REPUBLIC OF THE PHILIPPINES
NATIONAL POWER CORPORATION

LUZON EXTRA HIGH VOLTAGE TRANSMISSION SYSTEM DEVELOPMENT PROJECT

SYSTEM ENGINEERING REPORT

JANUARY 1981

JAPAN INTERNATIONAL COOPERATION AGENCY

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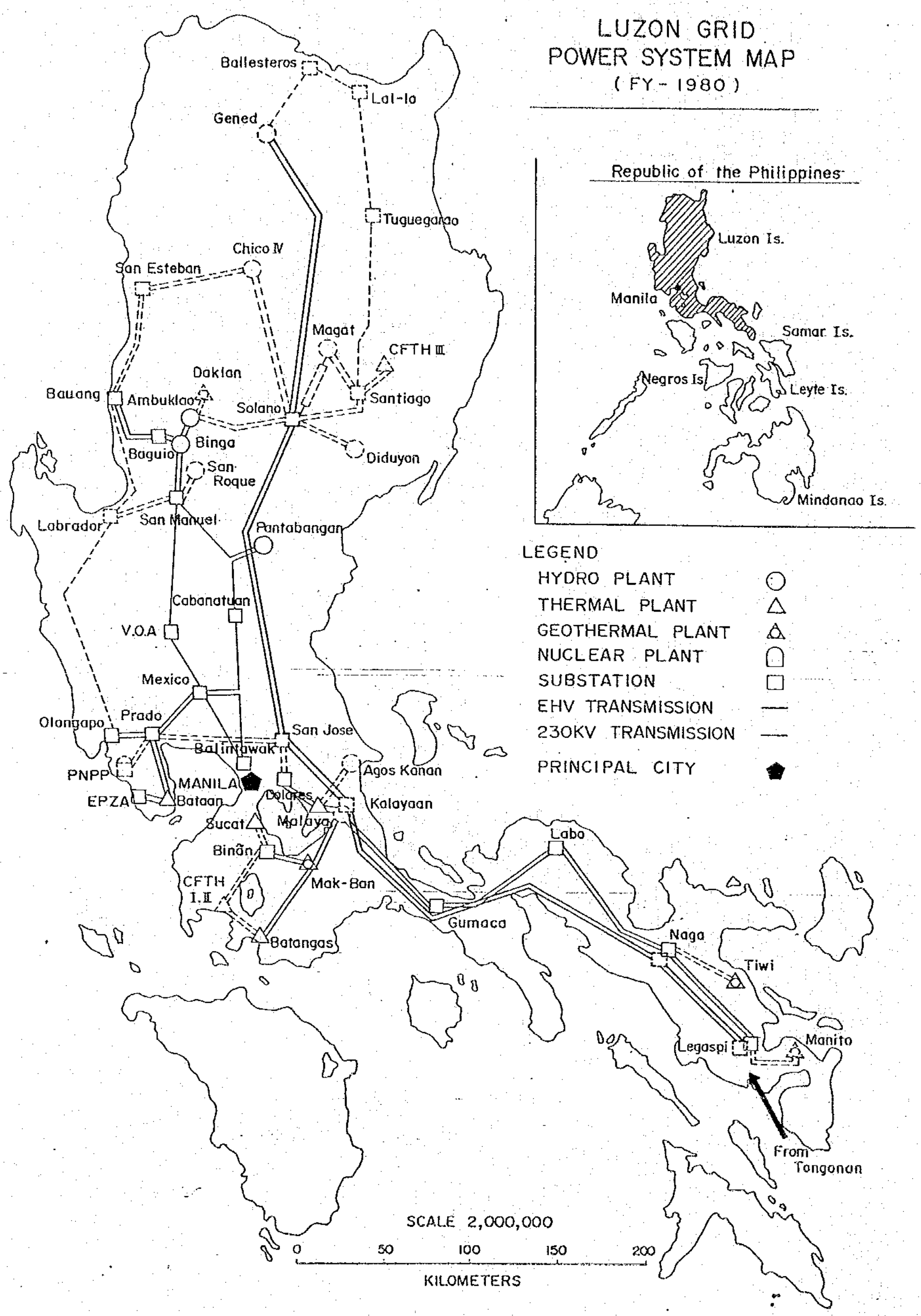
LUZON GRID
POWER SYSTEM MAP
(FY - 1980)
Republic of the Philippines
Luzon Is.
Manila
Samar Is.
Negros Is.
Leyte Is.
Mindanao Is.
LEGEND
HYDRO PLANT
THERMAL PLANT
GEOTHERMAL PLANT
NUCLEAR PLANT
SUBSTATION
EHV TRANSMISSION
230KV TRANSMISSION
PRINCIPAL CITY
Ballesteros
Lal-lo
Gened
Tuguegarao
Chico IV
San Esteban
Magat
CFTH III
Daklan
Bauang
Ambuklao
Solano
Santiago
Binga
Baguio
Diduyon
San Roque
San Manuel
Labrador
Pantabangan
Cabanatuan
V.O.A
Mexico
Olongapo
Prado
San Jose
Balintawak
Agos Kanan
PNPP
MANILA
EPZA
Bataan
Dolores
Kalayaan
Sucat
Malaya
Labo
Binan
Mak-Ban
CFTH I.II
Gumaca
Batangas
Naga
Tiwi
Legaspi
Manito
From Tongonan
SCALE 2,000,000
0
50
100
150
200
KILOMETERS

C O N T E N T S

Page

FEASIBILITY STUDY OF LUZON EXTRA HIGH VOLTAGE
TRANSMISSION SYSTEM DEVELOPMENT PROJECT

SYSTEM ENGINEERING REPORT

1. INTRODUCTION

1.1. Background of the Project

The Republic of the Philippines is composed of more than 7,000 islands. The largest among them is the Luzon Island, in which more than one-half of the economic activities of the entire country is concentrated and also the capital of the Republic, Metro Manila is located at the central area.

Luzon is also far larger in terms of electric energy consumption than others. Actually as of the year 1980, the electricity consumption in the Luzon Island occupies about 84 per cent of the country's total. Besides, approximately three-forth (3/4) of electric energy consumed in Luzon is depending on oil fuel thermal generation. This in turn is pressing serious impacts on the economic activities in the Philippines through recent repeated oil price hikes.

The Philippine Government has been exerting its maximum efforts to reduce dependency on the imported fuel oil. As one of the principal measures, the Government has, therefore, accelerated the country's indigeneous energy resources such as geothermal, hydro and coal thermal power sources and exploration of nuclear energy. The accelerated development of these non-oil energy sources will contribute to reduction of oil-oriented energy component whilst sustaining the future increasing demand.

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Among those various energy sources, however, hydro power sites are located in Northern Luzon and geothermal sites are mostly in the Southern Luzon area. Most of generated pwoer at these sites will have to be carried to Metro Manila area over 300 to 400 km long transmission system. Thus, introduction of EHV transmission system will be inevitable.

This study was made to scrutinize the power system in Luzon in order to produce the optimum transmission system that should be able to cope with future generation expansion.

1.2 The Study

In response to the request of the Government of the Republic of the Philippines, the Government of Japan has agreed to provide technical assistance through its official executing agency, Japan International Cooperation Agency (JICA) in carrying out a feasibility study on the Luzon Extra High Voltage (EHV) Power Transmission Development Project, hereinafter called the Project, in close cooperation with the Government of the Republic of the Philippines and National Power Corporation, a fully government owned public corporation and the implementing agency of the Project, hereinafter called as NPC.

The broad objective of the feasibility study proposed is to define the optimum plan of EHV transmission system in the Luzon Grid until the year 1995 by reviewing the previous related studies and to prepare a basic design of such facilities for the Project.

JICA, in compliance with above-mentioned agreement, sent to the Philippines two (2) experts for conducting a system engineering study for the duration of twenty (20) days from August 17, 1980, and subsequently carried out the review and analyses based on the data and information gathered by said mission. Presented hereinafter are the results of the system engineering study.

2. CONCLUSIONS

This system study was based mainly on power flow calculations and transient stability analyses for the system that is expanded as its generating sources are developed. The study also took into account system reliability and construction time schedules. The conclusions derived from the above study are enumerated below:

1) 500 kilovolts (kV) is deemed adequate as a transmission line voltage for carrying large blocks of power for longer distances.

2) As the generation development is implemented as programmed on Table 4.1., the transmission system expansion should be carried out as follows :

   a) In or by the end of 1982 : a 230 kV 2 x 795 MCM double circuit line should be completed for 60 km of the section between Tiwi and Naga. Besides, the existing 27 km long 230 kV 1 x 795 MCM double circuit line between Kalayaan and Malaya should be changed to 4 x 795 MCM conductor configuration.

   b) By the end of 1984 : a 500 kV designed double circuit line should be completed for 237 km of the section between Kalayaan and Naga. This line will be energized at 230 kV initially.

   c) By 1986 : 500 kV designed double circuit lines should be completed for 97 km of the section Kalayaan - San Jose and for 71 km of the section Naga - Legaspi. These lines will also be initially energized at 230 kV.

   d) By 1988 : a 500 kV double circuit line should be completed for 452 km of the section Gened (242 km) - Solano (210 km) - San Jose. This line will be operated at 500 kV from the beginning. At the same time, the line between San Jose and Kalayaan shall be boosted up to 500 kV line voltage. Then, six(6) 500 kV/230 kV transformers with unit capacity of 300 MVA will be installed at three substations;

two (2) units for Solano, three (3) units for San Jose and one (1) unit for Kalayaan. Two (2) shunt reactors of 700 MVAR and of 180 MVAR are needed at Solano and San Jose respectively.

e) By 1992 : By this year, the 500 kV design 230 kV energized line between Kalayaan and Naga shall be stepped up to 500 kV operation. Four (4) 500 kV/230 kV 300 MVA transformers shall be installed at two (2) substations; three (3) units for Naga and one (1) unit for Kalayaan, and two (2) units of 500 kV/115 kV 300 MVA transformers at San Jose substation. A 550 MVAR shunt reactor is needed at Kalayaan substation.

Thus, as of the year 1992, 500 kV trunk transmission system is completed from north to south to serve as a mainstay of the Luzon Grid.

f) No 500 kV transmission line is needed during the years 1992 - 1995. Any new generating source can be connected to the system by construction of 230 kV lines to the respectively nearest substations and addition of transformers to 500 kV substations.

In the year of 1995, the Luzon Grid will have 500 kV system as outlined below:

500 kV transmission lines	-	786 km
500 kV designed transmission lines	-	71 km
500 kV substations	-	4 places
500 kV/230 kV 500 kV/115 kV transformers	-	4,500 MVA
Shunt reactors	-	1,430 MVAR

3. LOAD FORECAST

3.1. Power Supply System in Luzon

Electric power utilities in the Luzon Grid are: NAPOCOR which is solely responsible for the construction, operation and maintenance of generating, bulk transmission and transformation facilities not only in Luzon but also in other areas of the country as a whole; Manila Electric Company (MECO), a privately owned utility distributing electricity to the Greater Manila area; and the local electric cooperatives (COOPS) under the administration of National Electrification Administration (NEA). Most of the COOPS purchase power from NAPOCOR and distribute it to their consumers on a local franchise basis, but some of them generate parts of their power requirements with their own small-capacity generators.

The power system of NAPOCOR is composed mostly of 230 kV lines and supplies load through 230 kV/69 kV transformer banks, while MECO's trunk system is composed mainly of 115 kV lines and supplies load through 115 kV/34.5 kV transformer banks.

The service area of MECO is about 2,600 km^2 embracing the Metro Manila area which corresponds to approximately 2.5% of the total land area of Luzon (104,000 km^2). However, the service area has the heaviest load density which consumes nearly two-thirds (2/3) of the total load in Luzon in 1978. On the other hand, NAPOCOR's service area involves non-electrified districts. NEA statistics as of the end of 1978 show that 71% of cities and villages in Luzon are electrified with 47% of the households enjoying the benefits of electricity. According to the present rural electrification program, all provinces in the Luzon Island will be connected to the power network in 1981 when the on-going Cagayan Valley Electrification Project will be completed, and the residential electrification level will reach 100% by 1990.

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As for generating facilities, before government purchase of MECO plants, NAPOCOR and MECO operated their own generating plants separately. However, starting November 1, 1978, the majority of MECO's oil-fired thermal plants with a total installed capaicty of 1,150 MW were turned over to NAPOCOR. At present, NAPOCOR absorbed all generating plants owned by MECO.

3.2. Historical Load Increase

Load increases in the Luzon Grid during the past ten years of 1969 to 1978 are tabulated on Table 3.1. As seen on the table, the peak load and annual energy requirement in 1969 were 1,020 MW and 6,087 x 10^6 kWH. They reached 1,780 MW and 11,223 x 10^6 kWH in 1978 which is nearly twice as much as those in 1969. The average growth rate in this duration was 7% both in peak load and annual energy requirement. However, the peak load in 1973 and the annual energy requirement in 1974 showed particularly low growth rates of only 0.3% from the previous year. This was due to the first oil crisis which prevailed in these years. Except for 1973 and 1974, other years show normal rate increases.

Although there are some variations by years, the load factor ranges from 65% to 72% which showed a higher figure in recent years.

Figs. 3.1 and 3.2 represent daily load curves in each month of 1979. They indicate that no remarkable difference is found in each other though the loads in January to March are slightly lower.

Fig. 3.3 shows a monthly peak load curve for three years of December 1976 to December 1979. As seen from the curve, there is no acute seasonal change observed but a gradual increase in the load.

The above trend in the power load is common characteristics to the countries in the tropical zone. The power load is projected to move in the similar trend in the future, too.

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3.3. Load Forecast

NPC formed up load forecast up to the year in June 1980, which was showed on Table 3.1. This load forecast gives that the growth rates of peak demand and energy requirement in 1979 are 10% and 5.5% respectively and after 1980 annual increases will be at the rate of 7%. That only 1969 has different growth rate from other years is considered to be almost actual record in view of the time of preparation of said forecast.

In the past, there were two available load forecasts of the Luzon Grid done by the consulting firms. One is 1973 load forecast by International Engineering Company (IECO), United States and the other is 1978 load forecast by Lahmeyer International GmbH. The former one indicates that average growth rate for 20 years (1973 - 1992) is 8.4% in peak demand and 8.2% in energy requirement, while the latter gives average 9.2% for both during the period of 23 years (1977 - 2000) with breakdown of 11.7% for 1977 - 1980, 10.7% for 1980 - 1985, 9.3% for 1985 - 1990, 8.1% for 1990 - 1995 and 7.2% for 1995 - 2000.

The methods applied by these consulting firms for load forecast were studied and the followings are noticed. IECO has made the load forecast in such method that loads are classified into residential, industrial, commercial, street lighting and others, and each load estimated region by region was finally integrated to derive a load forecast for the whole Luzon.

On the other hand, Lahmeyer formulated correlationship based on various indices of load models such as population, GNP, oil price and electrification rate. Our noticeable points in the developed correlations is that where fuel oil price is hiked, electricity tariff is increase accordingly, however there is some time lag between oil price hike and tariff revision and this would bring change-over of energy source from oil to electric power, resulting in increase of demand. This assumption is, however, considered

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questionable in view of nation-wide economy because the country depending on energy from oil-fired thermal plants will not lead to saving of oil consumption.

For non-oil producing nations and its high dependency on oil-fired thermal power generation like the Philippines, fuel oil saving directly means energy conservation. Besides, tariff system in the Philippines provides fuel price adjustment in billing the rate. Therefore, considerable time lag will not be caused.

Besides, change of economic environment due to world-wide oil crisis has brought that all forecasts in the past seems to be at a higher level. NPC also had to go overall review of such forecasts.

Upon scrutinizing of the NPC method for load forecast, it was found that the method is basically identical to the approach used by IECO, that is as outlined below:

(1) Historical loads are classified into the categories of residential, industrial and others.

(2) Residential load is forecasted by an analysis of trend of historical load growth.

(3) Future industrial load is forecasted by classifying loads into certain loads, certain loads subject to connection upon completion of supply facilities, and uncertain loads.

(4) Other demands considered include loads from military bases, consturction activities and street lighting.

(5) The load increase resulting from rural electrification was forecasted based on a correlation between the population and power demand in electrified areas, taking account of load growth rates after electrification.

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(6) As data for population which is one basic parameter for the load forecast, the lower value of population increase projection by NEDA in 1975 was used.

On the basis of the power loads by regions estimated in the above method, the annual total energy requirement in the Luzon Grid was estimated, assuming that the diversity factor of load within the jurisdiction of NAPOCOR is 1.1 and that between NAPOCOR and MECO is 1.03 and the loss rate in the power system of NAPOCOR is 10.1 and 4.8% in the distribution system of MECO. The annual peak load was forecasted based on the annual total energy requirement thus forecasted, assuming that the load factor is 70%. The method outlined above is conventional and no objectionable factor is seen in the estimate.

Fig. 3.4 gives a satistical relation between energy consumption and Gross Domestic Product (GDP) in 1974 in various countries in the World. This figure indicates that the Philippines is situated on the average expressed with a bold line.

In view of recent worldwide energy conservation efforts, the Philippine's national policy of oil import cut-down, use of non-oil energy for new industrial development and diversification of industry to the areas other than Luzon, a sharp load increase inside the Luzon Island would not be expected for the decade. In forecasting the power load for the coming 10 years, it is a normal practice that a growth rate of the load in the latter years is made a little bit lower. The projected growth rate of 7% per annum from 1979 to 1990 is, however, considered reasonable at the present, considering that the electrification program in Luzon is scheduled to be completed in 1990, energy use in recent years is suppressed due to conservation of oil-consumed energy and development of indigenous energy resources is being accelerated.

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In view of the above, it was decided to adopt the NAPOCOR load forecast for this study. After 1991, the annual growth rate of 6.5% is projected for the years up to 1995 and 6.0% from 1996 to the year 2000 as the load after completion of the rural electrification in 1991 is forecast to grow at somewhat lower rate.

3.4. Power Load Forecast by Bulk Substations

It is necessary to forecast load distribution by major bulk substations in the Luzon Grid, which will provide a base for the system planning and analysis.

As discussed in the preceding section, the NAPOCOR load forecast was prepared on the basis of integration of projected regional loads. For the projection of loads by regions, power load at the respective substations on the NAPOCOR power network was estimated by NAPOCOR for each year from 1980 to 1990. Likewise, bulk substation loads within the MECO service area for the years 1980 to 1989 were projected by MECO. The values in this MECO projection are, however, rather higher as compared with the overall load forecast as forecast in the preceding Section 3.3. Besides, there is available load forecast data at substations within the MECO service area in the year 1984 only which were prepared by NAPOCOR. Total of the substation loads on the NAPOCOR power network and the substation loads at the substations within the MECO service area, both in 1984, which were forecast by NAPOCOR, quite agrees with the overall load forecast in 1984. After having conferred with NAPOCOR regarding the treatment of different values of the substation loads within the MECO service area, following procedures were taken to arrive at final figures:

(1) Bulk substation loads forecast by NAPCOR were adopted as they are.

(2) To obtain the total load in the MECO service area in each year the sum of NAPOCOR bulk substation loads was subtracted from the overall NAPOCOR-MECO integrated load.

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(3) MECO bulk substation loads in each year of 1980 to 1989 which were forecasted by MECO were divided in proportion to agree to the total load in the MECO service area in the corresponding year obtained under the above item (2).

(4) MECO bulk substation loads in 1990 were projected by extending those in 1989 with annual growth rate of 7%.

(5) During the period 1991 - 1995, both NAPOCOR and MECO bulk substation loads were computed at the average annual growth rate of 6.5%.

(6) MECO substation loads, except the load at Tayabas, were grouped into four (4): Sucat, San Jose, Dolores and Malaya, because the MECO 115 kV system consists of many transmission lines in the form of a mesh which will make it possible to transfer loads among the groups and to deal with overloading or abnormal voltage drop of a transmission line.

The forecasted loads by substations which were estimated in the above method are presented in Tables 3.2. and 3.3.

4. GENERATION EXPANSION PROGRAM AND DEMAND-SUPPLY BALANCE

4.1. Existing Generating Facilities

As of the end of 1979, Luzon has generating facilities with total installed capacity of 2,991 MW, excluding small generators supplying local loads. This total generation capacity is consisted of hydro 541 MW (18%), geothermal 220 MW (7%) and oil-fired thermal 2,230 MW (75%). Almost all hydro stations are located in the north of Manila, geothermal plants in the south and oil-fired plants in and around Manila.

4.2. NPC's Principal Policy for Future Generation Expansion

NPC is implementing power development program in line with the following basic policy:

(1) Accelerated development of country's indigenous energy resources such as hydro and geothermal.

(2) Development of nuclear power.

(3) Promotion of domestic coal-fired thermal power development, and no more addition of oil-fired thermal plants.

(4) Suppression of operation of existing oil-fired thermal plants to the maximum extent and their gradual retirement in the order of lower efficiency plants as new power sources are placed in service.

The basic policy is considered reasonable in view of recent global energy situation, especially from the viewpoint of conservation of oil energy. The holding of existing oil-fired thermal plants as standby plants in the Generation Expansion Plan will give more flexibility in providing for more load increase than forecasted or change in the Generation Expansion Plan.

4.3. Generation Expansion Program

Based on the load forecast up to the year 1990 and in line with the above-mentioned basic policy for energy development, NPC formed its generation expansion program in June, 1980, which will increase the total installed capaicty of the Luzon Grid to 6,713 MW in 1990, composing of hydro 1,993 MW (30%), geothermal 1,345 MW (20%), nuclear 620 MW (9%), coal-fired thermal 600 MW (9%) and oil-fired thermal 2,155 MW (32%). What different from the former program is that some hydro developments are deferred in later years and instead, geothermal power sources are much accelerated. The acceleration of geothermal development is made on the account of substantial decrease of oil fueled energy at as earlier days as possible, since its construction period is comparatively shorter than other alternatives. The retired oil thermal plant in this duration is only one with 75 MW. Actually this retirement was made early 1980 due to deterioration. Therefore, no oil-fired thermal retirement is considered in the above-mentioned generation expansion program.

4.4. Load and Supply Balance

Using the load forecast and generation expansion plan which were discussed in the preceding sections, the load and supply balance in the Luzon Grid was analyzed by us. In the analysis, the following approach was used:

1) This study covers a period up to the year 1995. However, the demand and supply balance was analyzed until the year 2000 because the transmission line voltage and power conductor size should be selected so as to cater to the system requirements for a long term.

2) Generation expansion plan for the decade of 1991 to 2000 was programmed with the generation projects which have proven viable or feasible as the result of previous studies.

3) A maximum power output of the system is considered as the sum of dependable capacities of power plants in the system.

4) The reserve capability of the system is considered as reserved capability at the outage of the second largest generating unit in the system while the largest unit undergoes a periodical inspection.

As the power load in the Philippines does not vary much seasonally, the maintenance of plants should be averaged throughout a year, and a case of out-of-operation of the largest plus the second largest units would be unavoidable in any combination of various types of power stations.

The largest plus the second largest units are two units of the Malaya Thermal Power Station (total dependable capacity 630 MW) before the nuclear power plant is commissioned. After the nuclear power plant is placed in operation, there will be a single unit of the nuclear power plant and Unit No. 2 of the Malaya Thermal Power Station with a total dependable capacity of 930 MW. The system reserve capacity is defined as the capacity obtained by (total dependable capacity) - (peak load + dependable capacities of the two above-mentioned largest units in the system).

The load and supply balance in the Luzon Grid computed in the above approach is presented on Tables 4.1 to 4.2. The dependable capacities of thermal and hydro power plants used for the computation are presented on Tables 4.4 and 4.5.

Tables 4.1 and 4.2 indicate that the power balance (kW) showed a deficiency of 44 MW in 1981, but in 1981 no addition of a new plant could be expected to cover it up. The deficiency in power is equivalent to approximately 2% only. Therefore, the shortage will be overcome by lowering the voltage without restriction on power supply, unless any shutdown of the power plants occurs.

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After 1982, the system will augment gradually its reserve capacity which will reach a maximum of 1,666 MW in 1985. This reserve capacity is still less than the total installed capacity of oil-fired thermal plants, i.e., 2,155 MW or 2,015 MW in terms of dependable capacity. Therefore, the operation of all oil-fired thermal plants can not be suspended over the year.

On the other hand, Tables 4.1 and 4.3 show that the energy balance (kWH) would not pose any problem, for it has some surplus against the requirement. Then, if this surplus energy is offset by limiting the operation of oil-fired thermal plants, the years when oil thermal energy will not be required completely are only the years of 1985 to 1988 in figures. However, these years will need the power (kW) generated by oil-fired thermal plants, which accompany some energy generation, hence complete suspension of oil-fired plant operation can not be expected.

As a result, any apprehension is not foreseen on the load and supply balance over the projected period, except the year 1981. At a glance, it gives an impression that the system will have rather large reserve capacity, but from the viewpoint of oil conservation, the generation expansion program is not considered ambitious but it is desirable to implement more power source development as far as the situation permits.

5. EHV TRANSMISSION SYSTEM AND ITS VOLTAGE CHOICE

5.1. Introduction of EHV Transmission System for the Expanding Luzon Grid

Generally, projected power sources in Luzon will be hydro located in the north and geothermal in the south, whereas the heaviest load center is Metro Manila and its vicinity. Therefore, the trunk transmission lines should be extended from both north and south ends of Luzon toward Metro Manila.

The load forecast and corresponding generation expansion plan for Luzon give a quantity of differential power to be transmitted to Metro Manila as follows:

(Unit: MW)

	1990	1995	2000
Power Output in Northern Luzon	1,370	2,770	4,100
Power Load in Northern Luzon	448	613	820
(Difference)	922	2,157	3,280
Power Output in Southern Luzon	1,290	1,400	2,110
Power Load in Southern Luzon	108	149	199
(Difference)	1,182	1,251	1,911

The power output in Northern Luzon means power generated by power sources located farther north of the Binga Hydroelectric Power Station while the power load therein represents the total forecasted load in the area north of Baguio and Solano. Almost all of the power sources in Northern Luzon will be hydro power plants with a few exceptions of coal-fired thermal and geothermal units. The power output and power load in Southern Luzon are defined as those available south of Gumaca. The majority of the Southern Luzon power sources are geothermal generating units and 600 MW of a coal-fired thermal station.

These power sources in both south and north areas are about 300 to 400 km distant from the load center, Metro Manila. A bulk power transmitting capacity for such long distance is limited by the stability of the system. At present, the NAPOCOR standard 230 kV transmission system is 1 x 795 MCM double circuit, of which power carrying limit is approximately 300 to 350 MW.

The generation expansion plan adopted in this study will require the construction of 6 to 8 transmission circuits in Northern Luzon in 1995, if the line voltage is maintained at 230 kV. The locational concentration of power sources in the north of Baguio and around Solano will restrict an increase in the utilization rates of the transmission lines by interchange of power among them. There is a possibility that many more circuits of transmission lines may be required. Besides, more than 1,000 MW is planned for development until the year 2000. If the transmission lines are expanded at 230 kV level, every power plant construction will require the construction of a transmission line of more than 300 km, in the extreme case. This is quite unrealistic nor practicable. In view of the topographic conditions in Northern Luzon and the locations of power sources, the transmission system in Northern Luzon should adequately be planned to be less than two routes or four circuits. The introduction of an EHV transmission line is imperative to carry such large power with minimum number of line routes or circuits.

The generating capacity in Southern Luzon will reach to the order of 1,200 MW in 1990 and it will be doubled to 2,000 MW in the year 2000. The Southern Luzon power system is at present a 230 kV double circuit line only, but, as the power sources, existing and planned, are concentrated around its southern end, new transmission lines will be required to transmit the increasing power.

Southern Luzon is topographically very narrow and most of its land area, even the mountain ridges, have been developed for extensive coconut plantations. Therefore, the environmental

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constraints are deemed more severe. If the transmission voltage is maintained at 230 kV, two (San Jose - Kalayaan), one (Naga - Legaspi) and three (Kalayaan - Naga) additional routes of 230 kV double-circuit transmission lines will be required for construction to maintain the equivalent carrying capacity of a 500 kV transmission line. The right-of-way with a total area of 37.68 km^2 will be needed by NPC for the construction of the additional 230 kV lines, while the construction of an alternative equivalent 500 kV double-circuit line requires the right-of-way area of 25.35 km^2.

It is believed that the addition of one route of transmission line in Southern Luzon will have to be the limit because of the topographic and geographic restriction, hence the introduction of an EHV transmission line into the power system in Southern Luzon becomes necessary.

If EHV is adopted to both the systems in Northern Luzon and Southern Luzon, hourly variations in power flow will become large because of different characteristics in the main power sources in both areas (mainly geothermal in Southern Luzon and hydroelectric in Northern Luzon). The interconnection of both systems at EHV will bring an increase in the capacity of tie transformers and make difficult interchange between both systems. Accordingly, the interconnecting line between both systems should also be an EHV line.

For the above reasons, it is recommended that next transmission lines be constructed at a higher line voltage and operated initially at 230 kV as long as possible and then boosted to a designed higher line voltage at the appropriate time.

5.2. Optimization of EHV Transmission Voltage

Table 5.1. shows transmission voltage levels in the countries where extra high voltage transmission systems are in operation. Generally, a higher transmission voltage has been selected to be more than twice as much as the previous highest voltage level.

The carrying capacity of a transmission line considering its stability is determined in the following power equation:

$$P = \frac{E_s E_r}{X} \sin \theta$$

Where, P = carrying capacity
E_s = voltage at the sending end
E_r = voltage at the receiving end
X = Reactance
θ = Phase angle

As clearly known from this equation, the carrying capacity will increase in proportion to the square of a voltage; if the voltage is doubled, the carrying capacity will become four times. This is the major reason why higher voltage has been normally determined at a level more than twice as much as the previous highest voltage.

The present highest transmission voltage in the Luzon Grid is 230 kV. So the next higher should be selected at 400 kV or 500 kV.

The reasons why 500 kV was recommended as the optimum transmission voltage to the Luzon Grid are enumerated as follows:

(1) The European countries raised their highest voltage in power systems from 220 kV to 400 kV. This voltage-up was made in the latter half of 1950 to 1960. In those days, design criteria of 500 kV transmission lines were not established yet. However, nowadays design criteria for 500 kV systems have been throroughly developed and 500 kV lines are operated successfully.

(2) In Europe, excluding Sweden, the transmission lines are relatively short in distance. As the systems are inter-connected among the countries, the power systems in the different countries were required to be coordinated by the first adopted voltage level. In Sweden series condensers are used for compensation of shortage in the transmission capacity.

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(3) The frequency of power in Europe is 50Hz, while in the Philippines it is 60Hz. The transmission capacity of a transmission line at certain voltage in the 60Hz power system is reduced to 80% of the transmitting capacity of a transmission line rated at the same voltage in the 50Hz system. It is, therefore, justified to a higher voltage in the 60Hz system in order to cover this disadvantage.

(4) Considering the extensive generation expansion in the Luzon Grid after 1995 and difficulties in acquiring the right-of-way, the transmitting capacity of next transmission lines should desirably be maximized to a possible extent by adoption of 500 kV voltage level.

6. SYSTEM PLANNING CRITERIA AND VARIOUS PARAMETERS

6.1. Existing Luzon Power System

The present major power system in the Luzon Island is composed of NPC 230 kV system extending to the north and south of the island and MECO 115 kV network serving Metro Manila and the vicinity. These two systems are integrated with each other, called the Luzon Grid. Fig. 6.1. shows the outline of said system.

The Luzon Grid is characterized in the following:

(1) Metro Manila area has a number of MECO 115 kV lines in the form of mesh.

(2) Both north and south 230 kV systems of NPC have been interconnected to MECO 115 kV system through 230 kV/115 kV transformer banks. The transformer bank capacities at major interconnections are Balintawak 420 MVA connecting with the north 230 kV lines and 200 MVA at Biñan and 75 MVA at Malaya, both connecting with the south 230 kV system.

6.2. Luzon Grid Expansion Program

NPC's Luzon Grid Expansion Program up to 1990 and its extended plan to 1995 is shown on Fig. 6.2. Main characteristics of this expansion program are enumerated as follows:

(1) Establishment of 500 kV transmission system.

(2) Interconnection between the two systems in the south and the north by a 500 kV tie line.

(3) Reinforcement of the 230 kV system around Metro Manila keeping pace with the staged retirement of oil-fired thermal plants in or near Manila.

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(4) Extension and reinforcement of the 230 kV system to cope with load increase in Northern Luzon.

6.3. NPC's Criteria for Present System Planning

The criteria for system planning currently being applied by NPC are given below:

(1) The system shall withstand against at least single fault. This means that the pwoer system should be planned so as to function without disturbance against one circuit trip out or one transformer failure.

(2) The standard size of line conductors shall be 795 MCM.

(3) The maximum current rating of 1 x 795 MCM transmission line shall be 900 A.

(4) In case one circuit of double circuit transmission lines falls down, a short period allowable current limit for the lines carrying power from hydro plants shall be maintained within 140% of the rated maximum current and within 110% for the other lines.

(5) In case of failure of one transformer, the overloading of other remaining transformer units in a short period shall be kept within 110% of their rated capacities.

(6) The bus bar system shall be in principle the 1.5 circuit breakers system, or the ring bus system. The grounding system shall be direct grounding.

(7) The target value of voltage control shall be ±5% of the rated voltage.

(8) The system stability is measured by a difference in the phase angles between the two generating units obtained by

power flow calculation. The stability criterion is $\angle\delta \leqq 30°$, within which the system is said to be "stable".

(9) Where the system frequency is abnormally lowered due to a generator accident or line fault, the system shall be maintained by temporary load shutdown with frequency values of relays necessary for load shutdown in case a nuclear unit trips out of operation.

6.4. New Criteria Proposed for System Planning Including 500 kV System

(1) The stability of the 500 kV system is most important in this study. A combined method of power flow calculation and transient stability analysis was applied to produce more accurate analysis of the system stability.

For this analysis, following conditions were assumed:

- ° Fault condition - One circuit three phase to ground fault (3LG)
- ° Fault clearance time - 0.1 second (6 cycles)
- ° High speed reclosing - Not applied

The system was considered "stable" if no generating units trip out in the calculation under the above conditions, and it is considered "unstable" if any generating unit trips out.

(2) The allowable sending end voltage of the 500 kV system was limited to 1.1 P.U., to reduce the capacity of shunt reactors which would be required to compensate for the charging current rise of the 500 kV system. If it results in the voltage rise of more than 5% in the 230 kV system, such voltage rise will be suppressed by means of tap changing of 500 kV transformers.

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(3) The standard conductor of 500 kV lines shall be 4 x 795 MCM, and the tower structure shall be designed for two circuits.

(4) The unit capacity of 500 kV/230 kV or 500 kV/115 kV transformers shall be standardized at 300 MVA, and tertiary side transformers are rated at a unit capacity of 100 MVA. Also, the voltage at the tertiary winding is generally set at 69 kV, except for San Jose where 34.5 kV is selected.

(5) In working out the system plan, due consideration was given to the maximum effective utilization of the system facilities, existing and under construction. On the other hand, the 500 kV system was designed to be as much a simple system as possible, in order to minimize unexpected disturbances; the different voltage loop operation of 230 kV one circuit line and 500 kV line in Northern Luzon was avoided.

6.5. Basic Input Data for System Analysis

The system analysis was performed by means of power flow calculation, transient stability study and short circuit current limit.

Those basic technical data on various system components used for the calculations are presented as follows:

(1) Generating capacities, substation capacities, and size and distance of transmission lines.

See Fig. 6.3. The circled figures on the diagram means node numbers given for the purpose of computer run.

(2) Substation loads

The substation loads shown on Tables 3.2. and 3.3. were used for the load by substations. These substations are assumed to be charged with about 50% of their peak loads at light load time.

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The following NPC's target load factors were used as the load factors:

Peak load time - NAPOCOR 90%, MECO 95%
Light load time - NAPOCOR 95%, MECO 99.5%

(3) Transmission lines

The main characteristics of 795 MCM by voltages and number of circuits are shown on Table 6.1.

(4) Generators and transformers

The main characteristics of generators and transformers, existing and planned, are shown on Tables 6.2. to 6.4.

Based on the figures shown on Fig. 6.3 and Tables 6.1. to 6.4., the impedance map of the Luzon Grid was developed as shown in Fig. 6.4.

7. RESULTS OF SYSTEM ANALYSIS

7.1. Power Flow and Transient Stability Analyses

Power flow and transient stability calculations were carried out with electronic computer based on the system expansion plan shown in Fig. 6.2. for the system configuration in key years.

The calculations were made for peak load time assuming that hydro plants are being operated at their rated outputs and geothermal, nuclear and coal-fired thermal plants are operated at dependable capacities. For oil conservation, surplus supplying capacity over the load was offset by primarily stopping the operation of oil-fired thermal plants around Metro Manila, and further surplus, if any, was cut down by stoppage or suppressed operation of the pumped storage station, hydro or coal-fired plants around Metro Manila which have less influence on the north and south power systems. Detailed adjustments such as the system losses were made using the output of the Malaya Plant.

The results of analyses under the above conditions are summarized as follows:

7.1.1. 1982 Power System

The connection of a transmission line from the Tiwi geothermal plant to one circuit of the Naga - Lagaspi line, and the transmission capacity of the present Kalayaan - Malaya line were main problems to be studied.

The transient stability calculation of the connection of the transmission line from Tiwi indicates the system to be "unstable". Therefore, a new transmission line is required for construction between Tiwi and Naga.

Regarding the second problem, power flow between Kalayaan and Malaya will reach 158% of the rated current capacity of one circuit. This section will, therefore, need reinforcement.

7.1.2. 1985 Power System

As the 550 MW output of Tiwi is scheduled to be put in the system in 1985, the current capacity and stability in the section of Naga - Kalayaan pose a problem from the beginning of this study. Therefore, the calculations were made on the assumption that a 500 kV designed transmission line has been constructed in this section. As a result, the system in 1985 will not cause any problem.

An interim result of the analysis indicates that if the operation of all oil-fired thermal plants except Malaya were stopped, the voltage within the MECO service area dropped below 95% of the rating, partly lower than 90%. Therefore, the calculation was made assuming the power factor being raised up to 99.5%.

7.1.3. 1986 Power System

In 1986 the Luzon Grid will import geothermal power of 300 MW generated at Tongonan, Leyte through a DC transmission line extended to Legaspi.

The system analyses show that the Legaspi - Naga line will carry current equivalent to 101% or less of the rated current at peak load time, while at off-peak time when the load at Legaspi is assumed to be totally lost, the power flow will reach nearly 110% which is almost marginal. The system will be stable without stepping-up to 500 kV operating voltage in the section between Naga and Kalayaan. This may probably be due to the fact that the power from Tongonan will be transmitted on the DC transmission line which has no problem in stability.

7.1.4. 1988 Power System

In this year, Gened hydro with 600 MW is expected to come in to the Northern system. It is considered impossible to transmit this power through 230 kV line, since the distance between Gened and San Jose is approximately 450 km. However, for confirmation, the computer was run to examine the possibility. As a result, the system will become "unstable" if a line fault occurs in the section of Gened - Solano. It, in turn, implies that this transmission line should be operated at 500 kV from the beginning. The transient stability will be secured in 500 kV operation. Therefore, the system analysis on the further system after this year will be done only for 1995 that is the last objective year.

7.1.5. 1991 Power System

Manito in Southern Luzon will have additional 110 MW installation in 1991, and a new transmission line will definitely be needed for the section between Legaspi and Naga, which already being loaded to the limit in 1986. This transmission line shall be of 500 kV designed because in the future one coal-fired thermal station with capacity of 600 MW is being contemplated around Legaspi.

As accompanied with the increase of the Manito output, the necessity of step-up of the Naga - Kalayaan line to 500 kV was examined by analysis of the transient stability, however, it was not required yet.

In carrying out this analysis, the voltage has again dropped to 90% of the rating within a part of the MECO service area, so that

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the calculation was made assuming the power factor in the low voltage area as 100%. Likewise, the system located north of Baguio has also experienced the voltage drop. The power factor in such area is also assumed to be 99.5% for the purpose of calculation.

7.1.6. 1992 Power System

The transient stability calculation was performed for the system in 1992 when Tiwi will be expanded by 110 MW more. The result of the calculation showed that the transmission system will become unstable at a line fault occurred between Naga and Kalayaan, and thus the step-up to 500 kV operation is necessitated.

7.1.7. 1995 Power System

Power flow and transient stability analyses were performed on the power system in the year 1995, which resulted in the following:

The 500 kV system connecting Gened - Solano - San Jose - Kalayaan - Naga, and the 500 kV designed Naga - Legaspi line would still perform well.

Analysis results as explained above are illustrated on Tables 7.1 to 7.8 and Figs. 7.1. to 7.8.

7.2. Shunt Reactors

The charging current of the 500 kV system is quite large, about 7 times as much as that of a 230 kV 1 x 795 MCM transmission line. Accordingly, a considerable capacity of shunt reactors would be required, and the capacity of shunt reactors was calculated for the 1995 power system at both peak load and midnight time by means of power flow. The charging current was planned to be reduced by leaving one circuit of the Gened - Solano line out of operation on the assumption that all hydro plants will be out of operation in a draught period. The result of calculation indicates that the required capacity of shunt reactors will be as follows:

(Unit: MVAR)

	Peak	Midnight
Solano	327	726
San Jose	0	179
Kalayaan	130	565

Power flow diagram corresponding to above situations are given as Figs. 7.8. and 7.9.

This will give a guideline for approximate required capacity of chunt reactors and an extent of its variation.

7.3. Short Circuit Current Capacity

In order to estimate approximate value of breaking capacity of power circuit breakers and unit capacity of shunt reactors, the short circuit current was computed with respect to the power system as of 1995. For this calculation, all generators are assumed to be in parallel operation. Therefore, the value obtained could be considered as an estimated maximum short circuit current.

The calculation results are given in Fig. 7.10. It shows that the largest short circuit current is still below 10,000 MVA. In view of the present manufacturing technology of power circuit breakers, this will not pose any serious problem.

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8. TIME SEQUENCE OF SYSTEM EXPANSION

As stated in the foregoing Chapter 7, the system analyses indicate the timing of the system expansion. The time sequence of the system expansion has been defined. For explanation, the Luzon Gris is divided into three parts; Northern Luzon system, Central Luzon system and Southern Luzon system.

8.1. Southern Luzon System Expansion

(1) In 1982 : a 230 kV transmission line shall be constructed for 60 km distance between Tiwi and Naga. This transmission line will have 2 x 795 MCM double circuits in consideration of the ultimate capacity of the Tiwi plant: 660 MW.

(2) By 1985 and before the end of 1984 : a 500 kV designed 4 x 795 MCM double circuit line shall be completed for 237 km between Naga and Kalayaan. This shall be energized initially at 230 kV. Also, in association with the construction of the Manito geothermal plant, a 230 kV line shall be constructed in the section Manito - Legaspi with the distance of 43 km. The line should be configurated in 2 x 795 MCM double circuits for the expected ultimate capacity of 440 MW..

(3) By 1986 : 71 km of Legaspi - Naga shall be connected with a 500 kV designed 4 x 695 MCM double circuit line to be operated initially at 230 kV.

The power flow analysis results will not demonstrate its necessity of construction before 1991. From construction sequence view, however, it is desirable to construct this line successively following after the completion of Naga - Kalayaan transmission line.

(4) By 1992 : the Naga - Kalayaan transmission line shall be boosted up to 500 kV operation. At this time, the Kalayaan substation would be a 500 kV substation in connection with

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the Northern Luzon system. Then, one unit of 500 kV/230 kV 300 MVA transformer shall be installed in addition, and also a 550 MVAR shunt reactor should also be placed here. For the Naga substation, installation of three units of 500 kV/230 kV transformer each with unit capacity of 300 MVA will be necessary.

8.2. Northern Luzon System Expansion

(1) It is preferable to postpone the construction of a 210 km Solano - San Jose 500 kV designed 4 x 795 MCM double circuit line which is aimed to cover up the overloading of the 230 kV system due to the Magat extension to be on-line in 1985.

The reasons are stated as follows:

(a) 180 MW extension at Magat is merely for peaking power, without energy production. This means the additional units will be put in operation only in probable years of spilling water discharge or just as the reserve capacity when some other plant becomes out of order. The latter case will also be rare since the system is expected to have sufficient reserves at that time.

(b) System planning criteria provide the condition of single fault. Accordingly "at the time of failure of other power plant" means "occurrence of one fault" and so it is reasonable to consider that there is no fault on the 230 kV system. No overloading will happen whilst two circuits are being operated.

(c) Transmission line construction cost cannot be recovered since the Magat extension will not produce any energy.

(d) The 500 kV designed transmission line construction between Naga - Kalayaan in the south should be more hastened since the construction period is rather tight. In this sense the dispersion of the construction forces would not be desirable.

So the transmission line to be constructed by 1985 in the Northern Luzon system is only 17 km long 230 kV 1 x 795 MCM one circuit line for connection of Daklan geothermal plant to Ambuklao.

(2) By 1988 : 500 kV transmission lines shall be constructed for 242 km distance between Gened and Solano, and also for 210 km between Solano - San Jose, which will be operated at 500 kV. At this time, 2 units of 500 kV/230 kV transformers, each 300 MVA, and a 700 MVAR shunt reactor shall be installed at Solano and 3 units of the same rating transformers and a 180 MVAR shunt reactor at San Jose.

The overloading problem due to Magat additonal units will be solved by the above.

(3) By 1992 : a 9 km 230 kV 1 x 795 MCM double circuit line shall be constructed between San Roque plant and San Manuel substation. In connection with the expansion of the Southern Luzon Grid, San Jose should have installation of two units of 500 kV/115 kV transformers, each 300 MVA. This is because the loads are on the 115 kV system and thus 230 kV side is omitted for economy purpose. However, in performing design, if it becomes difficult to adopt this method, four units, i.e., 2 units of 500 kV/230 kV transformers plus 2 units of 230 kV/115 kV transformers, each with 300 MVA unit capacity, shall have to be installed. Final decision regarding this matter shall be made in the following design phase.

(4) By 1993 : a 230 kV transmission line shall be completed for 36 km distance between CFTH-III and Santiago. The coal-fired plant is planned to have the installed capacity of 600 MW, so that the line shall be of 2 x 795 MCM double circuit. No addition of transformers will be necessary in consideration of load increase at Baguio side.

(5) By 1994 : Chico IV should be connected to Solano by constructing a 107 km 230 kV line. Previously, Chico IV is planned to be linked on the 500 kV Gened - Solano line which was supposed to pass nearly the site. However, said 500 kV line route was changed. Aside from it, some 230 kV lines are become necessary to meet the increasing demand in the north of Baguio. This Chico IV - Solano line would be serviceable for this purpose.

Since the area includes various hydro potential sites, the line was considered at 2 x 795 MCM double circuit.

And this time, Solano and San Jose should be provided with additional one unit of 500 kV/230 kV transformer and 500 kV/115 kV transformer respectively.

(6) By 1995 : a 230 kV transmission line shall be constructed for 45 km distance between Diduyon - Solano with 1 x 795 MCM double circuit. At the same time, one unit of 500 kV/230 kV transformer of 300 MVA shall be additionally constructed at Solano.

8.3. Central Luzon System Expansion

Expansion program of the Central Luzon System should have a close relation to both expansion programs of south and north systems and it means that important factors of the whole Luzon system reliability, allotment of loads, etc. should be studied in addition to the standard system of power flow calculation, stability analysis, etc.

In this study, the expansion timing to meet construction period and reliability requirements is examined based on the expansion schedules of south and north systems considered in 8.1. and 8.2. respectively.

(1) By 1982 : the Kalayaan - Malaya transmission line of a 27 km 230 kV 1 x 795 MCM double circuit line shall be changed to 230 kV 4 x 795 MCM.

This transmission line, as stated in the current calculation, will be loaded at 158% of a single circuit rated current at the

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single circuit fault and the such figure is over the limit. The said figure appears only when the Kalayaan pumped storage power station is operated.

This transmission line seems not necessary in case the Kalayaan pumped storage power station is regarded as a reserve for peak load, as same as examined for Magat in the north system. However, judging from the demand and supply balance, shortage of reserve in 1981 is estimated and in 1982 the reserves are only 196 MW even after completions of new power sources of Tiwi 110 MW and Kalayaan 300 MW. It is also found that the condition of program for this system is quite far from the Magat case and the operation of Kalayaan power station will become extremely frequent.

Moreover, this transmission line will be an important line to take a supplemental part for maintaining system reliability when the 500 kV system is installed in Central Luzon in the future.

Therefore, a 230 kV 4 x 795 MCM double circuit line is adopted, which is the same line configuration as adopted for the San Jose - Dolores - Malaya transmission line.

(2) <u>By 1986</u> : a 500 kV designed transmission line with 4 x 795 MCM double circuits shall be constructed between the Kalayaan - San Jose 97 km, and shall be operated in 230 kV. The completion time of by 1986 is adopted with the following reasons :

(a) Transformers at Kalayaan and San Jose of the Kalayaan - San Jose transmission line shall be operated in 500 kV effectively and correlatively whenever whether south or north system may be operated in 500 kV. According to the present plan, 500 kV operation will be necessary in 1988 and it is desirable to proceed with the basic designs of 500 kV substations even though the constant values of the relative electrical equipment in the south system may be changed.

(b) The Naga - Kalayaan 500 kV designed transmission line will be completed by 1985, therefore, a part of the construction forces can be spared for the construction work of the San Jose - Kalayaan transmission line.

(c) In case the completion time of by 1988 is adopted, some shortage of the construction forces may occur since the Northern Luzon 500 kV transmission line construction (452 m) will be commenced.

(d) As the Central Luzon system is considered to encounter the most problems in Luzon Island in view of the right-of-way for the transmission line route, it is desirable to construct at the earliest time as possible.

(e) This transmission line covers the areas of Metro Manila, being the biggest power demand area of the Philippines. Therefore, it has more effects than the calculated in terms of the reliability.

(3) By 1988 : the Kalayaan - San Jose transmission line shall be boosted up to 500 kV operation. At San Jose, as mentioned in Northern Luzon system expansion, three units of 500 kV.230 kV transformers with 300 MVA and a 180 MVAR shunt reactor will be installed.

At Kalayaan, one unit of 500 kV/230 kV transformer with 300 MVA will be installed. No shunt reactor is necessary to be installed by the time of boosting up to 500 kV in the south system. When the south system will be boosted up to 500 kV first and then the central system will be boosted up to 500 kV subsequently, the number of transformers will be two units at San Jose and one at Kalayaan. Shunt reactor will be unnecessary at San Jose but 550 MVAR of it will be necessary at Kalayaan.

8.4. Summary of System Expansion Program

The system expansion program examined by each system is summarized in Table 8.1. In the Table 8.1., substation facilities at San Jose and Kalayaan are included in the central system.

Summary of the facilities adopted for this system expansion are as follows :

500 kV transmission lines	785 km
500 kV designed transmission lines	71 km
Associated 230 kV transmission line extension	344 km
500 substations	4 locations
500 kV/230 kV transformers	3,600 MVA
500 kV/115 kV transformers	900 MVA
500 kV circuit breakers	47 units
230 kV circuit breakers	63 units
115 kV circuit breakers	5 units
Shunt reactors	1,430 MVAR

Circuit breakers necessary for switching of shunt reactor are not included in the above list since their applied positions may depend on the installed conditions of each substation.

Therefore, they should be added in the separate calculations during the design stage.

9. REQUIREMENT FOR FUTURE STUDY

This report presents the optimum system expansion derived from power flow and transient stability calculations, taking into account construction periods and significance of the respective lines. This optimum system expansion is based on the latest load forecast and generation expansion program at the time of this study. It is, therefore, natural that if any change is made on these basis, the system expansion program should undergo review and modifications accordingly.

Major items to be noted in this regard are described below :

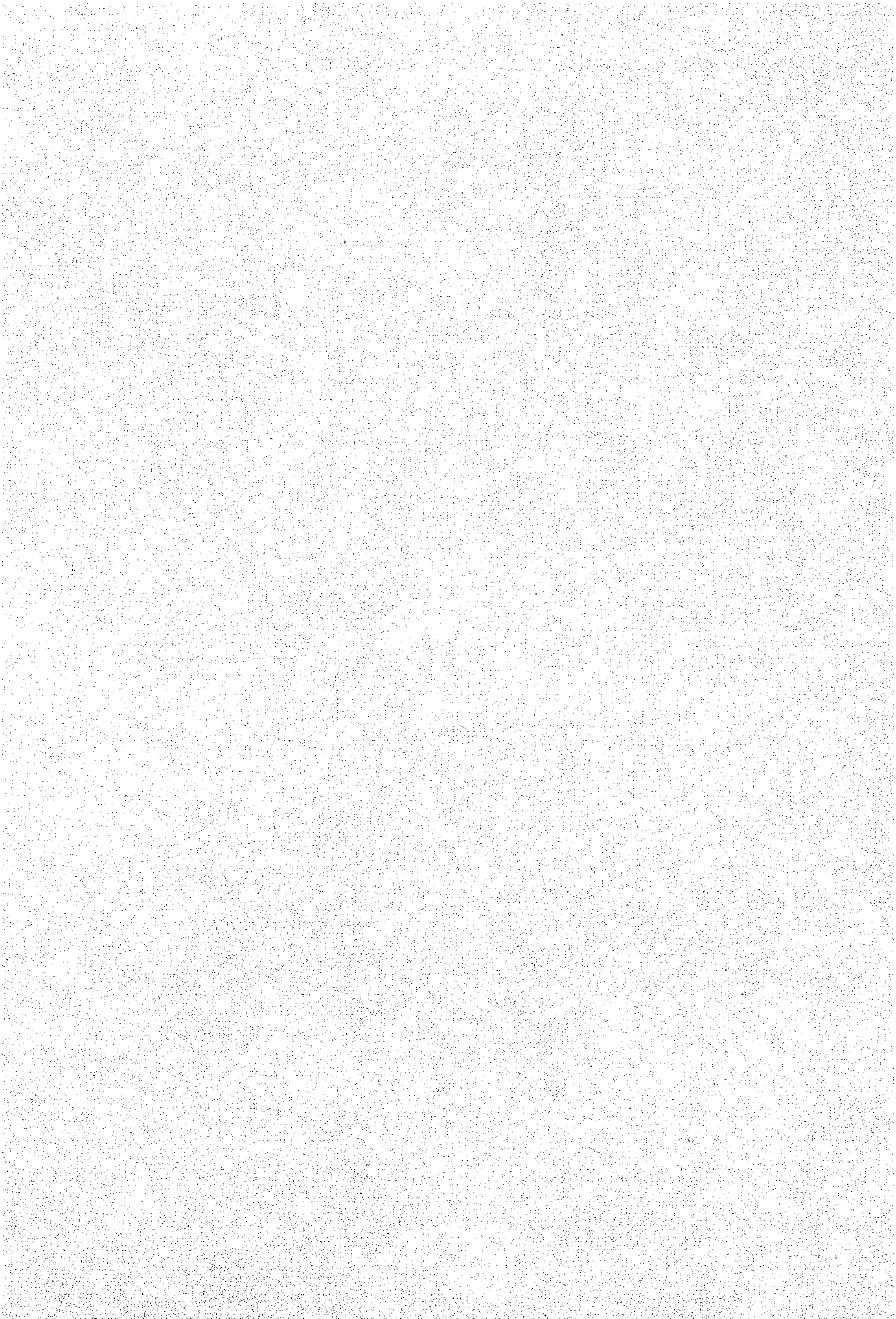
(1) Change in development sequence of power sources, particularly order of geothermal unit additions in the south area, for instance, accelerated development of Tiwi and Manito instead of Tongonan in Leyte, would largely affect the system stability.

(2) Design techniques of power equipment is advanced to reduce the cost of manufacturing. Variation of equipment parameters due to the above somewitmes results in adverse effect on system stability. Since there is no restriction of short circuit capacity in the Luzon Grid, the parameters of equipment shall be decided in full consideration of stability.

(3) The system analyses in this study were made under the condition of no oil-fired thermal plant operation except Malaya and therefore, the voltage drop occurred so that the calculations could not be carried out at the power factor set forth through discussion with NPC. As a result, the power factor was compelled to be revised. This means that if the existing power system in and around Metro Manila remains unexpanded, the oil-fired power stations can not be stopped. As counter-measures, power factor improvement, and system reinforcement of the MECO system and rotary condenser operation by stopped oil thermal plants can be considered. The counter-measure to be adopted is a subject of future studies.

Besides, as the voltage drop was observed in the loads north of Baguio. The system in this area should be reinforced by changing 230 kV single circuit lines to double circuits.

For the improvement of the voltage, a further examination of the power factor is essential as well as the reinforcement of the system itself.



LIST OF FIGURES

Fig. 3.1 Daily Load Curve Weekdays 1979 Luzon Grid

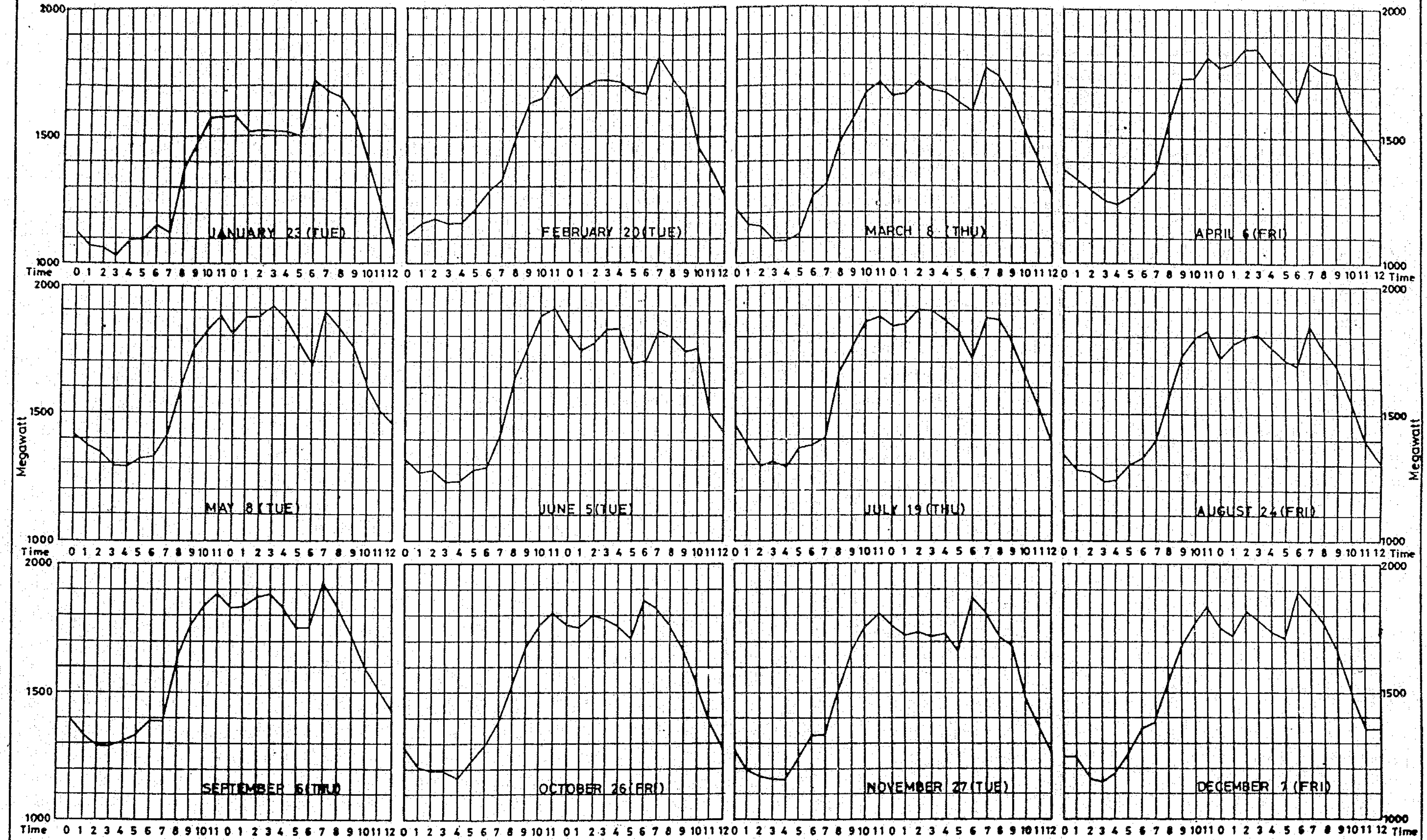


Fig. 3.2 Daily Load Curve Holidays 1979 Luzon Grid

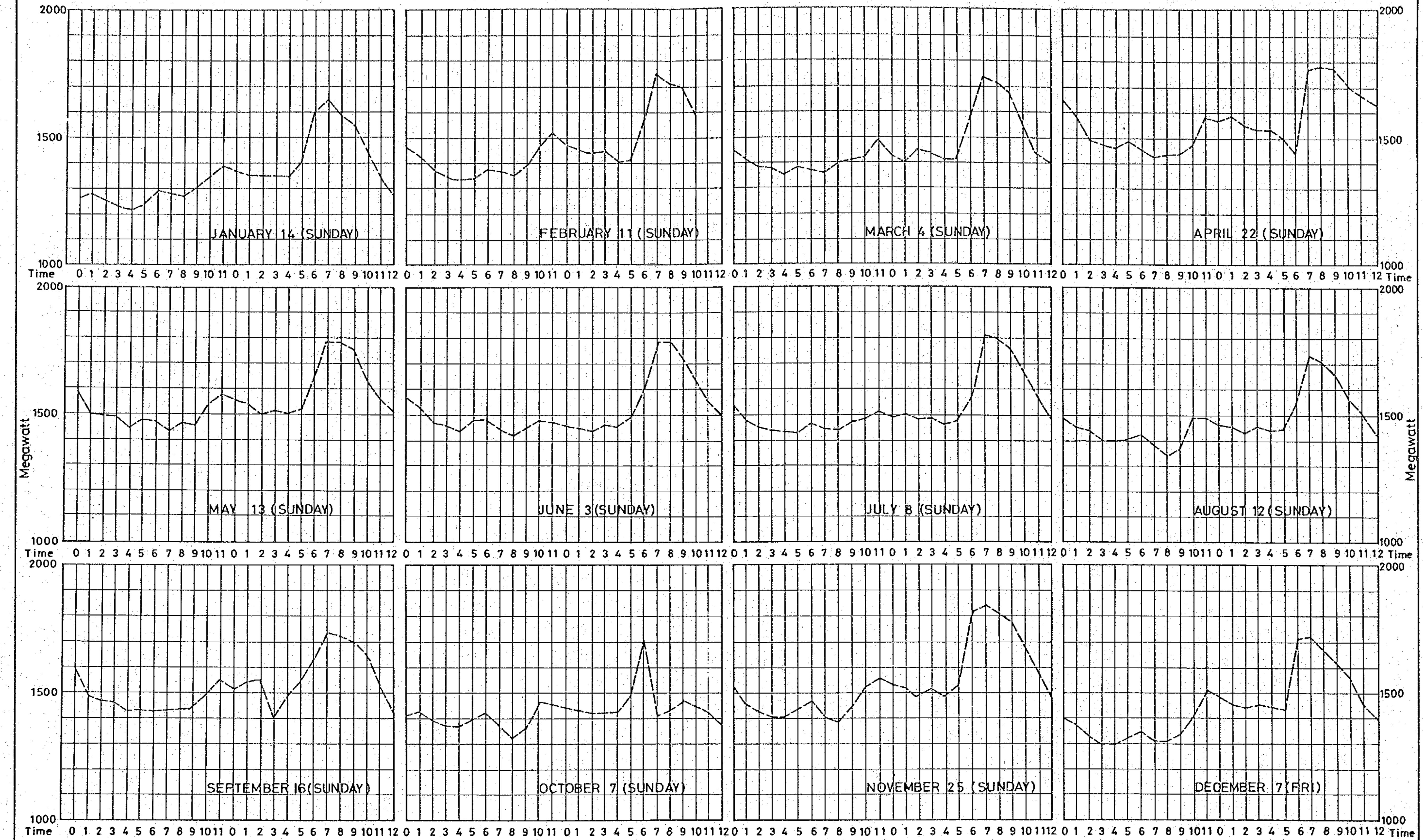


Fig. 3.3 Monthly Peak Load Curve (Dec. 1976 — Dec. 1979)

Fig. 3.4 Correlation between Electricity Consumption and GDP, per capita, as seen in the World

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

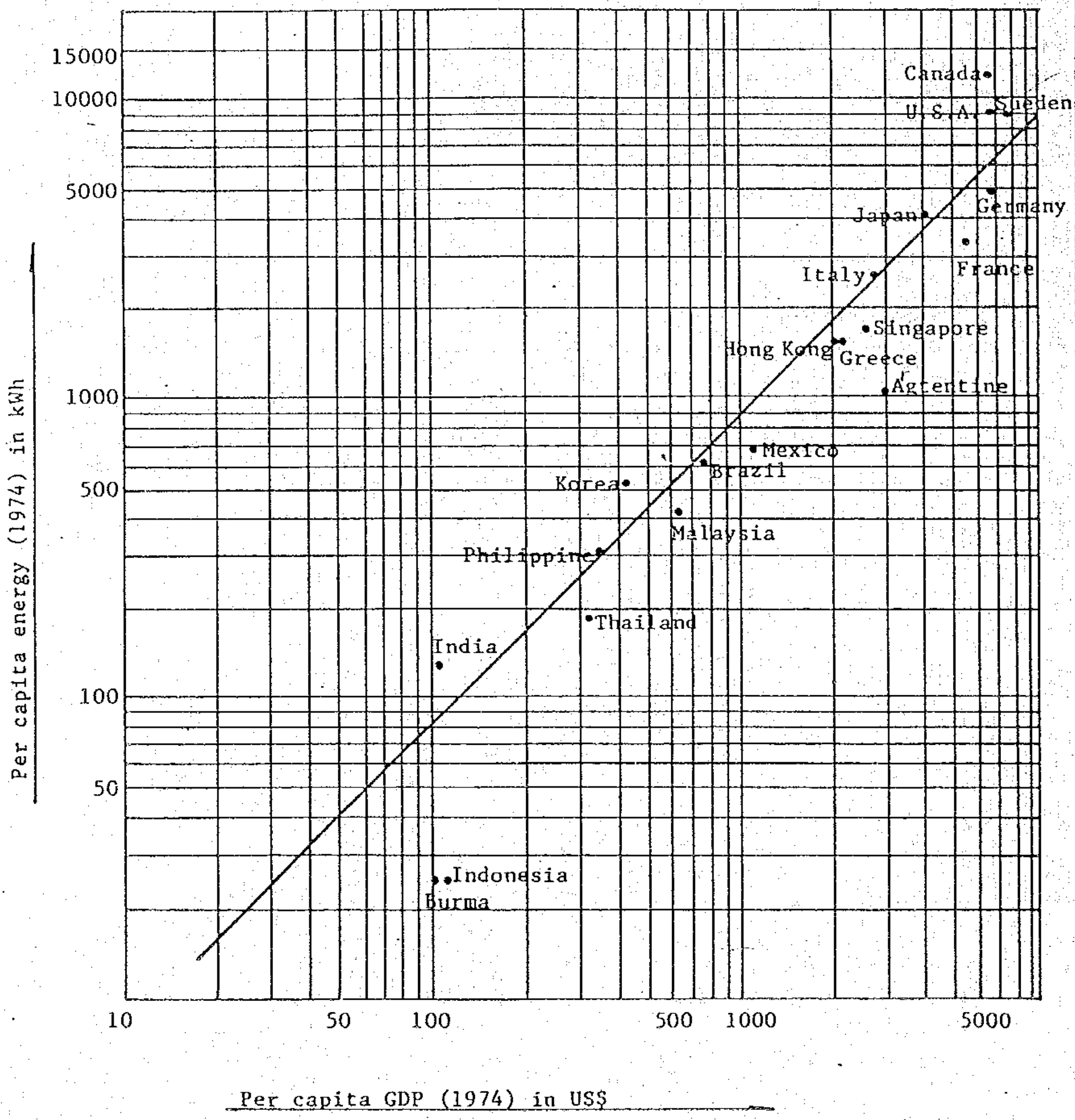


Fig 6.1 Existing Luzon Grid Outline (End of 1979)

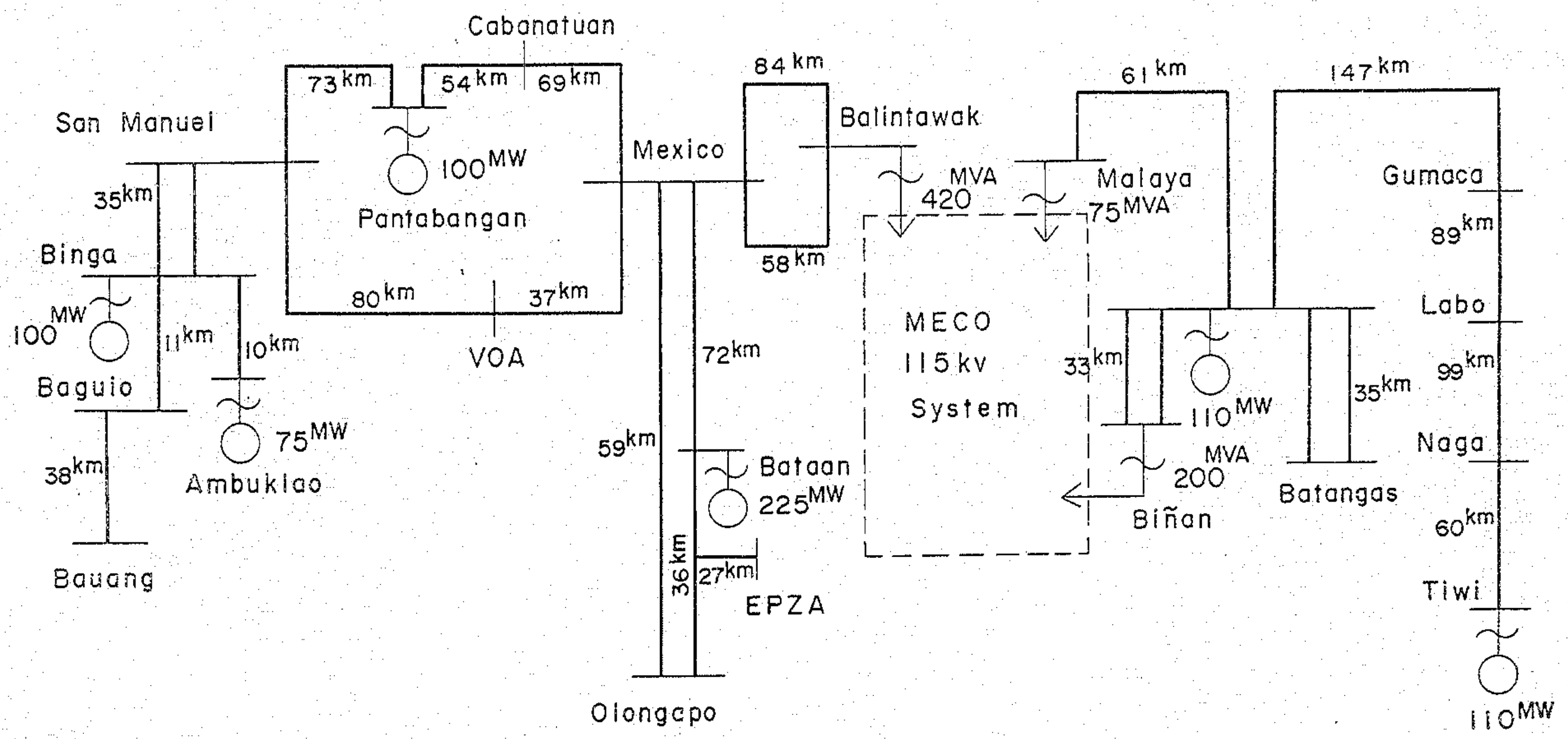


Fig 6.2 Luzon Grid Single Line Diagram

Initial Expansion Program

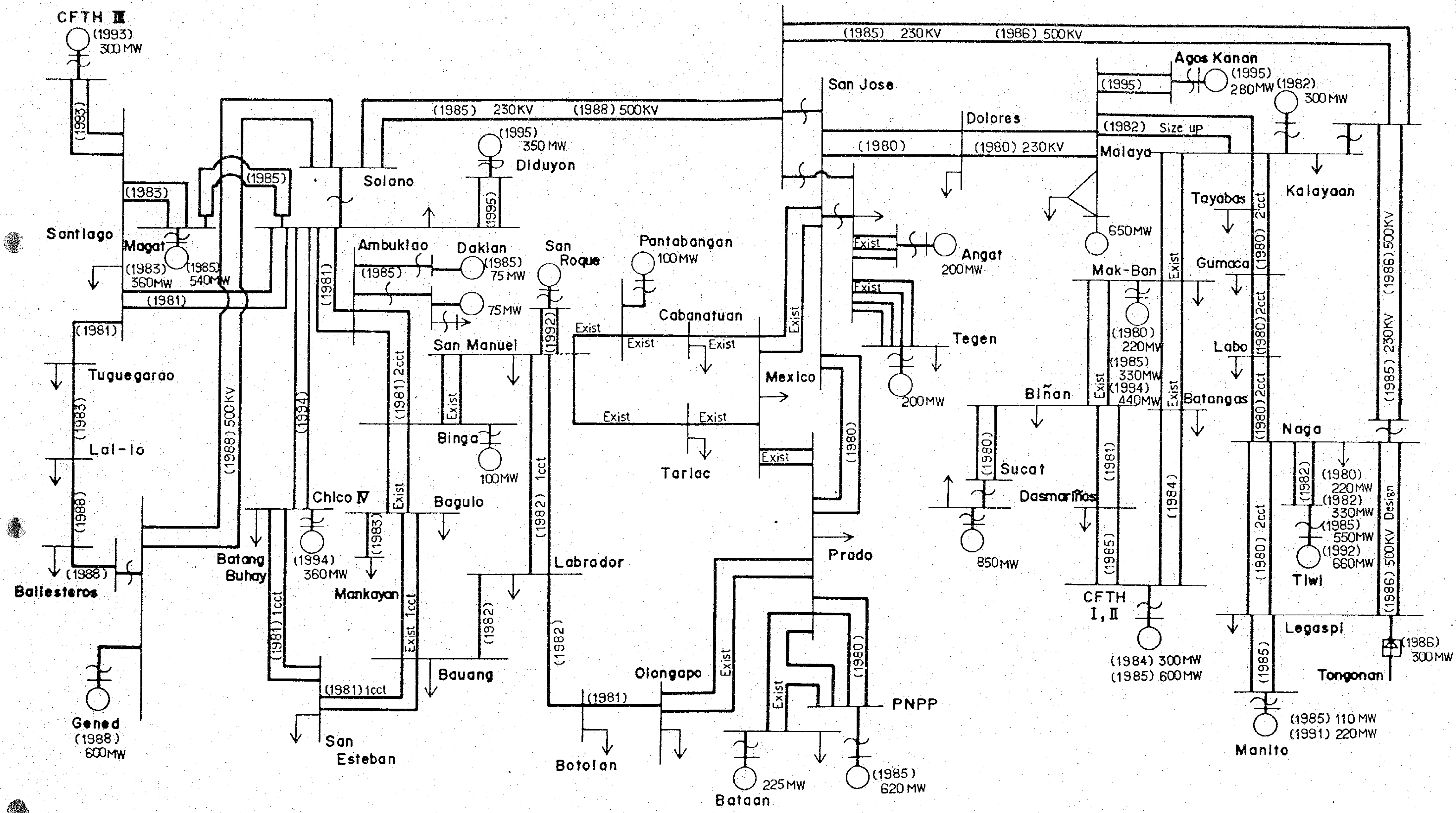
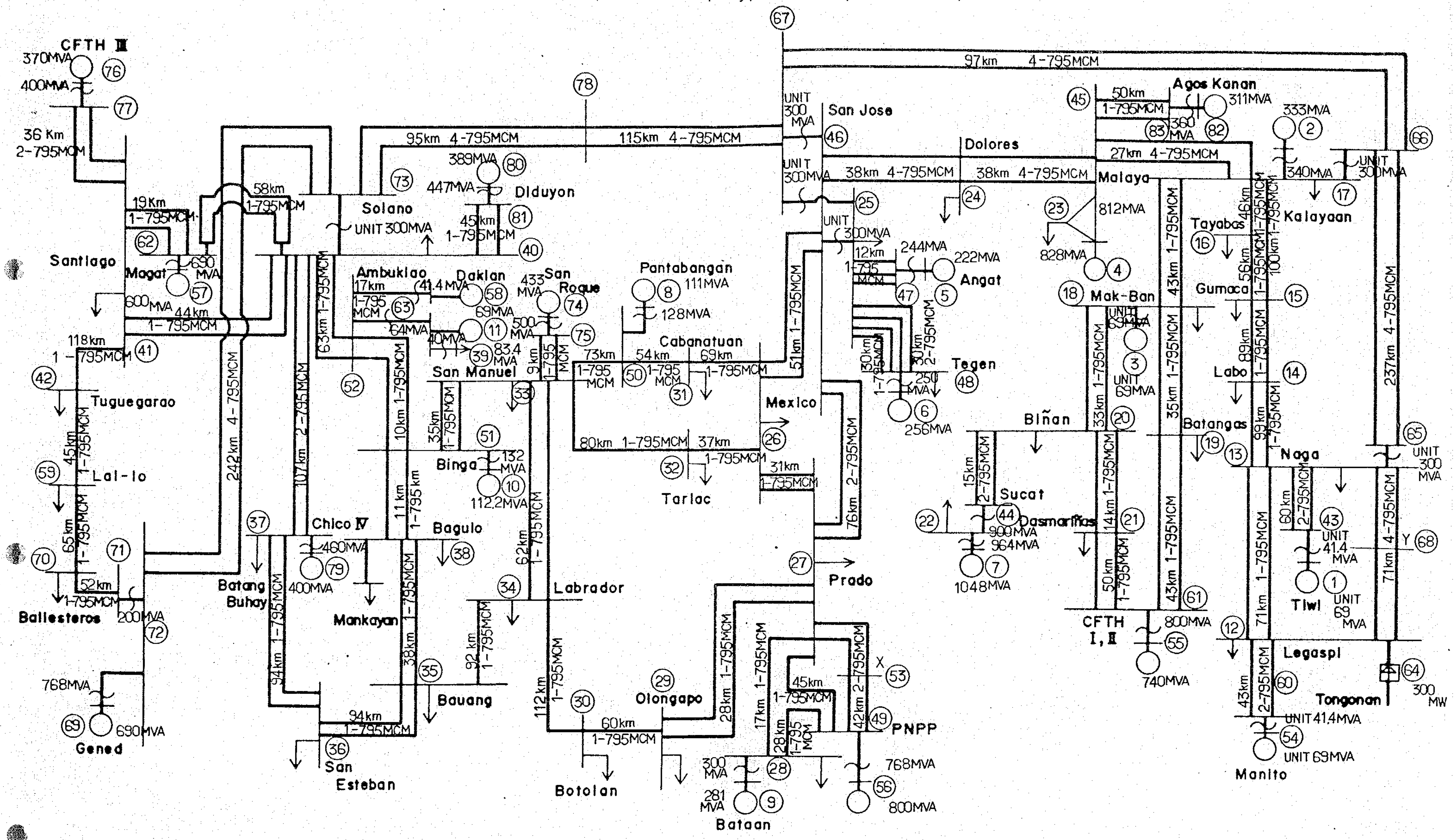


Fig 6.3 Luzon Grid Single Line Diagram

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



Note:
$\frac{R + jx}{Y/2 \times 2}$: on 100 MVA Basis
H, x'd, x''d : on Own Basis

Fig 6.4 Luzon Grid Single Line Diagram

Impedance Map

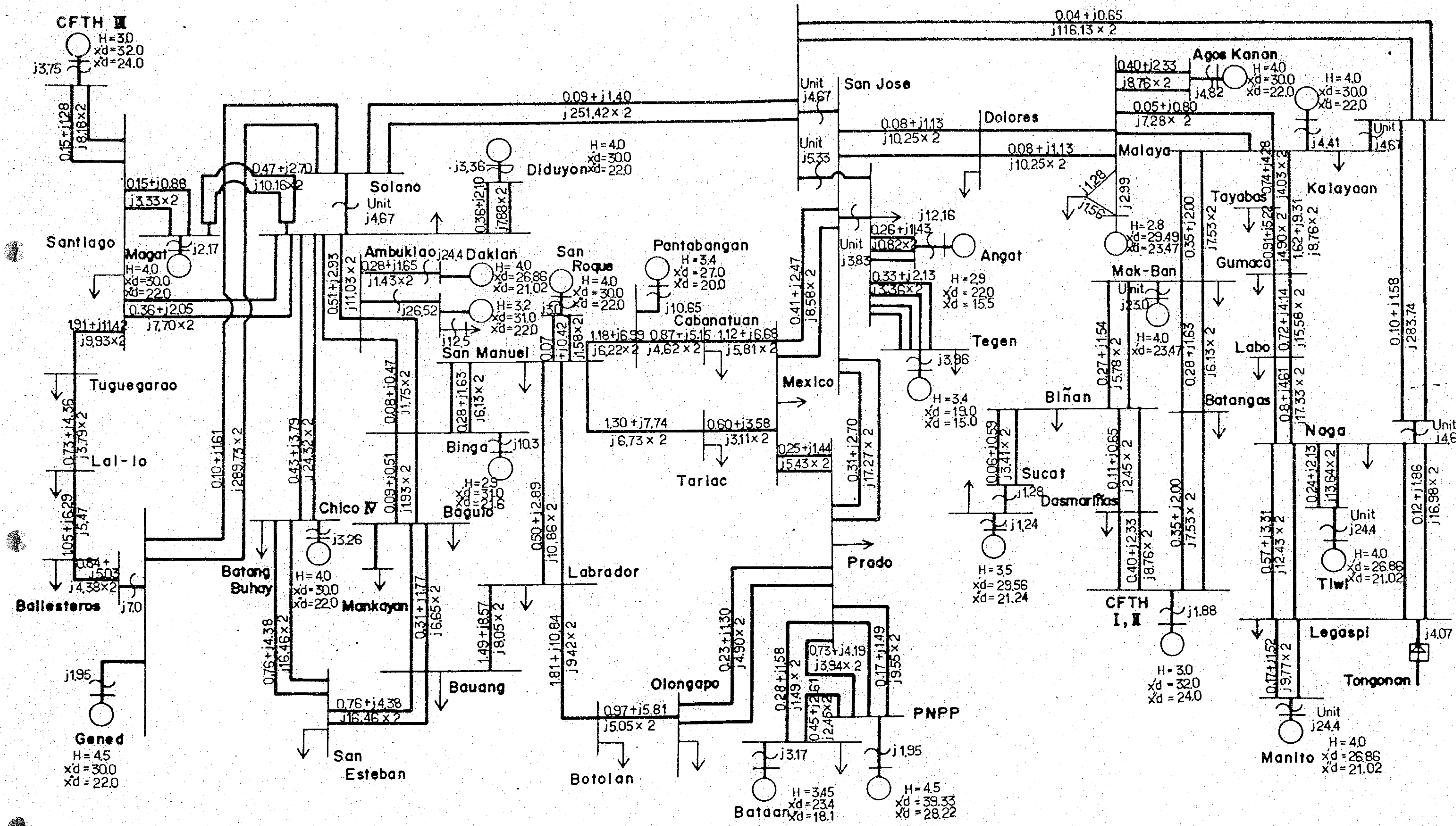


Fig 7.1 Luzon Grid Single Line Diagram

Case A

1982 Peak Power Flow

X : Not Completed

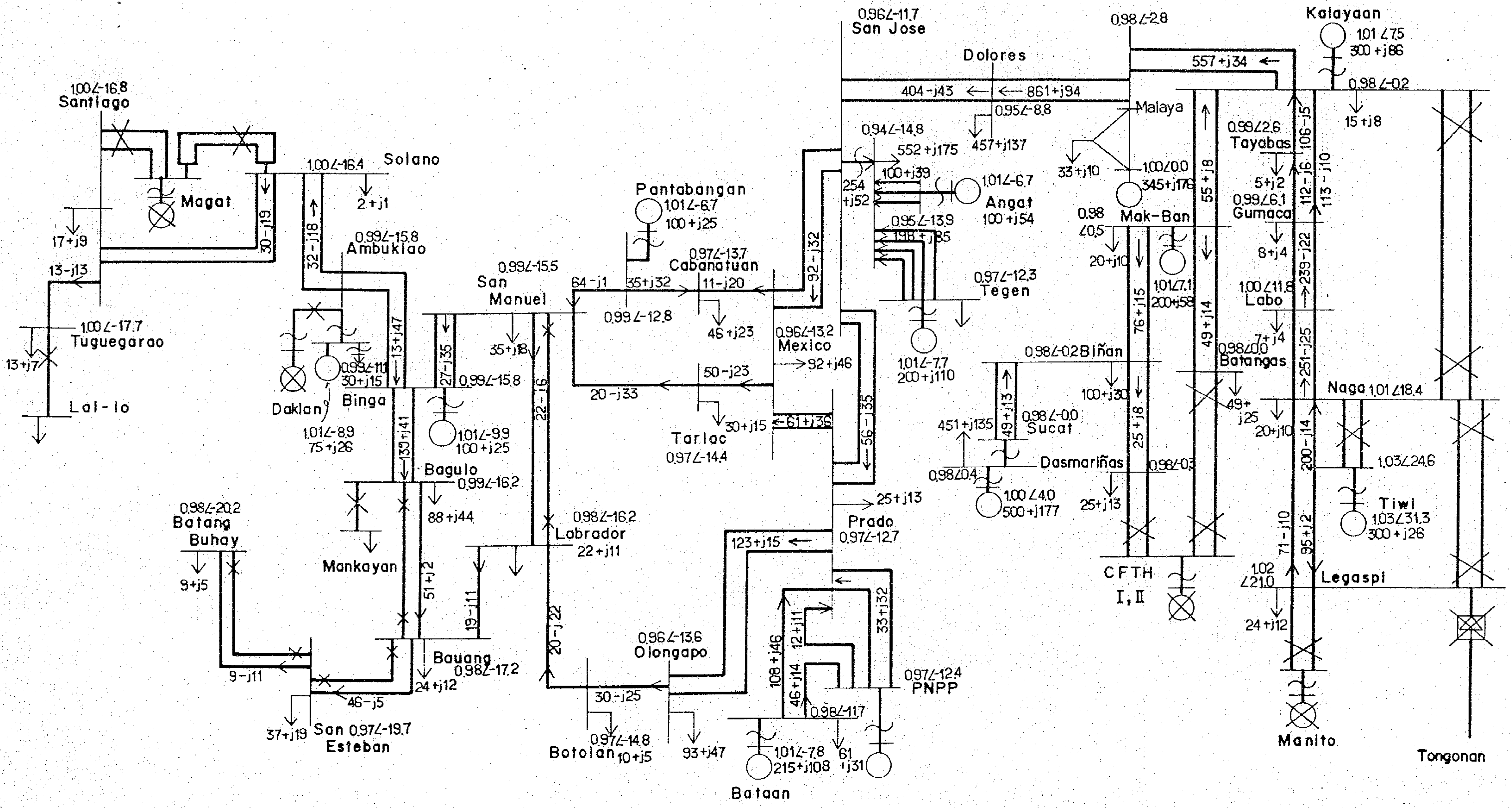


Fig 7.2 Luzon Grid Single Line Diagram

Case B

1982 Peak Power Flow

X : Not Completed

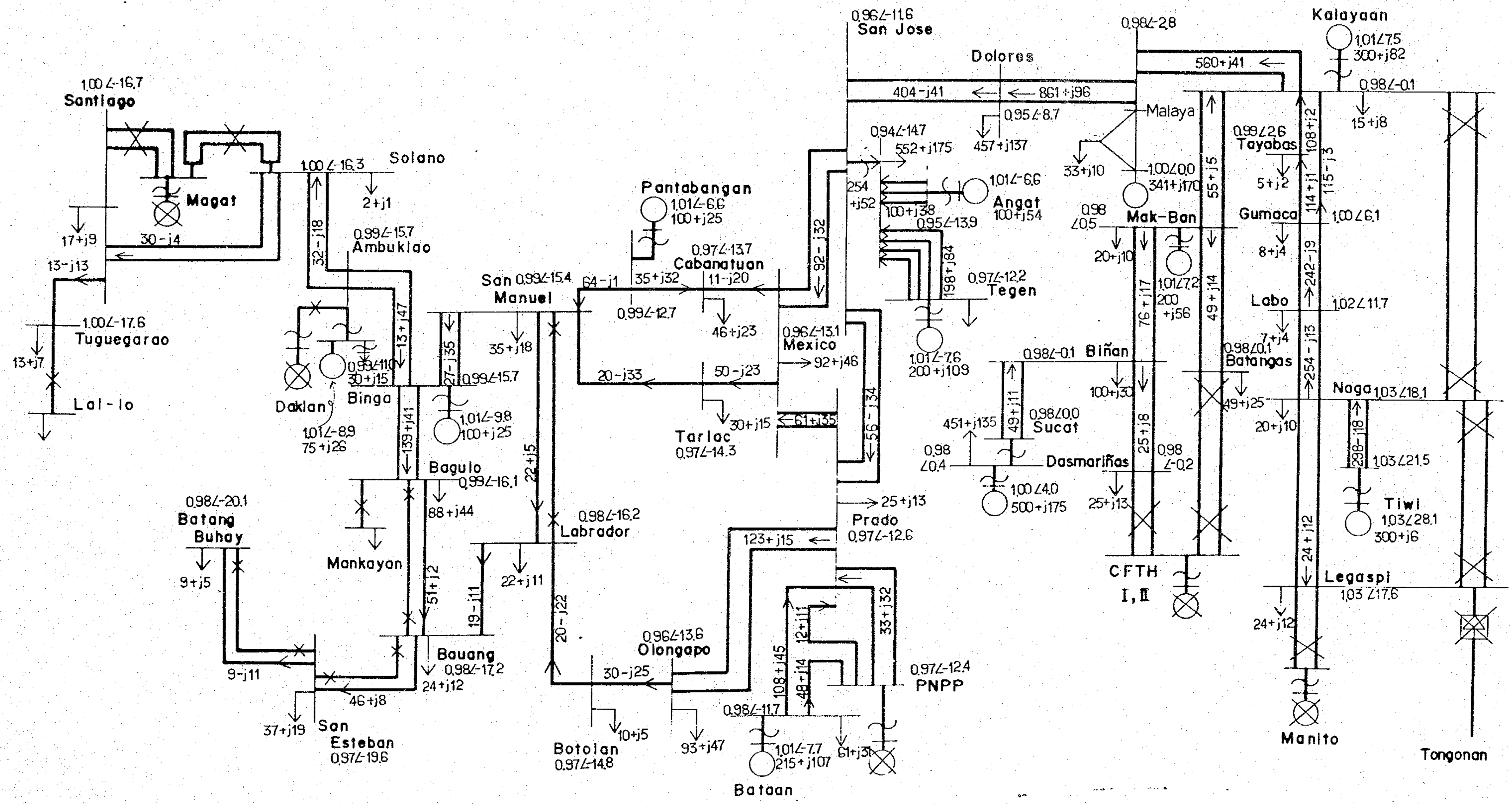


Fig 7.3 Luzon Grid Single Line Diagram

Case C, D 1985 Peak Power Flow

× : Not Commissioned

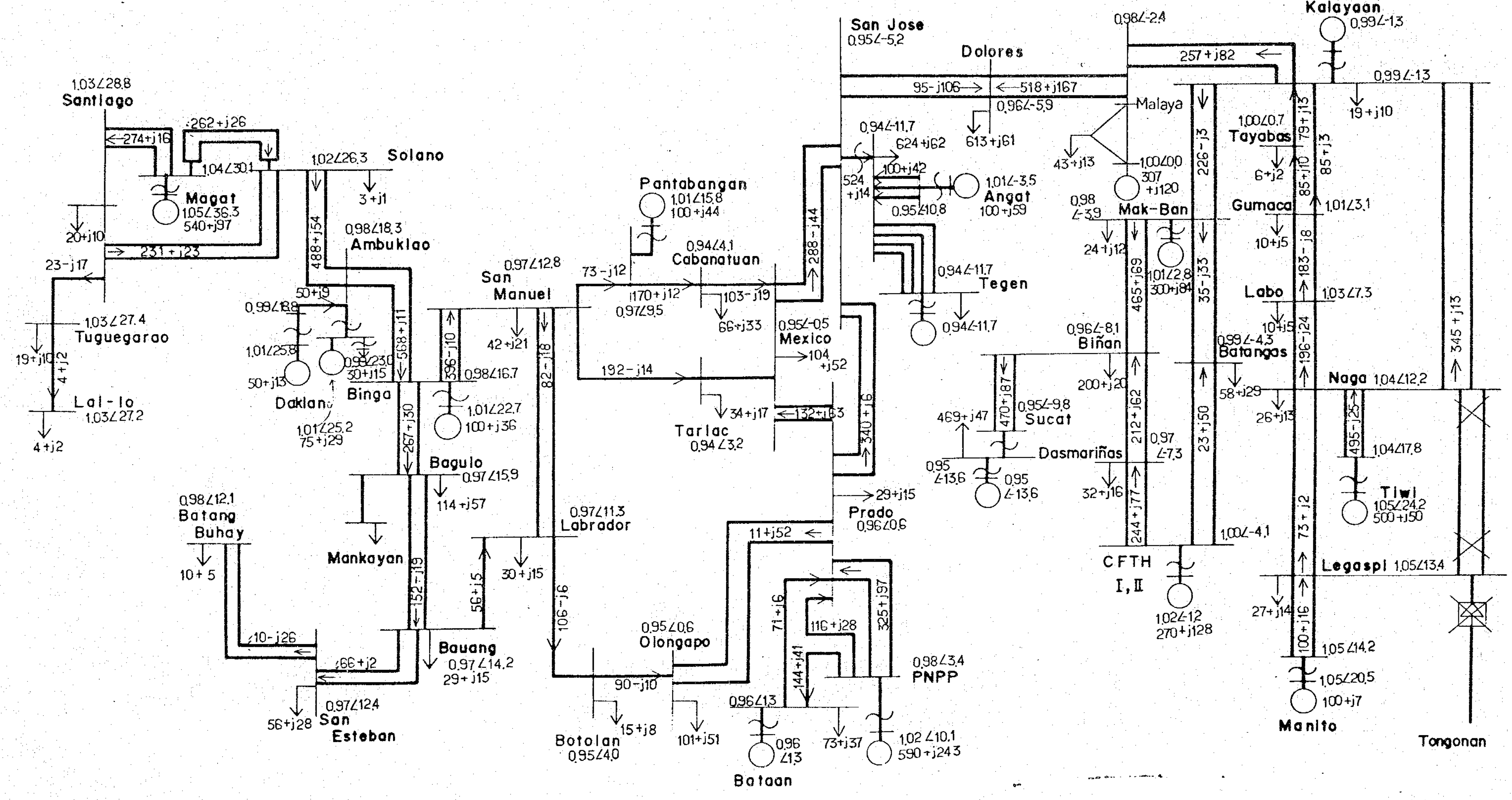


Fig 7.4 Luzon Grid Single Line Diagram

Case E 1986 Peak Power Flow

⨯: Normal open

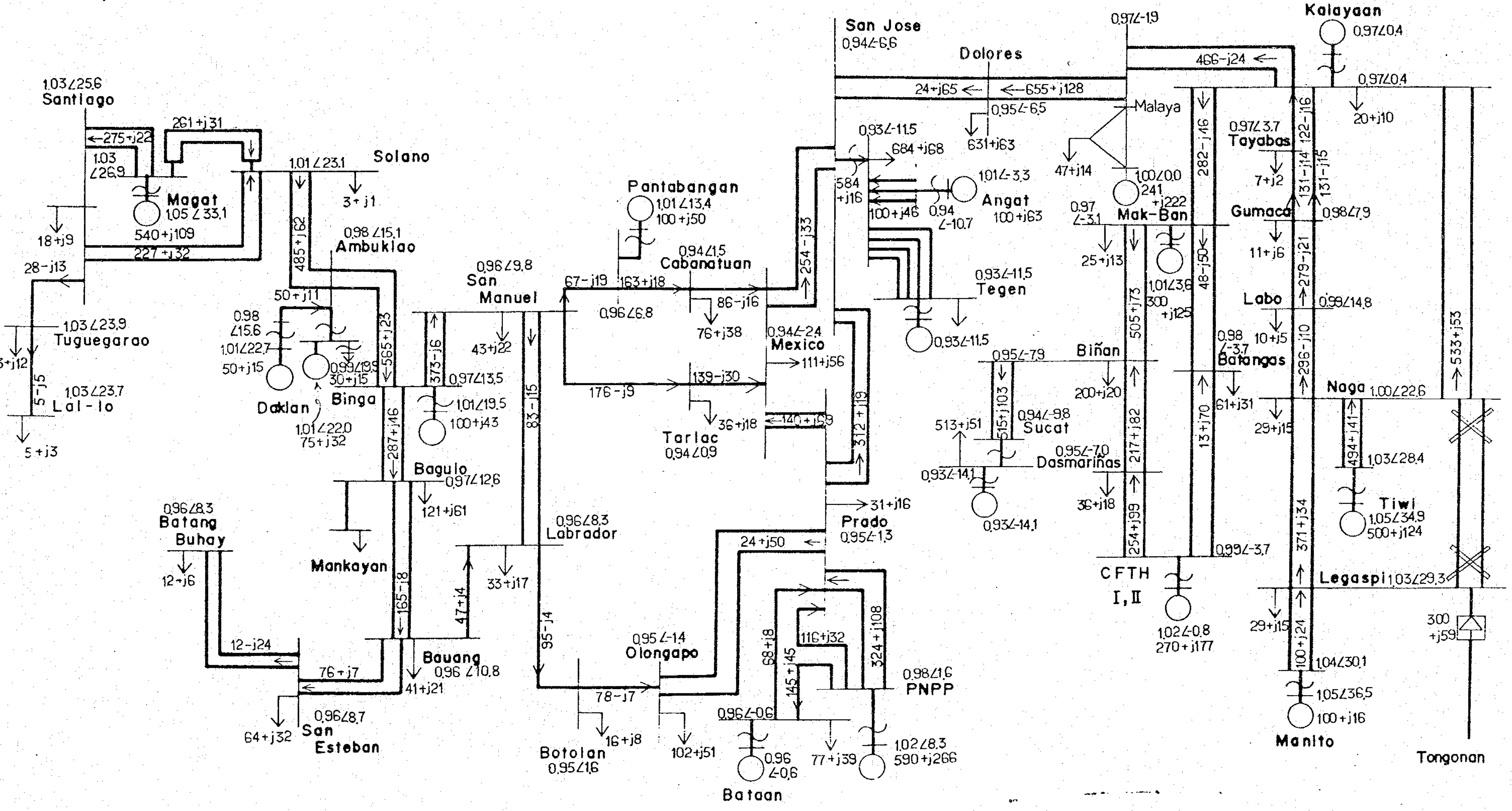


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Fig 7.5 Luzon Grid Single Line Diagram

Case F 1988 Peak Power Flow

✕ : Normal open

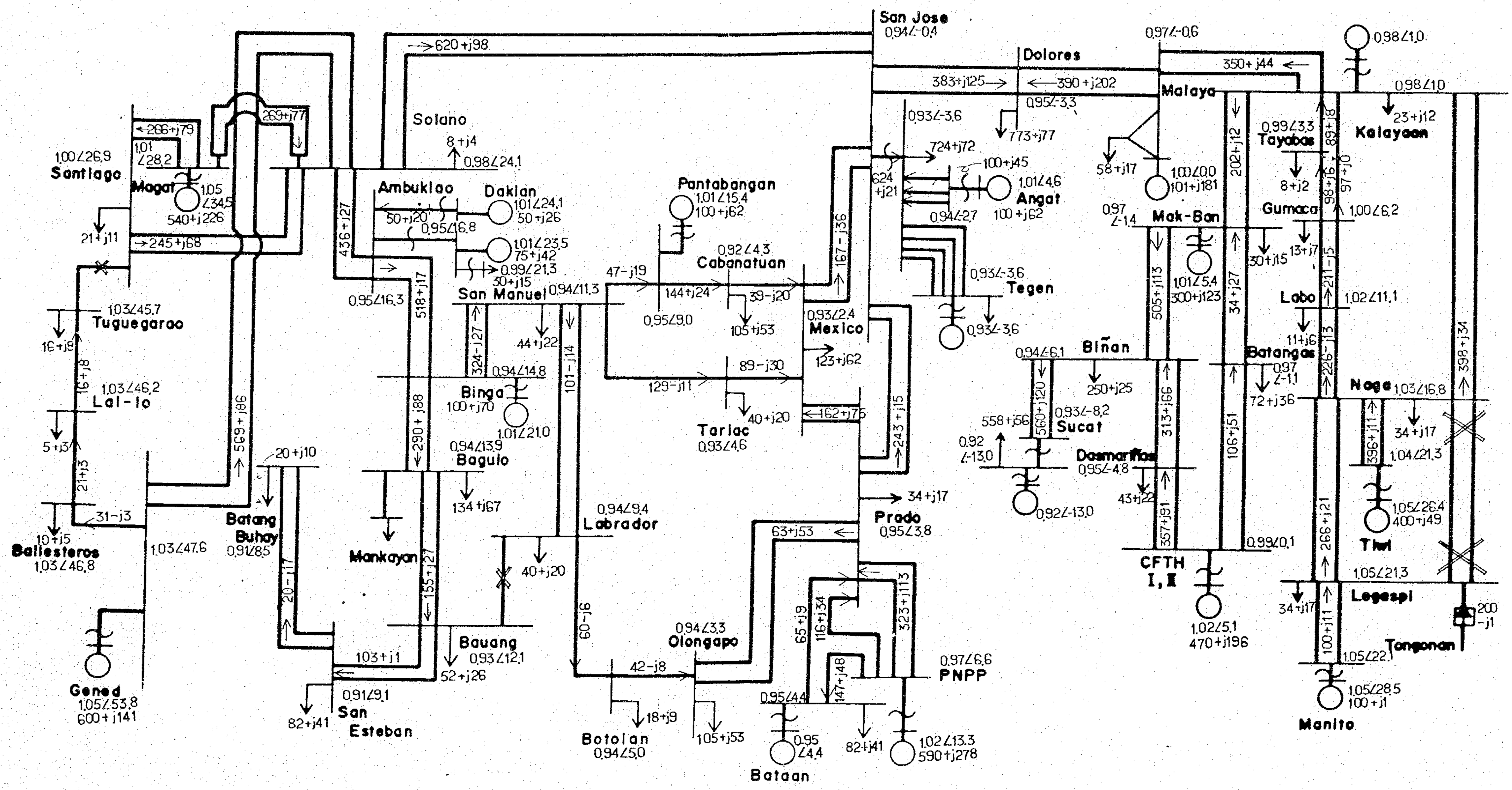

Fig 7.6 Luzon Grid Single Line Diagram

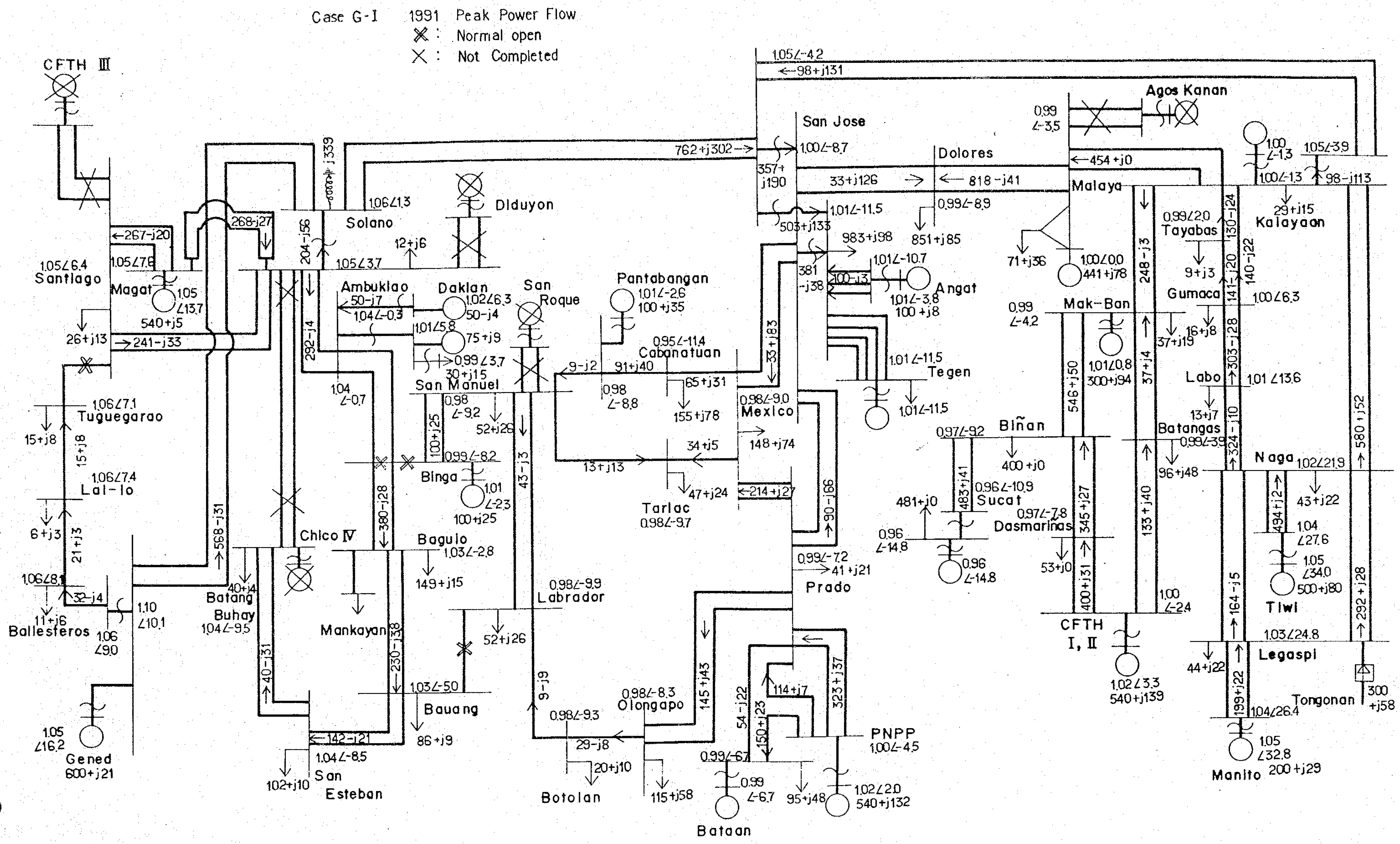

Fig 7.7 Luzon Grid Single Line Diagram

Case G-II 1992 Peak Power Flow

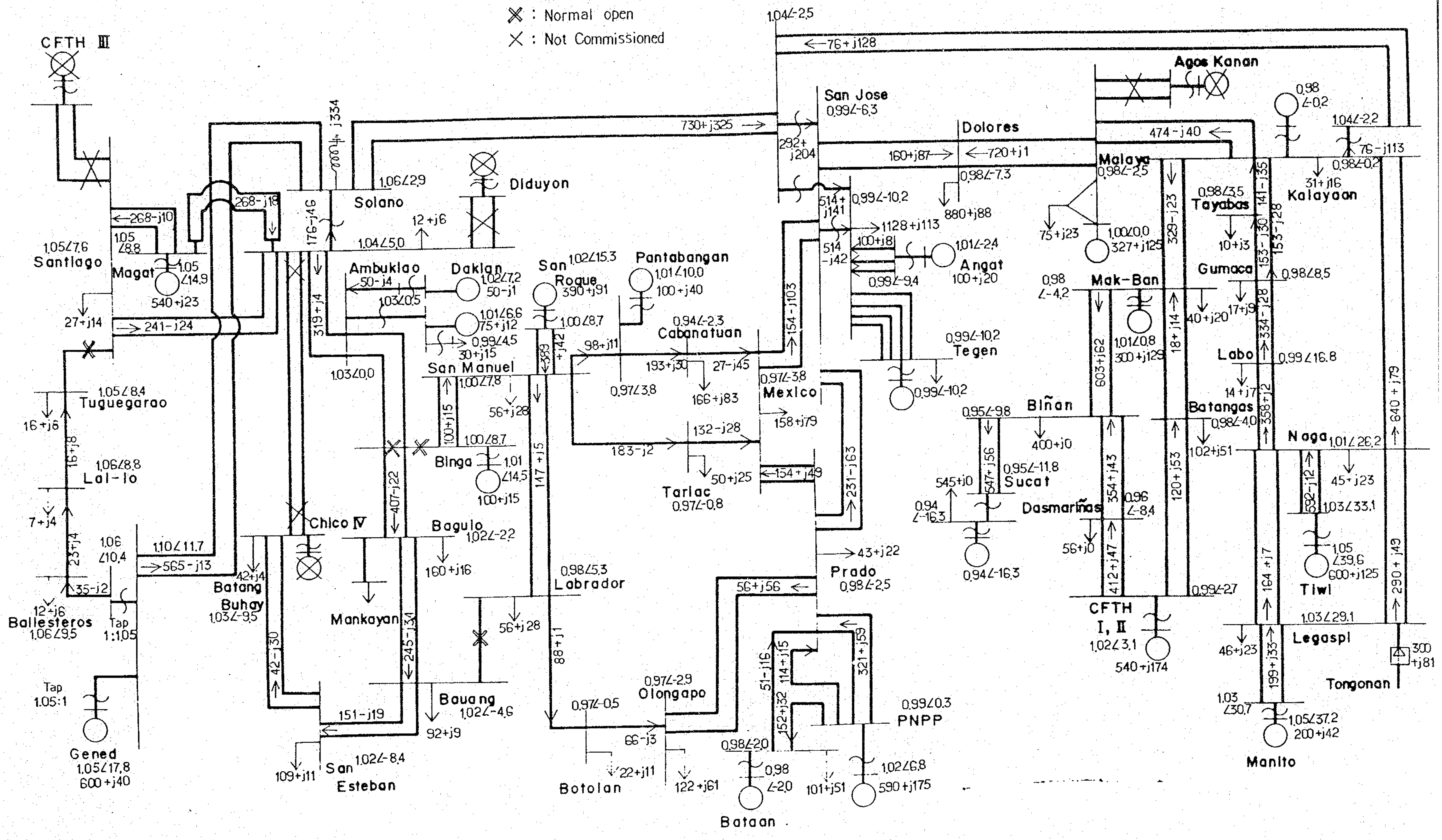

Fig 7.8 Luzon Grid Single Line Diagram

Case H, K-I 1995 Peak Power Flow

※ : Normal Open

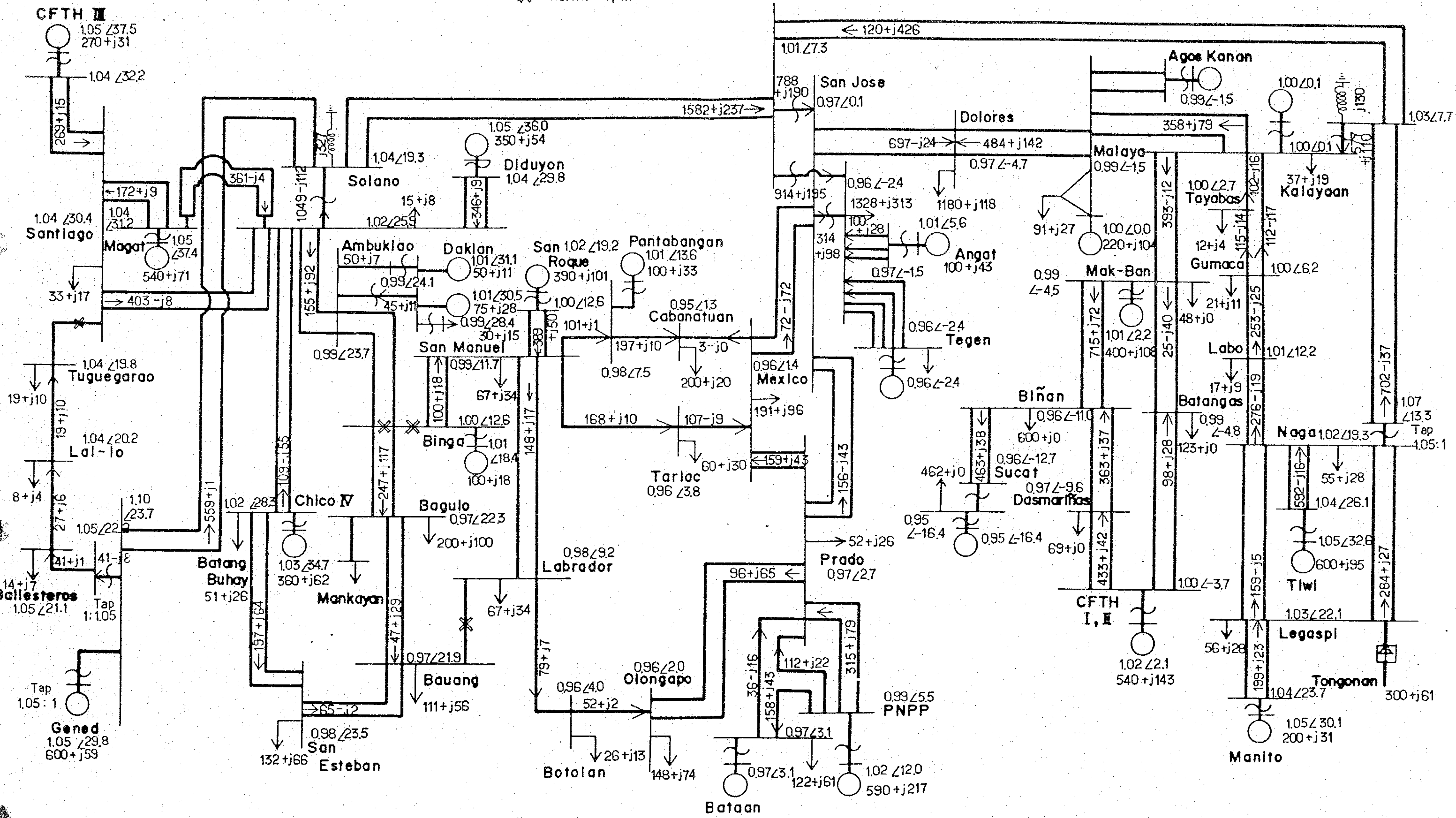

Fig 7.9 Luzon Grid Single Line Diagram

1995 Night Power Flow

✕ : Normal open

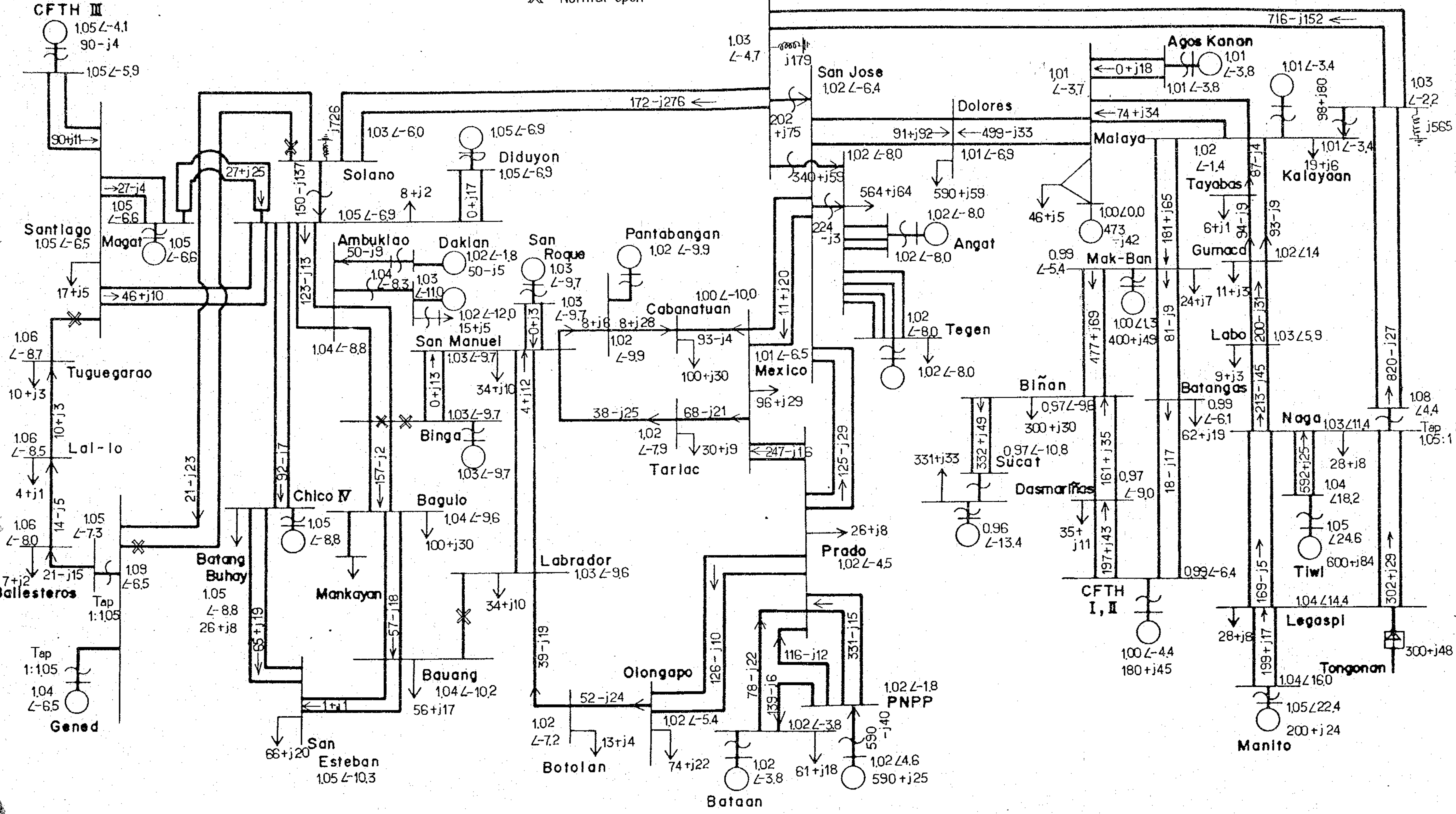

Fig 7.10 Luzon Grid Single Line Diagram

(Unit MVA)

1995 Fault Level

X : Normal open

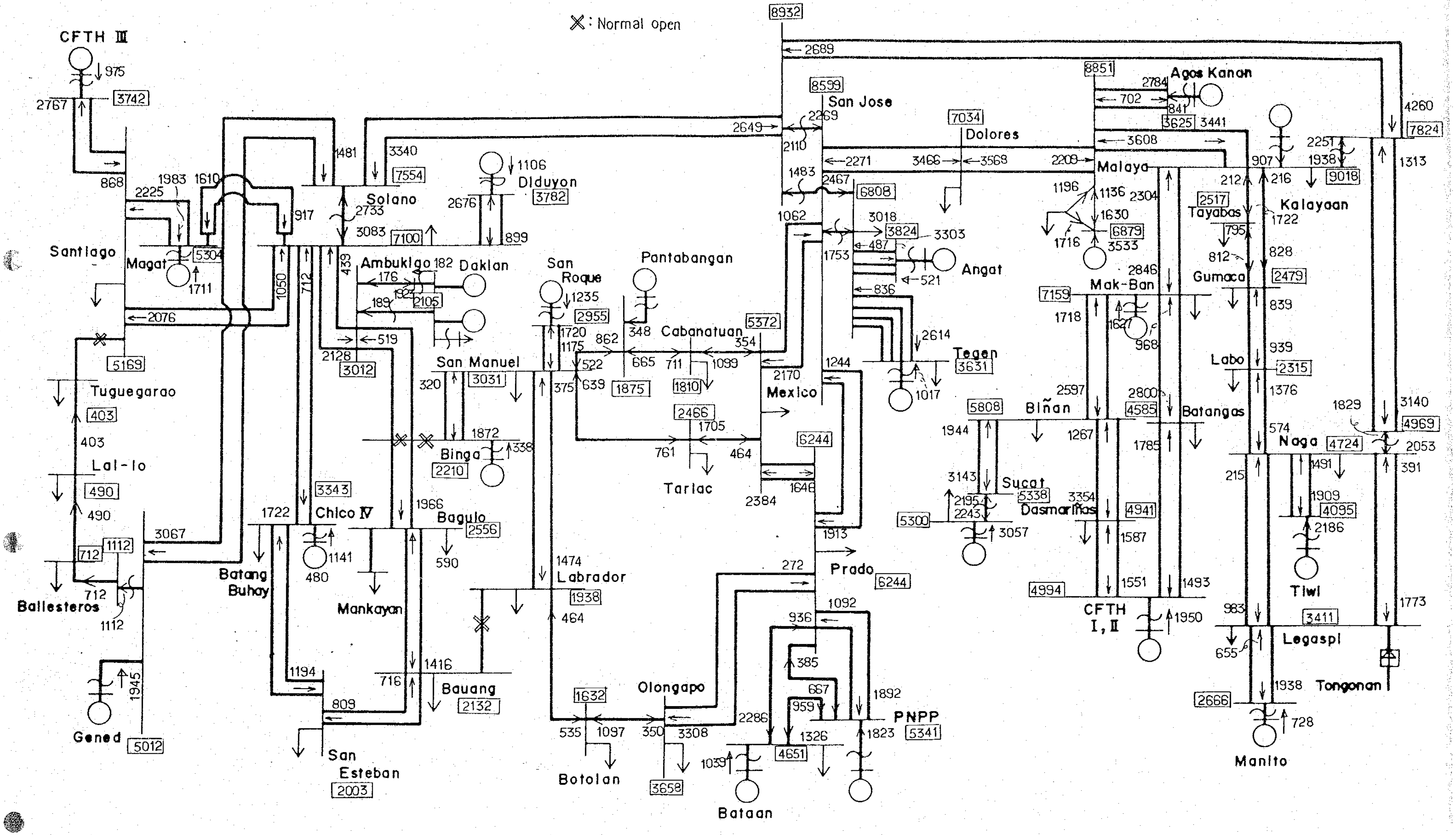

Fig 8.1 Luzon Grid Single Line Diagram

Final Expansion Program

Changed from Initial Program