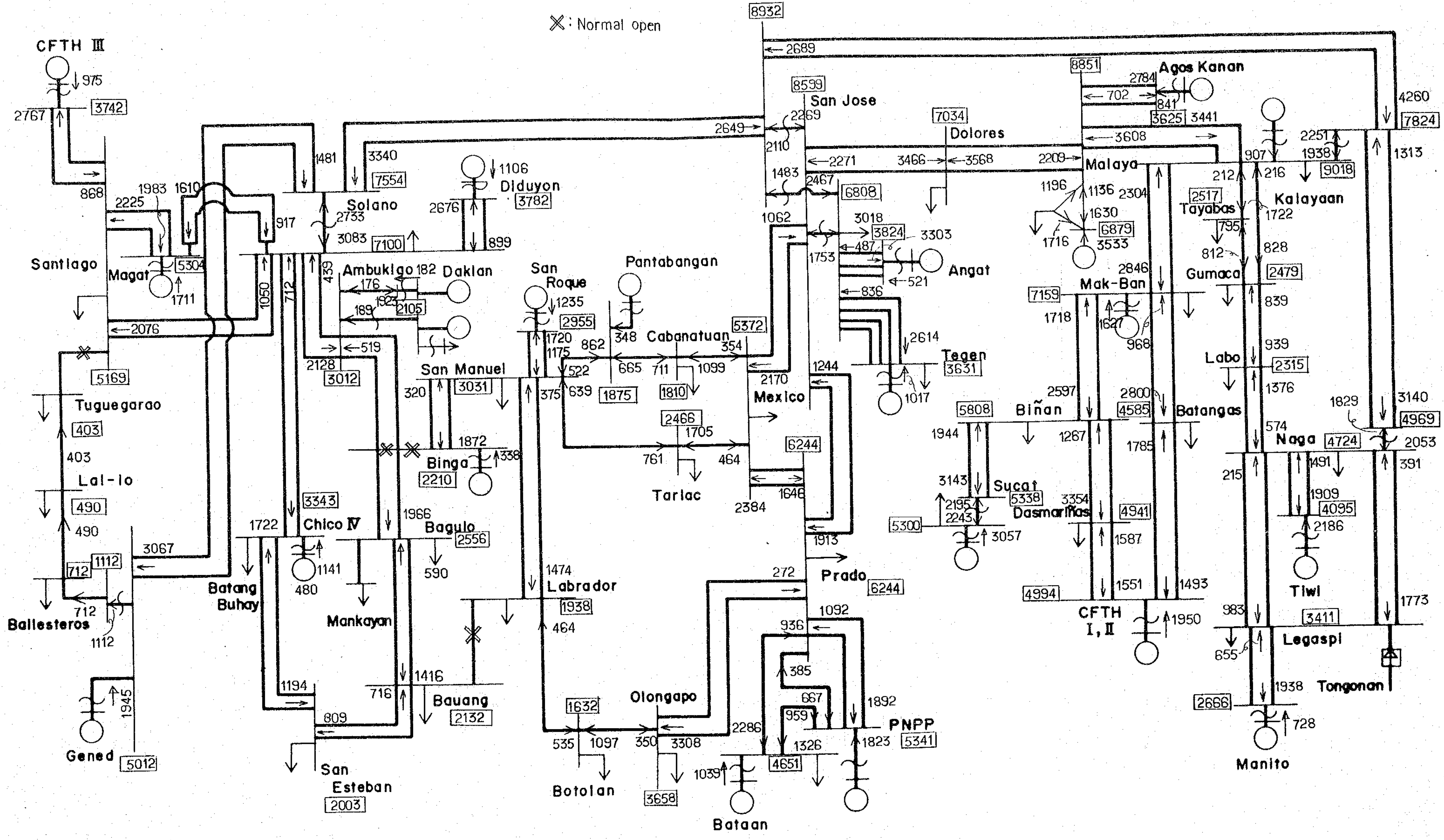
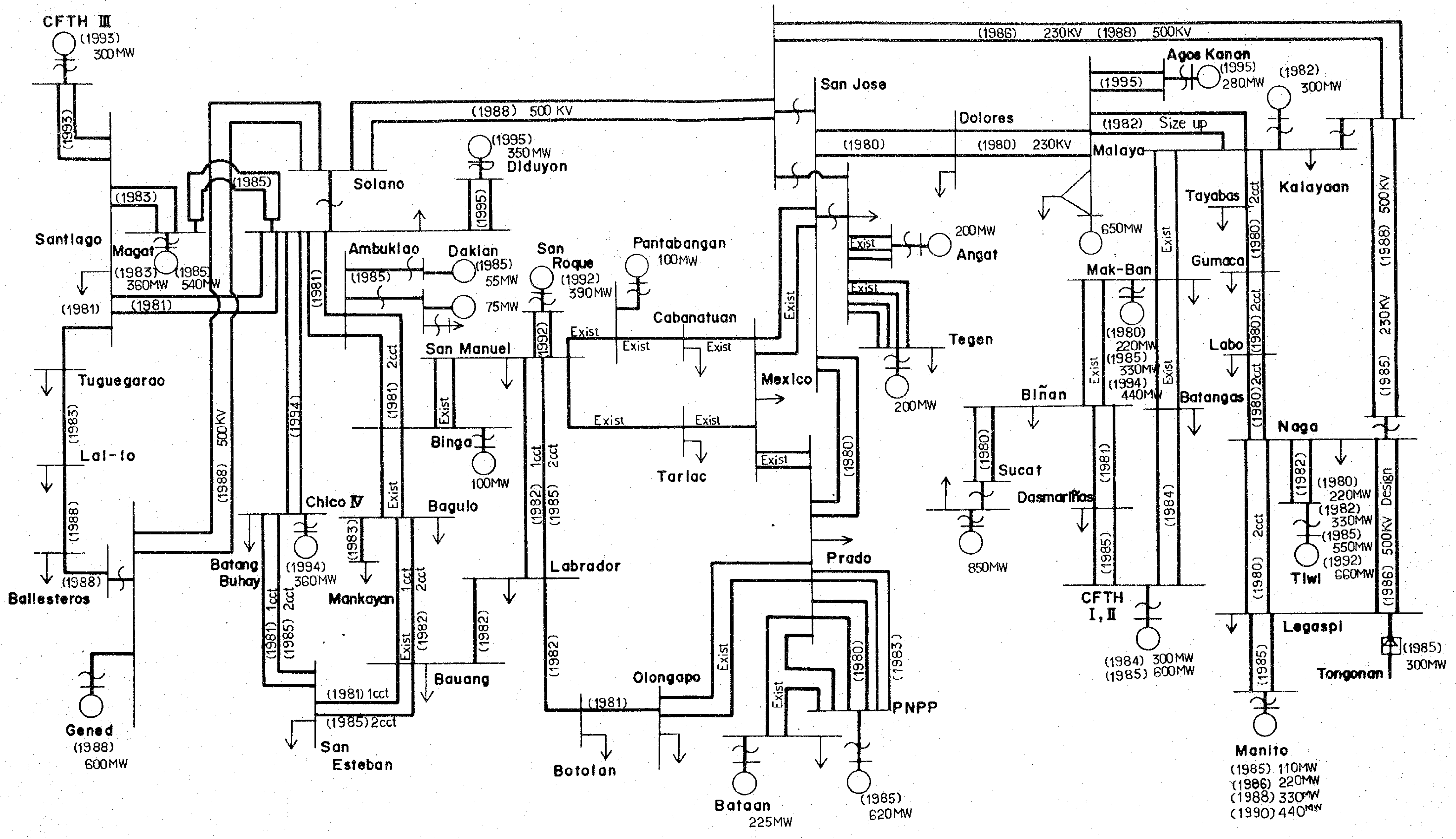


Fig 3-20 Luzon Grid Single Line Diagram

Final Expansion Program

Changed from Initial Program



4. PRELIMINARY DESIGN OF THE PROJECT

4.1. Location and Description of the Project Area

The Project area of Northern Luzon includes Region IV of Rizal and Laguna, east of Region III, composed of Bulacan and Nueva Ecija and the greater part of Region II, composed of Nueva Vizcaya, Ifugao, Isabela, Cagayan and Kalinga Apayao except Batanes and Quirino Provinces.

The area covered by the Project comprises of these nine Provinces with a land area of 44,114 km^2 that constitutes about 15% of the country's total land mass or about 42% of the total land area of the Luzon Island. The transportation network in the Region is characterized by the concreted Pan-Philippine Highway with a length of 595 km from Manila to Apari. The major seaport in the Region is the Casambalangan which is under construction. Agriculture forms the base of the Region's economy.

As mentioned in the foregoing, Metro Manila and its vicinity consumes two-thirds of the total power load in Luzon, which the power load in Northern Luzon is in the order of 450 MW in 1990 on a bulk substation basis which will increase to about 610 MW in 1995. Accordingly, the bulk of the power to be transmitted by the Project facilities will be for the supply of the loads around Metro Manila. Therefore, the Project is intended to serve not only the Northern Luzon area but also the Central Luzon area including Metro Manila.

4.2. Meteorological Factors and Topographic Data of the Project Area

(a) Climatic Factors

The main factors affecting the transmission system design are wind, temperature, frequency of thunderstorms and seismic disturbances.

Wind: Wind loads on transmission lines and substation structures have the greatest effect on the design. Desirably, data on 50 to 100 year return period wind velocities should be available for the transmission line design. The only wind data available are, however, the highest wind speed recorded in the past at the respective observation places, which is shown on Table 4-1. The maximum value in the data is 258 kph. The maximum wind velocity obtained by giving a gust factor to this value is 172 kph. But the design wind velocity for design of the 230 kV system is fixed at 185 kph.

Accordingly, the wind load for design of the Project was determined by taking into account an increase in the wind velocity on the basis of the above wind velocity of 185 kph.

Temperature: An average atmospheric temperature in Luzon is shown on Table 4-2. The maximum and minimum temperature observed in the data are 41.5°C and 16.1°C, respectively. For the purpose of design, however, 120°F (48.8°C), which the Electrical Code stipulates for checking a clearance above the ground was adopted as the maximum design temperature and 45°F (7.22°C) that is the same as for the design of the 230 kV system, as the minimum.

Frequency of thunderstorms: Annual frequencies of thunderstorms at various localities in Luzon are mentioned on Table 4-3. Average frequency of thunderstorms per year is 60 days. Therefore, internationally accepted isokeraunic level (IKL) 60 was adopted. This level is applied also by NAPOCOR for the design of the 230 kV system. It is considered adequate based on the worldwide IKL map.

Seismic disturbances: The Philippines is an earthquake prone region having the Philippine submarine trench and many volcanic mountain ranges. The record in the past shows frequent occurrence of earthquakes ranging in magnitude from 4 to 6. It is therefore proposed to use the lateral seismic force of 0.3 G for design of substation equipment.

Rainfall: The average annual rainfall of 2494mm was pronounced in the Luzon Island. Table 4-4 shows the records of annual average rainfall in each observation sites. The relative humidity is high and varies at 76% and 85%, and the annual humidity average was 81%.

(b) Topographic Data

The EHV transmission route in Northern Luzon can be classified into two types of topographic features in general. The route in the area north of Nueva Ecija Province is dominated by mountains and hilly terrains, and the route in the south of this province is rather flat or rolling terrains.

In the north area of the route, the steepest terrain is the mountains around Dalton Pass, having the elevations of nearly 1000m above sea level. The features of these mountains are mostly rugged and particularly at areas nearby Santa Fe, the traces of large-scale surface soil sliding are observed. Although no particular feature other than the above-mentioned is noticed, the accessibility in the area should be fully investigated prior to the start of construction.

The flat land in the rolling terrain extends to Isabela Province and the western boundary of the Cagayan Province. These plains are being utilized for farm and pastural fields.

The southern half of the route traverses mostly plains of rice and other cropping field or gently rolling terrains with no steep mountains. The entire route passes through the central part of the Luzon Island, so that the distances from the sea coast is always more than 20 kilometers the least of which is near to Metro Manila area. It is, therefore, considered that salt-contamination design of the transmission facilities would not be necessary.

The major rivers observed on the route include Chico, Magat, and Pampanga. Since the width of these river are large, the river crossing points should be selected in due consideration of floods.

Generally, the road network is well maintained with the Highway No. 5 as the trunk. The proposed transmission line route is mostly accessible through this Highway and its branch roads. The problem in accessibility would be posed around the Gened Power Station, Magat Dam and Dalton Pass as previously mentioned, for which detailed access survey is to be conducted.

Besides, the areas at San Jose Substation and east of the Cabanatuan City involve dense residential lots. The coordination of the Project's right-of-way alignment would be necessary in these areas.

As to geologic features, the route traverses mountaineous or relatively elevated farm fields and no swamp and marsh zones were observed. It is inferred that the bearing capacity of the route is fairly high, however, the places of rugged mountains should be subject to geologic survey in order to secure reliability of the proposed EHV transmission.

Table 4 - 1

Highest Wind Speed in and around Luzon (Kph)

NAME OF PLACE	RECORDS OF HIGHEST WIND SPEED
Baguio	167 SE, 1974
Laoag	145 N, 1968
Vigan	159 SSW, 1968
Dagupan	202 WNW, 1974
Basco	222 NE, 1969
Tuguegarao	169 SSE, 1967
Aparri	209 NNE, 1967
Iba	167 SE, 1972
Cabanatuan	108 S, 1973
Manila	200 WNW, 1970
Alabat	258 SW, 1970
Virac	241, SSE, 1970
Legaspi	204 S, 1972
Masbate	185 SSW, 1967

Source : PAGASA

Table 4 - 2

Atmospheric Temperature in Luzon (°C)

NAME OF PLACE	AVERAGE TEMPERATURE *			TEMPERATURE	
	AVERAGE	MAXIMUM	MINIMUM	MAXIMUM	MINIMUM
Cagayan, Tuguegarao	27.6	33.1	22.1	39.5	17.3
Dagupan City, Pangasinan	27.9	32.5	23.1	36.7	18.6
Cabanatuan City, Nueva Ecija	27.3	32.5	22.1	36.7	16.1
Iba, Zambales	27.1	31.6	22.4	35.0	17.6
Manila Airport	27.6	31.5	23.6	36.5	19.5
Diliman, Quezon City	26.7	31.8	21.6	36.4	17.2
Infanta, Quezon	26.8	30.2	23.4	41.5	19.9
Batangas	27.4	31.7	23.1	36.0	20.6
Daet, Camarines Norte	27.2	31.0	23.3	34.4	20.2
Legaspi, Albay	27.2	31.1	23.2	34.6	19.2
AVERAGE	27.3	31.7	22.8	-	-

* Average value of each year from 1952-1973.

Source : PAGASA

Table 4 - 3

Frequency of Thunderstorm in Luzon

NAME OF PLACE	ANNUAL FREQUENCY OF THUNDERSTORM
Baguio, Benguet	87
Laoag, Ilocos Norte	95
Vigan, Ilocos Sur	23
Dagupan, Pangasinan	95
Aparri, Cagayan	46
Banaue, Ifugao	69
Cagayan, Cagayan	27
Tuguegarao, Cagayan	32
Cabanatuan, Nueva Ecija	63
Iba, Zambales	71
Port Area, Metro Manila	53
MIA, Pasay City	73
Diliman, Quezon City	61
Alabat, Quezon	16
Balintawak, Quezon City	66
Legaspi, Albay	54
Daet, Camarines Norte	79
Casiguran, Quezon	63
Infanta, Quezon	57
Lucena, Quezon	55
San Francisco, Quezon	79
AVERAGE	60

Source : PAGASA

Table 4 - 4 Annual Average Rainfall in Luzon

Name of the Place	Annual Average Rainfall 1952 - 1973 (MM.)
Iba, Zambales	3,619
Castilla, Sorsogon	2,806
Diliman, Quezon City	2,185
Infanta, Quezon	3,948
Manila International Airport	1,999
Cabanatuan, Nueva Ecija	1,818
Dagupan, Pangasinan	2,368
Daet, Camerines Norte	3,751
Tuguegarao, Cagayan	1,656
Ambulong, Batangas	1,824
Lagaspi, Albay	3,371

5. BASIC DESIGN OF TRANSMISSION LINE

5.1. Design Criteria and Summary of Basic Design

The highest transmission voltage being adopted in the Philippines is 230 kV. In conducting the feasibility study of 500 kV transmission system, the existing design criteria for 230 kV line were scrutinized and it is considered that the said criteria can basically be extended to 500 kV transmission system. On the application of the criteria, however, due attention should be given to various conditions affecting larger tower size and higher voltage, for instance, increase of design wind velocity accompanied by hightening the tower and electrostatic induction and corona effect with higher voltage. The following are the major design criteria specially studied for EHV transmission system:

5.1.1. Ground Clearances Against Electrostatic Induction

The ground clearances against electrostatic induction were determined so that the induced voltage to automobiles below the transmission line would not give adverse effect on the human body. The result is shown below.

Designation	Application	Electric Field* Intensity (v/cm)	Minimum Clearance (m)
A	Places having frequent traffic, public roads, agricultural fields, railroads and residential areas	50	16
B	Place of very sparse traffic, mountains, forests	80	12

* The intensity at the point 1 m above the ground.

5.1.2. Insulation Design

Required number of insulator discs was evaluated under the switching surge multiplier of 2.0 in normal area and the equivalent salt deposit density of 0.06 mg/cm^2 (light contamination grade) in the area subject to salt contamination. The results including clearances to be secured for towers are tabulated below:

Standard Insulation Design

No. of insulator discs(pcs.)	Insulation clearance (mm)	
	Minimum	Standard
254 mm Suspension insulator - 23		
280 mm " " - 20	1,300	3,600
320 mm " " - 18		

Salt Contamination Design

No. of insulator discs (pcs.)	Insulation clearance (mm)	
	Minimum	Standard
254 mm Suspension insulator - 35		
280 mm " " - 30	1,300	3,600
320 mm " " - 27		

Standard insulation design will be applied for the northern Luzon area in general. Final application shall be determined after examination of the line route with respect to topography, distances from the sea coast, etc.

5.1.3. Lightning Protection Design

Clearance between conductor and overhead ground wire shall be twelve (12) meters which minimize back flashover at midspan due to lightning stroke.

Overhead ground wire shall be 7. No.6 Awg (corresponding to almo weld stranded wire 93 mm^2).

Shielding angle of zero degree should be adopted in order to minimize the outages caused by shielding failure against lightning.

5.1.4. Conductor and Insulator

Power conductor for EHV lines shall be ACSR 795 MCM "CONDOR" four (4) bundle in view of protection against radio interference by corona noises.

The maximum tension of conductors shall be 5,100 kg per conductor (The rounded value of tensile strength x 40%) in order to minimize weight of tower.

Following insulator strings shall be adopted in consideration of mechanical strength (safety factor - 2.5) and economy.

Tension assembly	- Two (2) strings of 320 mm insulators
Suspension assembly	- One (1) or two (2) strings of 280 mm insulators.

5.1.5. Tower Design

Wind velocity and pressure

As the height of towers for EHV lines will be more than 200 ft., the value of existing design conditions multiplied by 1.15 of increase rate shall be adopted.

	Existing	EHV
Wind velocity (kph)	185	198
Wind pressure (kg/m^2)	264	304

Tower type and design conditions

Following standards shall be adopted.

Tower Type		Angle	Wind Span
EDQ	Suspension	0° - (1°)	400 m
EDR_1	Suspension	0° - 5°	600 m
EDR_2	Strain	0° - 5°	400 m
EDS	Strain	5° - 15°	400 m
EDT	Strain	15° - 30°	400 m
EDU	Strain	30° - 90°, D.E.	400 m

5.1.6. Tower Foundation Design

The present design criteria of foundation being used by NPC is considered applicable.

Application of tower foundation is shown as follows.

Foundation Type	Typical Land	Soil Bearing Capacity
I	Mountainous Hill Forest Farm	30,000 kg/m^2 above
II	Ricefield Farm near the river or close to the rice field	20,000 - 30,000 kg/m^2
III	Rice field near the river Marshy ground	10,000 - 20,000 kg/m^2
IV	Marshy ground	10,000 kg/m^2 below

5.2. EHV Transmission Line Route in Northern Luzon

5.2.1. Results of Reconnaissance Survey

5.2.1.1. Objectives and Surveyed Section

Reconnaissance survey was conducted for the proposed EHV transmission line route in the northern Luzon area from November 24, 1980 to December 6, 1980. This reconnaissance survey is aimed to obtain the first-hand knowledge of topographic conditions along the proposed route and the major road crossings to the maximum extent possible through the existing roads in order to make preliminary alignment of the EHV transmission line.

Prior to commencement of survey, therefore, the route is subject to more detailed reconnaissance for final selection of the route.

The route sections surveyed in this study are as follows:

a) San Jose Substation Site - Solano (Bayombong) Substation Site

b) Solano (Bayombong) Substation Site - Gened Site

The preliminary EHV transmission line route mentioned above is shown on Fig.5-1. The route map at a scale of 1/250,000 is attached as appendix.

5.2.1.2. Description of San Jose - Solano Route

As shown on Fig. 5-1, two routes were considered; Route A is taken along the Highway No.5 with Dalton Pass, and Route B is a short-cut which traverses the mountainous area in the east of the said Highway. The features of each route are described below:

Route A

In the north of San Jose Substation Site located northeast of Manila, there is a area where housing lot development is extensively in progress. And dense residential lots are existing here and there. It is necessary to coordinate the EHV line route with these housing subdivisions or avoid such areas. The route passes through wide spread agricultural fields mixed with rolling terrains with gentle slopes. This extends from Norzaragay in the North of San Jose Substation Site up to San Jose City in the province of Nueva Ecija, and an almost straight route can be aligned in this area. Around the east of Cabanatuan, however, there are masses of houses along the Highway and the wide course of the Pampanga River. It is, therefore, necessary to select the highway and river crossings with due care at the time of the route survey.

The route in this section is about 20 km away from Manila Bay in the west and 35 km from the east coastline of the Luzon Island. With this condition the insulation of the EHV line in the section could be designed without considerating salt contamination.

The route extends further north along the Highway No.5 from the airfield in the southeast of the San Jose City in Nueva Ecija and crosses over the Dalton Pass.

The route can be aligned normally up to the south of the Dalton Pass, however, after that, it should be laid out partially to avoid the area of land slidings which are seen extensively on the mountains located east of the Highway near to Santa Fe. Thereafter, the route is taken side by side with the 230 kV Ambuklao - Solano line which is under construction.

Route B

This route was considered in order to shorten the length of the abovementioned route A that will have a detour in crossing the Dalton Pass.

The route B is taken to extend right northwards to the substation site in Solano, crossing the mountaineous area in the west of Pantabangan. Since the route involves steep mountains located in the boundary of the provinces of Nueva Ecija and Nueva Vizcaya, it is expected that the hauling of construction materials and maintenance work would be difficult. Besides, special insulation design will be required for the facilities to withstand the lower pressure in the area of elevations more than 1,000 meters. As a result of comparative study on these two routes, route A is recommended because of relatively less difficulty in design, construction and also in the line maintenance.

5.2.1.3. Description of Solano (Bayombong) - Gened Route

Three (3) comparative routes were considered in this section. These are routes A-1 and A-2, both passing the east of Tabuk which is located southwest of Tuguegarao and route B which is a short-cut traversing the west of Tabuk. The features of each route are outlined below:

Route A-1

The route of 40 km long from Solano to the west of Santiago in the province of Isabela runs in parallel to the on-going 230 kV Solano-Santiago line. This section will have advantages in both construction and maintenance aspect since it is along the 230 kV line.

The route will thence cross the Magat River at the west of Ramon, near the area where the construction of the Magat Multipurpose Project is in Progress.

A 230 kV line will be extended from the Magat project site to Santiago Substation. The river crossing point of the EHV line should therefore be selected carefully in due consideration of the Magat Dam and crossing with the 230 kV line. After spanning over the Magat River, the route passes through between the western hills and the eastern agricultural field, and encounters the Chico River in the east of Tabuk. This portion of the route is laid along the road connecting Roxas, Mallig and Quezon, so that construction and maintenance work will be convenient. As to the possibility of inundation of the route due to flooding of the Magat or the Cagayan River, the route is passing in the land of relatively high altitudes and therefore, no problem is expected.

The crossing point of the Chico River was located at Batani where the river narrows.

After this crossing point, the route enters into the mountaineous area until it reaches the Gened site. Although there is no road in this section 30 km long section, no alternative route can be considered.

Route A-2

This route is taken along the left bank of the Magat River, which is shorter than route A-1. Since the route goes into the mountains, no access road is found nearby the route. It may be worth to study if access road construction will be able to compete with the cost of shorter length.

In addition, the route alignment should consider the reservoir area created by the Magat Dam.

Route B

This route extends northward in the east side of high mountain ranges soaring from the Kalinga-Apayao Province to the Ifugao Province, and is the shortest in distance among three alternatives. The route will, however, entirely traverse the mountainous area and difficulties in access road construction as well as material transportation and maintenance are expected. This route was discarded also in view of peace and order problem in the area.

Route A-1 is considered the best route because it will involve the least difficulty in construction and maintenance. As for the route A-2, it is worthwhile to examine this in more details, so that in detailed reconnaissance before the actual survey, the feasibility and viability of the access road could be studied.

5.2.2. Conductor Height and Clearances of EHV Transmission Line

The height of conductor and clearances of EHV transmission lines should be determined in due consideration of electrostatic induction effects on the human body as well as to meet the electrical codes of the country.

5.2.2.1. Ground Clearance against Electrostatic Induction

The electric field of EHV transmission line induces electric potential to the objects existing in its vicinity. This phenomenon of induction will become susceptive to the human body at or above 200 kV line voltage.

Since the magnitude of the potential induced varies depending on the distance between line conductor and the objects, namely the height of the conductor from the ground, it is necessary to select suitable clearances according to the circumstances along the route of a transmission line.

Discussed below are examples being practised in Japan and the United States, and the proposed clearances to be applicable for EHV lines in the Philippines.

(a) Examples of Countermeasures for Electrostatic Induction Problems

Example in Japan

In Japan, the clearances are determined depending on the degree of discomfort sensed by the human body through an umbrella, a sample of which is shown on Table 5-1.

The above values have been determined from the relation between the electric field intensity and the height of the conductor as shown on Fig. 5-3 upon due reflection of sensibility test results presented on Fig. 5-2.

The height clearances of power lines in Japan have been restricted due to the particularities in population and land, thus resulting in disadvantage in the construction economy.

Under 500 kV lines with such clearances, the electric current induced to the human body thru umbrella is very little, about the order of several tenth of ampere. As compared to the impacts on the human body as shown on Fig.5-2, the value can be said to have sufficient margin of safety from the viewpoint of hazard to the human body.

Example in the United States

In U.S.A., the electric field intensity for determination of clearance from the ground is generally at the level of 75 V/cm. Adopted at B.P.A. are 80 V/cm under the line conductor and 60 V/cm at the edges of the right-of-way. It was reported that recently 90 V/cm was adopted.

(b) Proposed Ground Clearance

It is apparent that the determination of necessary clearance on the basis of degree of discomfort to the human body would adversely affect the economy of construction.

Judging from the planned EHV transmission line routes in Luzon that mostly pass the areas of sparse population density, the ground clearance being practiced in U.S.A. is considered adequate.

The proposed clearance for the EHV transmission lines in the Philippines are specified on Table 5-3.

As mentioned above, the target value of electric field intensity is limited to 50 V/cm for places having frequent movement of peoples. The necessary height of conductor to keep the intensity within this value is 16 meters according to Fig. 5-3.

Under this clearance of 16 m, the safety of the human body in case he contacts with non-grounded thing was examined. Fig. 5-4 shows the relation between grounding current and conductor height of EHV line. According to this figure, the ground current of a large bus under 16 m high conductor is 2 mA. Actually, as the current to human bodies is attenuated by shunting effect, this state is regarded to correspond to Grade 3 shown on Table 5-2, and will not cause a hazarous influence to the human body.

The clearance for the other areas, with sparse traffic is set at 12 m based on the field intensity of 80 V/cm.

The above-mentioned figures are, however, only general application for electrostatic induction countermeasures. Therefore, final clearances to be applied in the areas which are not mentioned in above table shall be determined depending on circumstances or particularities along the transmission line route.

Further to above, the lateral profile of electric field intensity at antiphase is given on Fig. 5-5. The profile shows that the electric field intensity becomes maximum right beneath the conductor. It is also applicable for rainy weather conditions.

5.2.2.2. Clearances of the Philippine Electrical Code

The vertical clearances of wires above ground or rails without consideration of electrostatic induction are stipulated in the Philippine Electrical Code. The clearances for 550 kV line were obtained and given on Table 5-4.

5.2.2.3. Recommended Clearances for 550 kV

The vertical clearances required for 550 kV lines, which satisfy the requirements from both electrostatic induction and the Philippine Electrical Code are given on Table 5-5. The values on this table are recommended to be adopted as standard clearances for EHV lines in Luzon.

5.2.2.4. Separation/Clearance from Communication Wires, Bridges and Buildings

The required clearances are given on Tables 5-6. and 5-7.

5.2.2.5. Clearance from Tree

Clearance from tree is proposed as 8m. In keeping the clearance, growth of tree for more or less 10 years must be taken into account if such conditions are predicted.

5.3. Insulation Design

5.3.1. Standard Insulation Design

This section discusses standard insulation design to be applicable for the transmission lines in the areas of no salt contamination such as inland area. In the study, insulation level was assessed on the basic concept that lightning flashover is to be permitted to some extent for economic and physical reasons, but no flashover due to internal abnormal voltage is allowed.

Internal abnormal voltages include switching surge voltage and continuous abnormal voltage. In general, design value against switching surge is apt to show more severity. It was, therefore, decided that insulation level will be examined with respect to the switching surge.

(a) Number of Insulator Unit

The required number of 250 mm insulator units for switching surge was computed at first and the result is given on Table 5 - 8. Likewise, computation was made for 280 mm and 320 mm insulators. Generally, where insulator string falls within the length of 3 m, the insulator strings in the same length will have identical flashover characteristics.

As a result of study, the required number of respective insulator units are summarized on Table 5 - 9.

Subsequently, insulation level for continuous abnormal voltage was examined.

The most popular one among continuous abnormal voltages is voltage rise in sound phases at one line to ground fault. The requirement of 250 mm suspension insulators was examined for such voltage rise and presented on Table 5 - 10.

As indicated by abovementioned table, the required insulation strength and number of insulators are less than those for switching surges. Accordingly, the insulation design hereinafter shall be studied with respect to switching surges.

The number of insulators required against switching surges were determined as follows:

250 mm suspension insulator	23 units
280 mm suspension insulator	20 units
320 mm suspension insulator	18 units

However, these figures should be considered as standards for the inland area with no fear of contaminations.

(b) Gap between Arc Horns

Table 5 - 11 presents the result of study for necessary gap between arc horns or shield rings to be fixed to insulator strings. From the table, the minimum gap is required to be 2,600 mm.

It is recommended in view of economy to apply shield rings to line side and short horn to earthing side for corona prevention in the section of standard insulation design. In this case, the required gap between shield ring and short horn is about 3,200 mm.

Then, this figure of 3,200 mm shall be applied for the are horn gap of EHV lines.

(c) Other Clearances

This section discusses about necessary gap spacings between conductors and tower structure and between conductors.

(i) Between conductor and tower

Clearance against switching surge

2,700 mm of the clearance is necessary as shown on Table 5 - 12.

Separation from commercial frequency lines

1,300 mm of the clearance should be taken at the max. swing of power conductor, as shown on Table 5 - 13.

Standard insulation clearance

This clearance means the minimum separation between the conductor and the tower structure at which no flashover will take place while the insulators or horns will flash over when lightning strikes the tower. This can be obtained in the following equations :

$$\ell s = 1.115z + 0.021$$

where ℓ_s = gap between conductor and tower (m)

z = gap between horns (m)

By giving the gap between horns of 3,200 mm mentioned previously to the above equation, standard insulation clearance is obtained as follows :

$$\ell s = 1.115 \times 3.2 + 0.021 = 3.589 \text{ m} \simeq 3.6 \text{ m}$$

(ii) Clearance between conductors

Neceesary gap between conductors for switching surges is 4,300 mm as shown on Table 5 - 14 .

5.3.2. Contamination Design

In the preceding section, standard insulation design was studied without consideration of contamination. This section will discuss the examination of insulation and clearances for the line sections that are subject to possible salt contamination.

(a) Number of Insulators

IEEE Transactions on Power Apparatus and Systems (Vol. 1 PAS - 98, No. 5 1979) presents general design method for salt contamination. Based on this method, the required number of insulators in area of salt contamination was studied as given on Table 5- 15. Contamination severity in the table should be reassessed for practical application on the scrutiny of atmospheric or climatic surveys of proposed line route, sampling investigations and record of line faults concerning the existing 230 kV line. In this section, the number of insulator units was estimated on the basis that there were no record of the line faults attributable to salt contamination on the existing 230 kV line. The withstand voltage per unit of insulator strings composed of 14 or 15 units for the existing line is calculated:

$$\frac{230 \times 1.1}{\sqrt{3}} / 14 = 10.4 \text{ kV/unit} \qquad 71.2 \text{ kV/m}$$

$$\frac{230 \times 1.1}{\sqrt{3}} / 15 = 9.7 \text{ kV/unit} \qquad 66.4 \text{ kV/m}$$

Equivalent salt deposit densities to above are 0.05 mg/cm^2 and 0.06 mg/cm^2, respectively. According to table 5- 16, these contamination densities fall in the category of "Light" (0.03 - 0.06) and the required number of insulators is obtained as follows:

320 mm - 27 units
280 mm - 30 units
250 mm - 35 units

(b) Clearances

Insulation design for salt contamination results in longer insulator string and inevitably entails to require larger clearances. One considerable measure to reduce such length is to attach arc horns to the insulator string concurrently for the purpose of flashover prevention.

Standard insulation clearances are studied for both insulator strings with and without arching horns.

Insulation clearance of insulator string without arching horns

Flashover voltage of arc horns is given in the following equation:

$$V = 550\ell + 80$$

where, V = 50% Rod-Rod impulse flashover voltage (kV)
ℓ = Gap length (m)

Now, 50% impulse flashover voltage of 250 mm suspension insulator string composed of 35 pieces is 2925 kV as obtained from Table 5-13.

Corresponding horn gap is computed:

$$\ell = (2925 - 80) / 550 = 5.17 \text{ m}$$

The standard insulation clearance is obtained as follows:

$$\ell s = 1.115 \times 5.17 + 0.021 = 5.79 \text{ m}$$

As compared with 3.6 m which is standard insulation clearance in standard design, the length is larger by about 2 m and results in higher tower structure required. It is, therefore, advisable to reduce the clearance by attaching arching horns.

Standard insulation clearance of insulator string with arching horns

In standard insulation design, the insulation clearance is determined at 3,600 mm by providing shield rings and short horn with 3,200 mm clearance.

This design shall be applied to the areas of salt contamination in order to coordinate the insulation level.

For anti-flashover design, normally it is possible to protect the insulator from breakage of skirts due to arc at lightning stroke by suppressing Ƶ/Ƶo below 75%, where Ƶ = horn gap and Ƶo = the length of insulator string.

At Ƶ = 3,200 mm, Ƶ/Ƶo is obtained as follows:

Ƶ/Ƶo = 3,200/(146 x 35) = 63%

Accordingly, the above-mentioned clearance shall be applied to the areas of salt contamination.

Other insulation clearances

Other insulation clearances shall be the same as for standard design.

5.4. Lightning Protection Design

5.4.1. Clearance between Conductor and Overhead Ground Wires

Vertical clearance can be determined through assessing the relationship of the clearances between conductor and overhead ground wire and the failure rate due to midspan flashover incurred by lightning strokes.

(a) Lightning Stroke Current

Lightning stroke current causing midspan back flashover is given by the following equation :

$$I = \frac{V-E}{(1-K)\cdot Z}$$

where, $V = V_{50} \times \eta \times \frac{1}{1.1}$

V_{50} = 50% impulse flashover voltage (Fig. 5-14)

η = Wave factor (1.18 for 4 μS wave)

E = Crest value of voltage to ground in the system

K = Coupling factor 0.3

Z = Stroke surge impedance at stroken point

1.1 = Insulation deterioration factor

(b) Potential Impedance Rise

Assuming a lightning stroke at midspan, potential impedance rise is obtained by the grid diagram calculation method.

Where the height of tower = 70 m,
tower footing resistance = 10 ∿ 30 Ω, and
span length = 400 m,
the reflection coefficient and the transmission coefficient for lightning surge are computed as presented on Fig. 5 -15 . and wave shape calculation with use of the grid diagram is given in Fig. 5 - 16.

As the result, the following values are derived :

Tower footing resistance (RTΩ)	Potential impedance rise (ZTΩ)
10	77
20	80
30	82

(c) Midspan Flashover and Outage Rate

Using the above-mentioned impedance rise, the lightning current which causes back flashover at midspan is examined to relate with vertical clearances as shown on Fig. 5 - 17. With this table and the lightning frequency curve depicted on Fig. 5 - 18 , the relation between vertical clearance and outage rate caused by midpan flashover was obtained and shown on Table 5 - 16 .

(d) Separation between Overhead Ground Wire and Conductor

The relation among vertical clearance, lightning current and outage rate in Table 5 - 16 indicates that the outage rate becomes remarkably higher as the vertical clearance is reduced below 11 to 12 m, and appreciable change is not demonstrated even though the clearance is made larger.

Also, as known from the lightning frequency curve on Fig. 5-18 the frequency does not decrease so much in the region of 120 kA and above.

It means that the increase of clearance over the abovementioned level is not advisable.

The clearance to be adopted shall be 12 m between ground wire and conductor at midspan.

As for the clearance between ground wire and conductor at the supporting points on tower, the above-mentioned midspan clearance can be decreased to the extend of sag difference, namely as the overhead ground wire is strung at the sag equipment to 80% of the conductor sag.

Such difference in sag under the condition of 45°F and no wind will be more or less 1.5 m. Then the clearance at tower shall be 10.5 m.

5.4.2. Choice of Kind and Size of Overhead Ground Wire

The kinds of overhead ground wire include two kinds : one is galvanized steel stranded wire, and the other aluminum clad steel stranded wire. For size selection, determinant factors are mechanical strength and instantaneous current carrying capacity at ground fault. Generally even smaller size of wires will often meet the mechanical strength requirement. Therefore, it is considered enough to examine mainly the aspect of instantaneous current carrying capacity of the wires. The instantaneous current carrying capacity can be computed by the following equations.

$$I = K\frac{S}{\sqrt{t}}$$

where, I = Instantaneous current carrying capacity (A)

S = Sectional area of the wire (mm^2)

t = Charging time (sec.)

K = Constant : galvanized steel wire - 49

aluminum clad steel wire - 85

For both galvanized steel wire and aluminum clad steel wire, the relation between I and S is obtained by giving t as parameter and depicted on Fig. 5 - 19 .

Here, the maximum ground current in the system is estimated to be of the order of 20,000 A. And the breaking time by back-up protective relay would be proposed to be set at $t = 0.5$ sec. Assuming total ground current concentrates to overhead ground wires at a ground fault, the grounding current per wire would be 10,000 A. From Fig. 5 - 19 , the minimum required sectional area at $t = 0.5$ sec. is obtained to be 83 mm^2 for aluminum clad steel sire and 144 mm^2 for galvanized steel wire. The latter is too large in size and also disadvantageous in view of salt corrosion.

Then, aluminum clad steel wire and the size of 7 No.6 Awg (93 mm^3 equivalent) according to ASTM B416-69 shall be adopted since it is the closest to the size of 83 mm^2.

5.4.3. Outage Rate by Lightning Strokes

The reliability of 500 kV transmission lines mostly depends on the ligntning protection as far as the maintenance work is being performed completely. In this section, therefore, the transmission failure due to lightning strokes is discussed for assessment of the reliability level.

(a) Lightning Current and Impedance Rise

Lightning current (I) which causes back flashover at the top of tower or at midspan is expressed by the following equation:

$$I = \frac{V - E}{(1-K)\ Z\ k}$$

where, V = Flashover voltage at the insulator string or between the ground wire and the conductor

E = Crest value of voltage to ground in the system

k = Coupling factor

Z = Impedance rise at the stricken point

k = The ratio of tower top potential to the insulator string potential

0.8 for the stroke to the tower

1.0 for the stroke at the midspan

The impedance rise is obtained in the same manner as explained in the foregoing Section 5.4.2 and the result is given on Fig.5- .

(b) Calculation of Lightning Outage Rate

The lightning current I is obtained in the above-mentioned equation and the corresponding failure rates are derived by referring to Fig. 5- . For these cases, percentage of the lightning strokes is assumed as 50% to the tower on top and also 50% at midspan and flashover voltages at insulator string and between ground wire and conductor are as follows:

For insulator string V = (550 x 3.2 + 80) x 1.18/1.1 = 1974kV
For ground wire-conductor V = 7350kV x 1.18/1.1 = 7885kV
Based on these figure, the rates are given on Table 5- .

(c) Lightning Outage Rate in Luzon

The outage rates examined in the above item (b) are approximate values in the area of IKL - 25 - 30. As shown on Table 5-), the IKL in Luzon is estimated at 60, so the values in the above item (b) is multiplied by the ratio of 60/30 = 2 to obtain the approximate values of outage rates in Luzon. The results are given on Table 5- .

(d) Target Value of Ground Resistance Reduction

The results obtained in the above item (c) are depicted on Fig. 5 -). The figure shows that, within the ranges of tower-footing resistance 40 ohm to 10 ohm, the outage rate become lower proportionally as the resistance is reduced, but in the range below 10 ohm, the lowering of outage rate would not be expected by reducing the resistance for the stroke frequency would not decrease although flashover current is increased. It is, therefore, considered reasonable to adopt 10 ohm as the target value of ground resistance reduction.

5.4.4. Selection of Shielding Angle

Since 500 kV class transmission lines are designed at comparatively higher insulation level than 230 kV class lines, the lightning current causing back flashover failure of the line is considerably large, estimated to be 80 - 140 KA. This would lessen the probability of back flashover but on the other hand, require higher towers and increase the pobability of direct stroke to the conductors due to shielding failure. Assuming the line insulation strength = 1840 kV and stroke surge impedance of the conductor = 350 ohms, the lightning current that will cause a flashover due to shielding failure is computed as

$$\frac{1840\ \text{kV}}{350\ \text{ohms}/2} = 10.5\ \text{KA}.$$

In 500 kV design, the shielding of such rather small current is a predominant factor to reduce the outage rate of lines. Based on the theory of Armstrong-Whitehead, the outage rate at shielding failure was calculated, the result of which was depicted on Fig.5-22.

In the meantime, the height of the top conductor on this 500 kV line will be 47.2 m in the area of A-grade static induction and 43.2 m in the other area, or say more or less 45 m.

From Fig. 5-22, the shielding angle 0° is required for 45 m high top conductor. The Armstrong-Whitehead theory is explained in Appendix.

5.5. Selection of Power Conductor and Its Characteristics

5.5.1. Corona Characteristics

Electric corona occurs when the potential gradient at the surface of a conductor is raised to such a value that the dielectric strength of the surrounding air is exceeded, namely local insulation breakdown. This corona discharge is accompanied by a high frequency noise so called corona noise, which causes power loss and radio interference.

Suppression of this corona noise can be attained by means of reducing surface gradient of a conductor. It is, however, necessary to further examine corona noise level beneath the line in a weak radio area. So this section discussed about conductor surface gradient, corona noise level and corona loss for determination of conductor size.

(a) Maximum Conductor Surface Gradient

The maximum surface gradient of n conductors can be obtained as follows:

$$G_{max}(1) = \frac{0.4343V}{r \log D/r}$$

$$G_{max}(2) = \frac{0.4343V(1+2r/eo)}{2r \log D/\sqrt{reo}}$$

$$G_{max}(3) = \frac{0.4343V(14r/eo.\sin\pi/3)}{3r \log D/(r^{1/3}.eo^{2/3})}$$

$$G_{max}(4) = \frac{0.4343V(1+6r/eo.\sin\pi/4)}{4r \log D/\{r^{1/4}.(2^{1/6}eo)^{3/4}\}}$$

$$G_{max}(n) = \frac{0.4343V\{1+2(n-1).r/eo.\sin\pi/n\}}{nr \log D/(r^{1/n}.e^{(n-1)/n})}$$

where, n = No. of conductors per phase

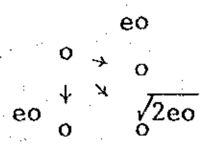
V = Voltage to ground of the conductors (kV)

D = Distance between conductors (cm)

r = Conductor radius (cm)

eo = Conductor spacing (cm)

(4 bundle conductor - $e = \sqrt[3]{\sqrt{2}eo^3} = 2^{1/6}eo$



It is empirically known that the conductor surface gradient below 15 v/cm will not cause any radio interference.

The maximum conductor surface gradient of the existing lines in the Luzon Grid is considered to be at 230 kV ACSR 795 MCM single conductor. Assuming D = 6.5 m, its surface gradient is computed as follows:

$$G_{max}(1) = \frac{0.4343 \times \frac{230}{\sqrt{3}}}{1.39 \log \frac{650}{1.39}} \doteq 15.5 \ (kV/cm)$$

This value almost corresponds to the above empirical value. It is said that the 230 kV transmission lines in Luzon is situated at the critical point of corona noise occurrence. Likewise, the surface gradients of various sizes of ACSR are computed and given on Fig. 5-23, on which the curve of 15.5 kV/cm is also drawn.

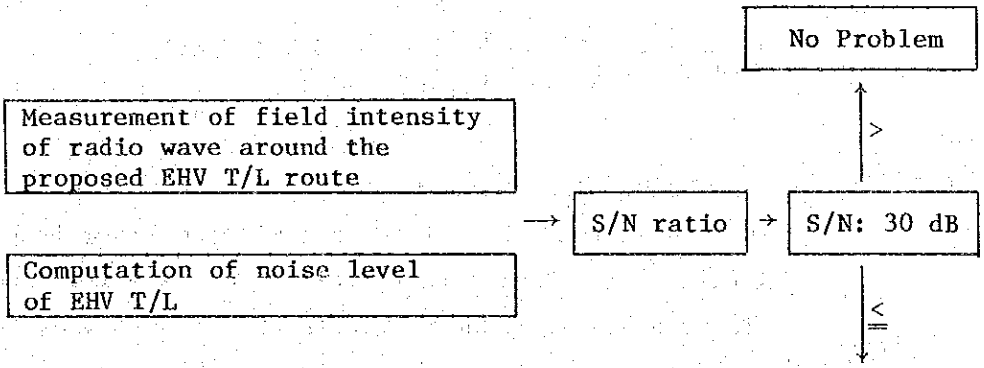
(b) Selection of Conductor Size

It is recommended as basic concept that the surface gradient of 500 kV line conductor should not be aggravated below the level of the existing 230 kV (15.5 kV/cm). With reference to Fig.5-23, there are several sizes of conductor with the surface gradient below 15.5 kV/cm. It is, however, proposed to adopt ACSR 795 MCM (CONDOR) x 4 bundle as the conductor for 500 kV system since this conductor, being the same as for the existing lines, has advantages in construction and maintenance works that can be done with same kinds of tools and in use of stock materials.

The conductor spacing in a bundle shall be 45.7 cm (18") being practiced for the existing 230 kV lines.

(c) Corona Noise

In the foregoing section, corona noise was examined in the conductor surface gradient aspect. However, individually, the degree of radio interference is determined at the ratio of telecommunication wave (S) to noise level (N). Following procedure should be taken to examine the noise level in weak radio wave area and the route may be placed in farther distance from housing areas.



Noise level below the conductor

Corona noise level at 10 m beneath the lowest phase conductors in 2 circuit vertical configurated line is expressed by the following formula:

Corona Noise Level in Fair Weather

$$N_1 = (3.7\,G_{max} - 12.2 + KD) \pm 3.0 \text{ (dB)}$$

G_{max}: Maximum Conductor Surface Gradient (kV/cm)

$$KD = 40 \log_{10} \frac{2r}{2.53} \text{ (dB)}$$

2r : Outside Diameter of the Conductor (cm)

Corona Noise Level in Rainy Weather

$$N_1' = (N_m - N_o)/(\alpha/R + 1) + N_o \text{ (dB)}$$

$$N_m = \begin{cases} -(G_{max}/2.K)^2 + 10.5\ G_{max}\ K - 31 + KD & (G_{max} \leqq 17 \text{ kV/cm}) \\ -(G_{max}/2.K)^2 + 17.5(G_{max}/4.K) + 19.5\ KD & (G_{max} > 17 \text{ kV/cm}) \end{cases}$$

$$N_o = -0.16(G_{max}\ K)^2 + 9.5\ G_{max}\ K - 50.5 + KD$$

$$\alpha = -0.16\ G_{max}/K = 3.72$$

K	: Coefficient :	Single	1
		Double	$1/(1 + 2r/S)$
		Triple	1
		Quadruple	$(1 + r/S.3)/(1 + r/S\ 3\sqrt{2})$

S : Conductor spacing

R : Rainfall (mm/H)

In the use of these expressions, corona noise level for each size of conductors was computed and shown on Table 5-19.

As found in the above results, the corona noise level of "CONDOR" 4 bundle conductor in rainy weather is about equivalent to that of the existing 230 kV "CONDOR" single conductor.

Attenuation of corona noise level

The foregoing formula is to compute a corona noise level right beneath the line conductor. The corona noise level will attentuate as the line becomes farther, which can be expressed as follows:

$$A = 20 \log_{10} (1 + X^2/H^2)$$

where A = Attenuation of noise level (dB)
X = Horizontal separation from the line (m)
H = Ground clearance of the line conductor (m)

The attenuation thus obtained was depicted on Fig. 5-24, from which necessary clearance can be determined between the line and housing area. Fig. 5-25 shows the corona noise levels measured for the actual lines.

(d) Corona Loss

Computation of corona loss

Based on actual measurements made for the test lines, corona loss under 1 mm/hr rainfall can be computed by the following formula:

$$P = 0.087\ nr^2 e^{0.52E} \times 10^{-3}\ (\mathrm{KW/KM.1\phi})$$

n : Number of sub-conductors a phase
r : The radius of the conductor (cm)
E : Maximum conductor surface gradient (kV/cm)

The corona losses at fair weather and at high humidity are about 10% and 20% of the above corona loss, respectively.

Annual corona loss

Annual corona loss can be computed by the following formula:

$$W = P_1T_1 + P_2T_2 + P_3R\ (\mathrm{kwh/km.1\phi})$$

where, P_1P_1 = Corona loss at fair weather and rainy weather (kw/km.1ϕ)

P_3 = Corona loss at rainfall of 1 mm/H (kw/km. 1ϕ)