No. 4

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

INSTITUTO ECUATORIANO DE ELECTRIFICACION (INECEL)
THE REPUBLIC OF ECUADOR

STUDY
ON
SERVICE RELIABILITY IMPROVEMENT PROJECT
OF
NATIONAL INTERCONNECTED SYSTEM (SNI)

FINAL REPORT

SUMMARY

JULY 1994

ELECTRIC POWER DEVELOPMENT CO., LTD.

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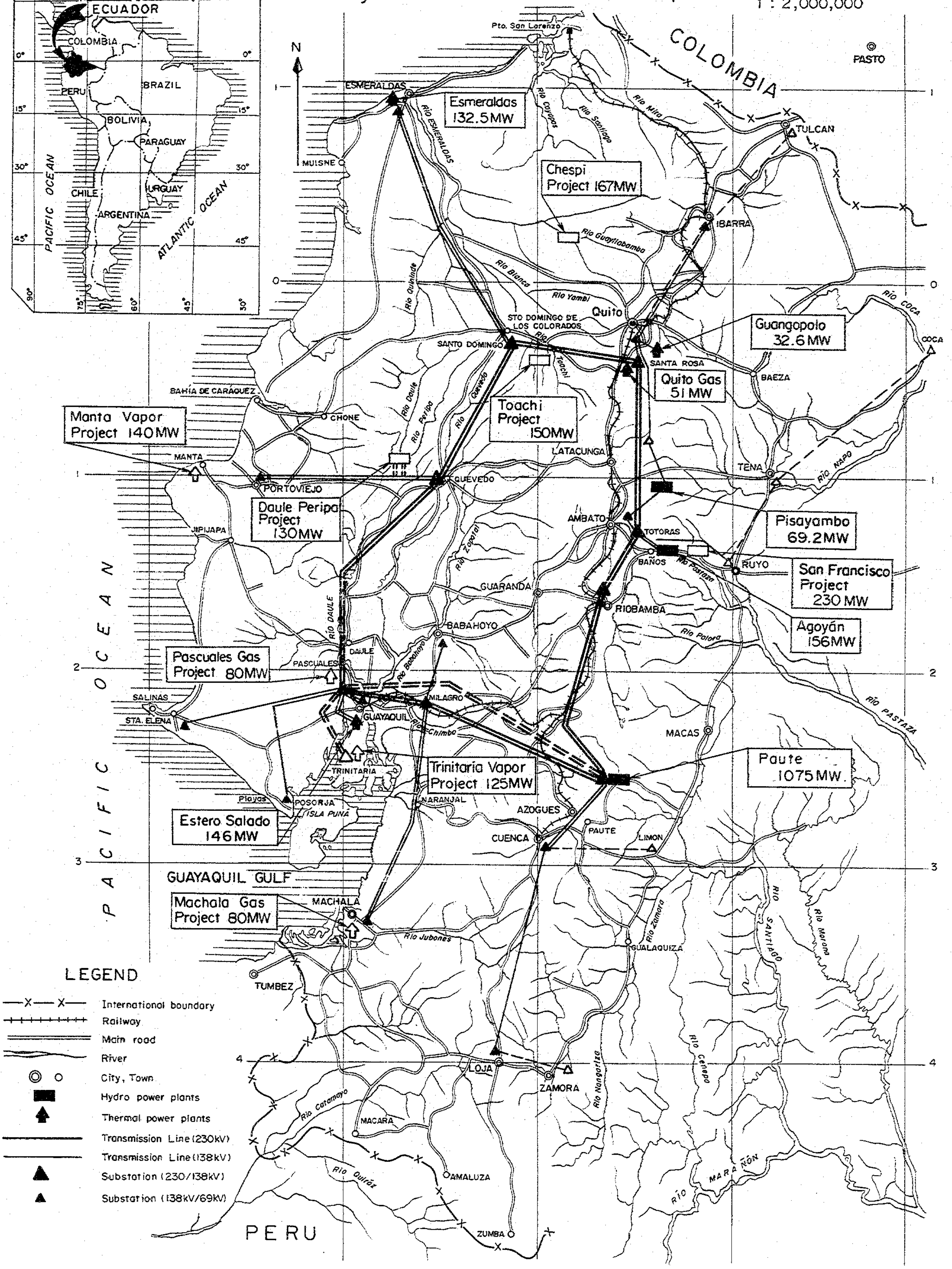
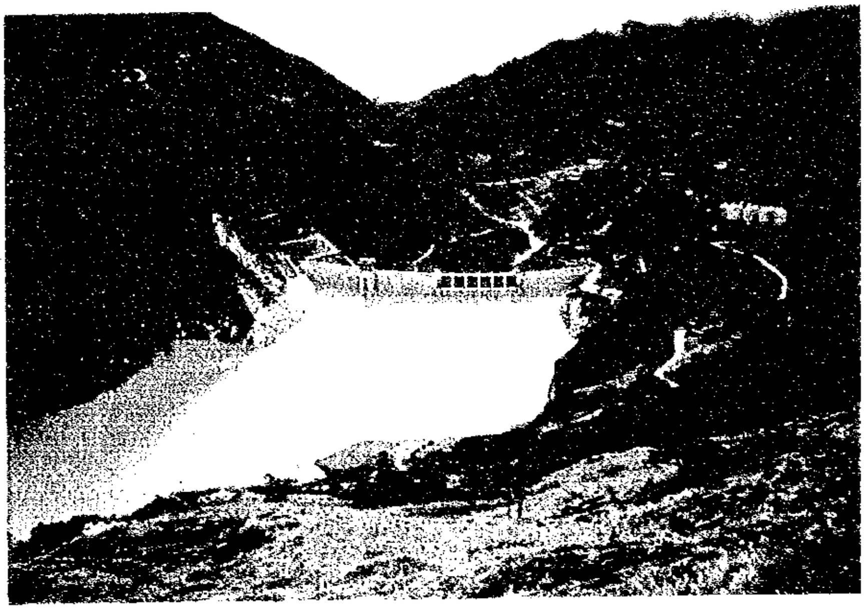
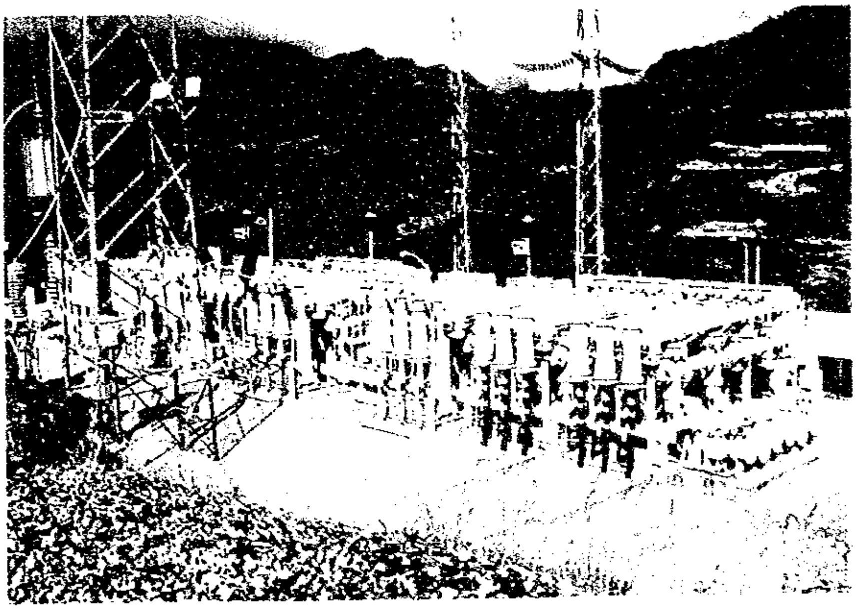
Key and S. N. I. Location map

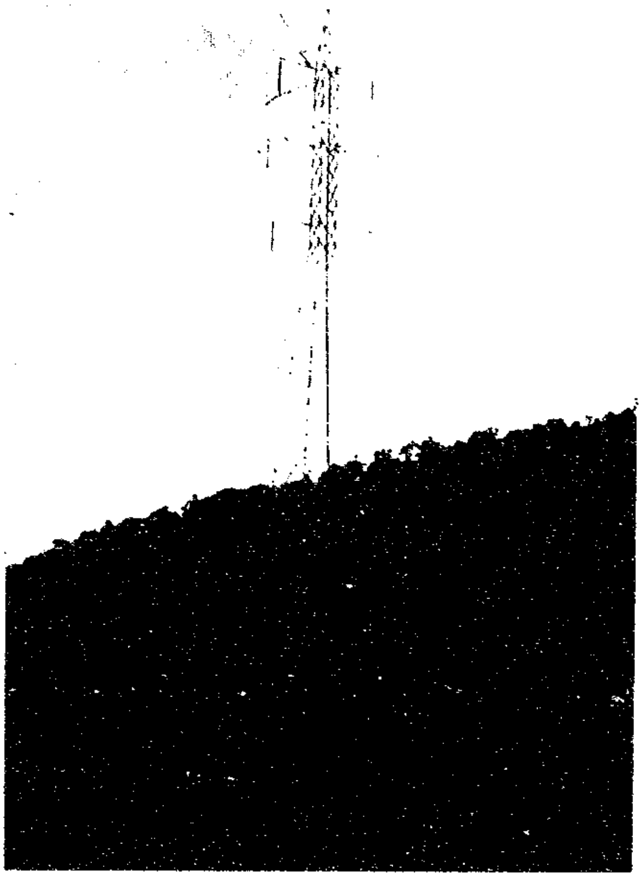




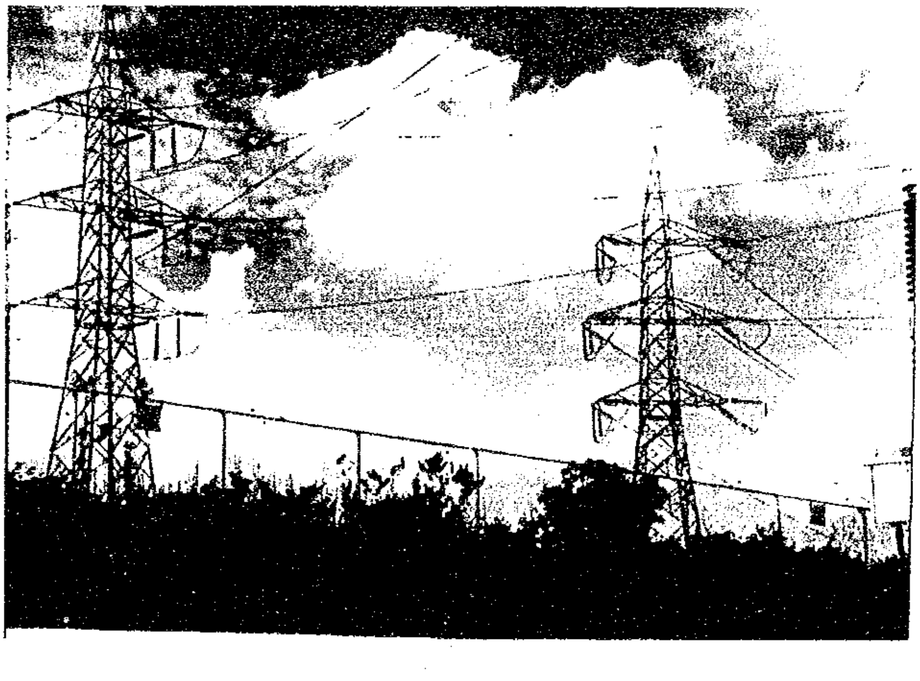
Reservoir of Paute Power Plant of SNI



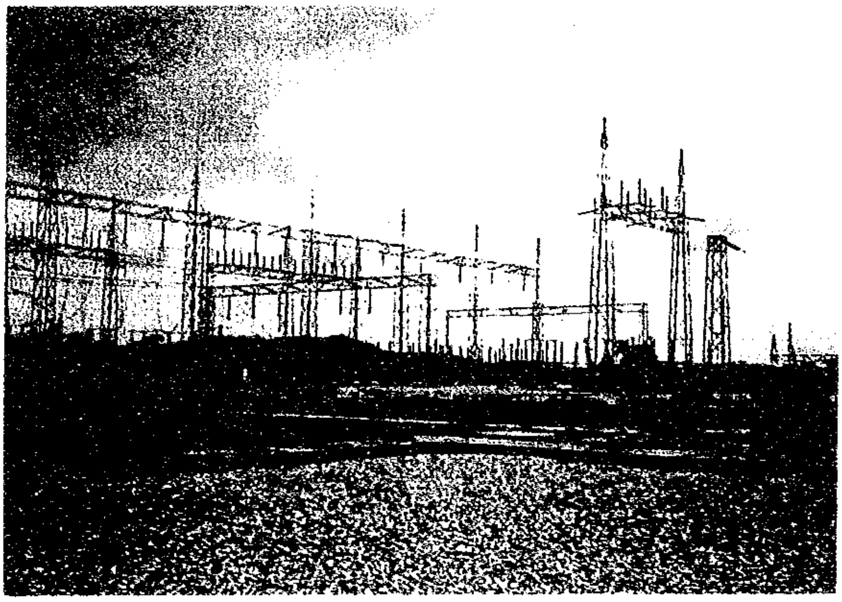
Out door substation of Paute Power Plant of SNI



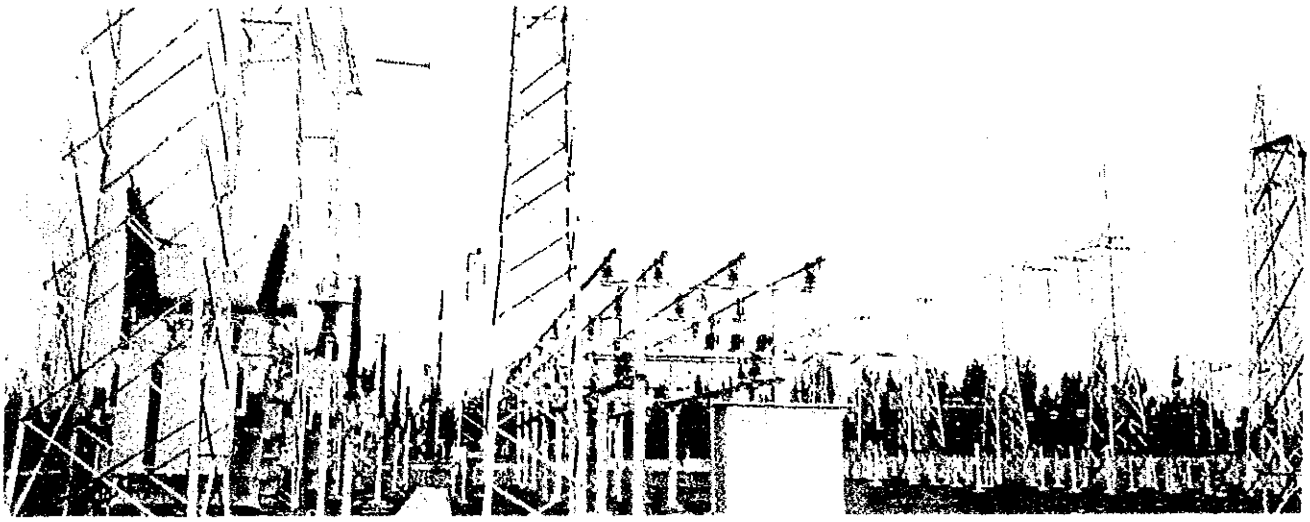
230 kV Transmission Line of SNI



230 kV Transmission Line of SNI
(The suburbs of Quito city)

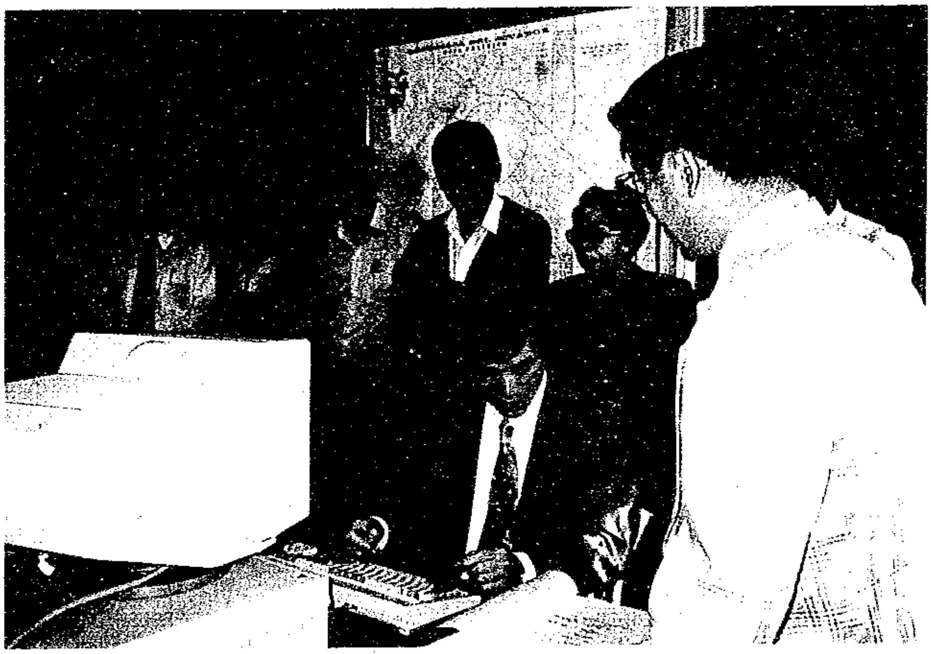


Pascuales Substation (230 kV)
(Guayaquil city)



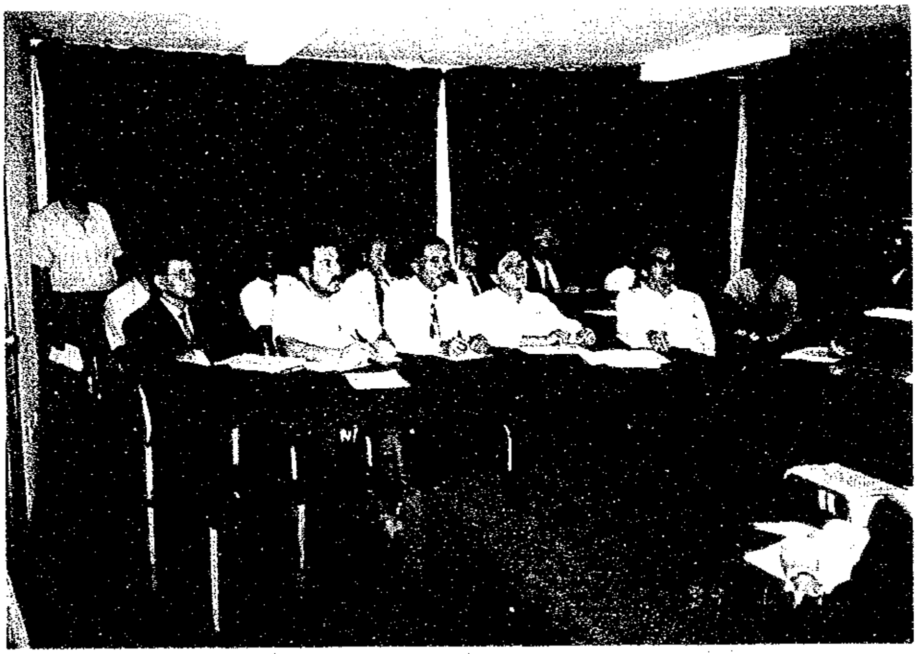
Totoras Substation (230 kV)

Technical Transfer
(Application of a personal computer and
Software donated by JICA)



Technical Transfer
(Operation of a personal computer and
Software donated by JICA)

Seminar of Technical Transfer



Seminar of Technical Transfer

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CONCLUSION AND RECOMMENDATIONS

1. CONCLUSION

1.1 Conditions of Electricity

1.1.1 Power generation Facility

As of January, 1993, there are 2,278.2MW power generation facilities in SNI. Classified by corporation, INECEL generates 74.26% with local electric power companies generating 25.74%. Classified by power generation type, hydro power plants generate 64.5% with thermal power plants generating 35.5%.

The total power generation facility output increased approx. 4 times over the 10 years 1971/1981 and increased approx. 2.2 times in the 10 years 1981/1991.

As waterflow decreases in Ecuador during the dry season from November to February, the secured output of the hydro power plants drops to 1,209.4MW against a facility output of 1,470.1MW.

Also, the potential output of the thermal power plants has declined to 583.2MW against a facility output of 808.1MW due to inadequate maintenance. This provides a max. potential power generation of 1,792.6MW throughout the entire SNI, which is equivalent to 78.7% of the total facility output.

Ecuador's electricity consumption peaks in December. However, December's rainfall is very slight and the subsequent power shortfall provides a serious problem.

The Paute Hydro Power Plant is the main hydro power plant in SNI. This plant has a facility output of 1,075MW, representing 47% of the total SNI facility output (2,278.2MW), or 73% of that of the whole hydro power generation facility.

The potential power generation energy is 5,366.9GWh which is 50% of the total potential generation capacity, or 71% of the potential hydro power generation energy. Therefore, the total supply capacity of the SNI depends on the Paute Hydro Power Plant so much.

The effective reservoir capacity of the Paute Hydro Power Plant is 100,000,000m^3. (90,000,000m^3 as of the end of 1992) This is enough for 122 hours or approx. 5 days operation only, assuming the plant is operated at a total facility output of 1,075MW.

Approximately 3 million cubic meters of sedimentation accumulates every year within the dam. A dredging vessel (min. removal capacity/year; 500,000m^3 or 150m^3/h) has been operated since 1991 and removes approx. 1 million cubic meters of sediment annually. Thus, supply shortage (kW and kWh) in the dry season becomes a serious problem.

The major hydro power generation facilities belong to the Paute, Agoyán, and Pisayambo hydro power plants, all of which are located at the upstream reaches of the Amazon River. Their locations are concentrated and it is, therefore, necessary to disperse the plants appropriately throughout SNI. Such dispersal would (a) eliminate supply shortages during drought periods, (b) ensure power supply despite facility failure, and (c) increase transmission facilities to ensure supply not only under normal conditions, but also in the case of accidents.

In the majority of instances, the thermal power generation facilities are old. Adequate repair and maintenance have not been conducted due to shortages of auxiliary parts, thereby disabling the retention of sufficient facility output.

In the case of facilities owned by local electric companies, the related companies plan to carry out recovery measures in the near future.

Also, some gas turbine power plants such as Electro Quil (25MW x 1, 50MW x 1) and Electro Quito (33MW x 1) are under construction. These will be operated by a new company in 1993. These new power plants are countermeasures against power shortage due to the abnormally inadequate rainfall of 1992.

1.1.2 Power Transmission and Substation Facility

The electric system is installed as the SNI for the nationwide operation by INECEL. A loop of 230kV transmission lines form the trunk transmission network. A 138kV line links to the power stations or the local transmission lines.

There are 7 main substations with 230kV in SNI. Its total facility capacity is 1,451MVA, as of the end of 1992.

The facility capacity of the 138kV substations linked to these 7 substations is 1,618MVA. Each of three main substations with 230kV (Pascuales, Santa Rosa, Totoras) is equipped with one single phase auxiliary transformer. The Milagro, Sto. Domingo, and Quevedo substations share one single phase auxiliary unit. The Riobamba Substation, however, only has three single phase transformers with no auxiliary units. Of the substations with 138kV lines, the Santa Elena, Ibarra, and Loja substations have 3 phase autotransformers, sharing one auxiliary unit.

Since the demand for 138kV substations has increased, it is now time to consider installation of new units, including auxiliary units.

The routes of the 230kV and 138kV transmission lines forming the SNI are varied; a highly contaminated area along the Pacific coast, a high temperature/high humidity zone, along a large scale agricultural area in a tropical climate zone, and a mountainous area. Different maintenance methods are required for each area because the types of accident vary according to the local conditions.

1.2 Assumption of Demand for Electricity and Supply Plan

1.2.1 Demand Assumption

INECEL prepared long term demand assumption to the year 2010. In this study, we assumed the overall demand from a correlation between power consumption per capita and the economic growth ratio. Consequently, our assumed value was lower than INECEL's as a whole. However, ours did match the INECEL's relatively. Therefore, we use the INECEL's assumed demand, considering the margin for the demand/supply balance plan.

According to the assumed demand, the demand of 1,442MW (7,422GWh) of 1992 is expected to reach 1,991MW (10,462GWh) in 1998, and 2,595MW (13,654GWh) in the year 2003.

1.2.2 Power Supply Plan

As the result of this study, the firm output at the time cross section is 1,784MW (with the total install capacity of 2,278.2MW) as against the maximum demand of 1,442MW, and there is sufficient supply margin so long as the kW balance is concerned.

Concerning the annual kWh balance, however, the firm energy supply at the time cross section of 1992 is 6,875GWh, as against the maximum energy demand of 7,442GWh, that is, a supply shortage is excepted under INECEL's expansion plan. To deal with this situation, base thermal power plants such as Vapor will be required. However, this shortage have to be covered by gas thermal power plants which can be constructed with short lead time, and INECEL plans to construct gas thermal power plants in 1993 and 1994. There is no alternative to this plan in view of the short lead time.

The supply shortage in the kWh balance will continue after 1995. In dealing with the expected power supply shortage, INECEL's expansion plan is indispensable, and this plan must be implemented without delay. In addition to this plan, it will be required to construct a base thermal plant having 125MW capacity or so to supply additional kWh in 1997.

1.3 Power System Analysis

Although there was no particular problem with the short circuit current level and the overloading of transmission lines and transformers at each time section year of studies, concerning the operating voltage conditions in the 1993 time section, the operating voltage at a few substations in the northern region did not fell within the allowable range. Although the power system was stable in the 1993 time section, the system was near the stability limit.

In the study of 1993 time section, analytical studies were conducted on the actual power flow record at March time section. Even with no particular countermeasure, the above problems would be alleviated in 1998 and 2003 time sections as the transmission line from Paute to Pascuales is reinforced to 4 circuits, and the power development projects near Guayaquil and in the northern region are implemented according to INECEL's plan. And also Paute power station can operate nearly at the full output in June, the rainy season.

Year/Month	Output of Paute (MW)	Stability	
		1 cct	2 cct
1998. 6	1,008	O	X
	954	O	O
1998.12	915	O	O
2003. 6	954	O	X
	897	O	O
2003.12	798	O	O

However, some transformer tap changers (OLTC) and phase compensating condensers will be required in some substations in the northern region power system in 1998 and 2003 time sections in order to maintain voltage in steady state operations.

1.4 Supply Reliability Analysis

(1) LOLP 0.3 days/month of Supply Reliability will be secured up to 2003.

(2) An accumulation of data is not enough to make the most of software donated by JICA.

(3) Paute Hydroelectric Power Plant is a large scale hydroelectric power supply resource which accounts for 47% (1,075MW) of the total installed capacity of SNI of 2,279MW. And it has much influence on Supply Reliability. The outline of this hydroelectric power plant is as described below.

	Rated Output (MW)	Number of Units	Firm Output and Energy (MW)	(GWh)	Record of Energy Generation	Year of Commis-sioning
Paute (Phase A&B)	500.0	5	438.5	2,456.7	3,481.8	1983
Paute (Phase C)	575.0	5	459.4	-	1,883.0	1992
Total	1,075.0	10	897.9	2,456.7	5,364.8	-

The proportions of the supplies of Paute Hydroelectric Power Plant in the total power supply of SNI are calculated based on the 1993 data for the dry season and presented below, together with the actual records of generation.

The total supply of SNI in 1993

Maximum power (MW): 1,532.0

Maximum energy (GWh): 7,868.0

The proportions of Paute in dry season and by actual records:

	Dry season	Actual record
For maximum power:	59%	70%
For maximum energy:	31%	68%

According to these data, the kW output in the dry season is short of actual record by 11% or a little less than 170MW, and the energy output in the dry season is short of actual record by 37% or a 2,900GWh. The shortage of 2,900GWh is equivalent to a thermal power plant of 330MW.

1.5 Load Dispatching Function and Protective Relay Systems

1.5.1 Load Dispatching Function

The load dispatching function is indispensable for systematic and efficient operation of power system, and the comprehensiveness of power system monitoring performance and promptness of response against power facility failures are the key factor in maintaining high supply reliability.

In attaining high supply reliability by load dispatching operations, suitable load dispatching organization and the automatic load dispatching systems supporting the dispatching operations are indispensable. Judging from the scale of the power system of SNI, a load dispatching organization having the central load dispatching office at Santa Rosa Substation premises at the top would be satisfactory. Concerning the automatic load dispatching systems, a system incorporating the first large scale computer in Ecuador is currently under construction, and this system is scheduled for commissioning in December, 1994. Although it is expected that more efficient load dispatching is expected with this system, the information transmission systems supplying this computer system as well as the load dispatching telephone lines will not be changed from the existing PLC systems, and this may leave some problems.

1.5.2 Protective Relay Systems

In the power systems of SNI, appropriate protective relay systems are being employed according to specific power system configurations, transmission line voltage classes and specific conditions of application. Concerning the relay systems for the 230kV systems, which are basically composed of parallel double circuit lines, the directional comparison system employing power line carrier are used.

The 138kV transmission lines are basically radial systems having parallel double circuit lines and single circuit lines, with single circuit loop systems adopted in certain sections. The protective relay systems are basically distance relays, and directional comparison relays and over-current relays are used in some sections.

Based on the study of operations of protective relay systems, several cases of protective relay malfunctions which caused power system faults have been found in the power system fault records of 1992 and 1993.

Although the proportion of power system faults caused by protective relay malfunctions is small in the total system faults, the details of the relay malfunctions are not known, and it is important to clarify these causes and prevent recurrence of such events, in view of the role of protective relays.

The settings of protective relays have been surveyed, but there was no particular problem.

1.6 Power Facility Expansion Plan

1.6.1 Power Generation Facilities

It is recommended, as the JICA's plan for power generation facility expansion to supply the demand for the period from 1992 to 2005, to develop the following power plants in the sequence illustrated.

Project Name	Installed Capacity	Year of Commissioning
(1) T. Gas (Estero Salado)	30.9	1993
(2) Rehabilitation - Diesel	62.5	
(3) Rehabilitation - Bunker	49.2	
(4) T. Gas (Electro Quil)1)	75.0	
(5) T. Gas (Electro Quito)1)	33.0	
(6) T. Gas (Pascuales)	80.0	
(7) Rehabilitation (Estero Salado)	146.0	
(8) T. Gas (Machala)	80.0	1994
(9) T. Vapor (Trinitaria)	125.0	1995
(10) Duale Peripa2)	130.0	1996
(11) T. Vapor (Manta)	140.0	
(12) T. Vapor	125.0	1997
(13) San Francisco2)	230.0	1999
(14) T. Gas (Santa Rosa)	80.0	2000
(15) Mazar2)	180.0	2001
(16) Toachi2)	150.0	2003
(17) T. Vapor (Santa Elena)	125.0	2004

Note: 1); Private power company facility, 2); hydroelectric power plant

1.6.2 Transmission and Substation Facilities

JICA's plan for expansion of transmission line and substation facilities for the period from 1993 to 2002, consistent to the power generation facility expansion plan, is as presented below.

Project Name	Year of Commissioning
A. Short Term Plan	
1. SNI Phase C	1994
2. SNI Phase D1	1994
3. SNI Phase D2	1995
4. Cuenca-Limon T/L	1993
5. Portoviejo S/S Expansion	1993
6. SNI S/S 138 kV Expansion	1995
7. Agoyán S/S 138 kV 1 Bay Expansion	1995
8. Puyo - Tena - Coca T/L	1995
9. Pascuales G/T, T/L	1993
10. Machala G/T, T/L	1994
11. Trinitaria V/T, T/L	1995
B. Medium Term Plan	
1. Milagro - Machala 230 kV T/L	1996
2. Daule P. - Chone 138 kV T/L	1997
3. Cuenca S/S Transformer 40 MVA	1997
4. Guayaquil S/S Transformer 50 MVA	1996
5. Cuenca - Loja T/L 2nd circuit	1998
6. Manta V/T, T/L	1997
C. Long Term Plan	
1. S. Francisco-Totoras T/L	1999
2. Sta. Rosa - Pomasqui T/L	2000
3. Guayaquil S/S Transformer 125 MVA	2000
4. Mulalo S/S Transformer 60 MVA	2000
5. Coca. Tena S/S Expansion	2001
6. G/T 2000 T/L	2000
7. Mazar H/P 138 kV 5 Bay	2001
8. Mazar - Cuenca T/L	2001
9. Toachi H/P 230 kV 4 Bay	2003
10. Pascuales - Sta. Elena 138 kV T/L	2001

1.6.3 Construction Cost

This Expansion Plan (period 1994 to 2003) requires a total funding of US$1,528,442,000. (Power facilities US$1,417,760,000, Transmission and Substation facilities US$110,682,000).

2. RECOMMENDATIONS

2.1 Assumption of Demand for Electricity and Supply Plan

(1) Regarding assumption of a long term demand to the year 2010, especially in the distant future, both the assumed value and actual value may differ significantly due to changes in national development plans, social conditions, and economic movement.

It is, therefore, necessary in the future to survey the actual demand and analyze the factors causing the errors between the assumed value and actual value.

Where significant changes are expected in demand for electricity in the future, the assumed demand must be reviewed.

(2) Should any power plant (especially the Paute Hydro Power Plant) not be operated at its rated output due to the dry season, the supply against demand will not provide marginal capacity and a supply shortfall, especially in kWh, is expected.

The regular maintenance and inspection are necessary as the preventive measures to ensure that all plants operate at their rated outputs. For the basic supply, this is especially important for the thermal power plants.

(3) According to INECEL data, the established output of the Paute Hydro Power Plant is approx. 890MW . This is calculated based on a 3 hour peak duration. However, the actual peak duration is 6 to 7 hours.

Since the Paute Hydro Power Plant provides approx. 47% of the total SNI facility output, the operation of this plant affects the supply significantly.

It is, therefore, necessary to review the supply and demand proportion of this plant within SNI and determine its firm output accordingly.

2.2 System Analysis

(1) In 2003, the phase compensating condenser with 18MVar will be required in Ibarra sub-station to keep the normal voltage.

(2) Some transformer tap changer (OLTC) will be required in the following substations in 1998, 2003.

1998:	Selva Alegre,	Chillo Gallo,	Kennedy,
	No. 18, No. 19,	Pomasqui	
2003:	Tena, Ambato		

2.3 Supply Reliability

(1) Thoroughness of operation rule of reservoir and securement of firm output of Paute Hydro Power Plant are indispensable.

(2) The present LOLP 0.3 days/month is desirable as an aim of supply reliability. In order to keep this, it is very necessary to reduce a rate of forced outages by maintaining existing facilities adequately and to develop new power sources on schedule.

(3) Improvement of accuracy is necessary in accumulation and management of data.

2.4 Load Dispatching Operations and Protective Relay Facilities

2.4.1 Load Dispatching Operations

(1) Load Dispatching System

Load dispatching is to direct the ever changing power system so that it operates systematically and uniformly. The load dispatching office must be able to send directions and be accessible under any circumstance. In emergencies such as abnormal weather or system failure the telephone line becomes congested. And it is common that the number of load dispatching instructions increase. Therefore, the delay of load dispatching instructions caused by telephone line failure will lower supply reliability. It is essential to install a direct telephone line between power plants, substations, and district load dispatching offices where instructions are sent directly.

(2) Data Transmission System

The system is to install a data logger type terminal at power plants and substations, etc., and connect it with the computer and modem (integrated modem) at the central load dispatching office. It is difficult to use it for transmission of telemeters where frequencies change continuously.

Therefore, to continuously indicate operation values such as system frequency, interconnecting line power flow and system voltage to recording meters or indicating instruments, and to closely monitor operations by a computer system it is necessary to use a data transmission system such as a Cyclic Digital Transmitter (CDT) which can send data continuously.

(3) Communication Method

In the future, the power system will expand greatly and will become more complex, and the data collected at the central load dispatching office will increase tremendously. To secure system reliability it will be necessary to change the protective relay into a micro carrier type one. Therefore, it will be necessary to employ a second communication method such as a micro wave radio network.

Because the Andes range runs north and south in the center of Ecuador and the large power source in the Amazon River Basin in the east is distant from large load centers, we recommend that the micro wave radio transmission method which can transmit long distances and is applicable in steep mountain areas be employed and used together with the existing PLC method.

(4) Power Supply Management

The main power source of SNI is the Paute hydro power plant which generates 47% of the entire installed capacity. The supply reliability is affected greatly by how Paute power station is operated.

In daily load dispatching operations, it is required to preserve a suitable size of spinning reserve capacity at large supply sources such as Esmeraldas Thermal Power Plant and Estero Salado Thermal Power Plant, in order to prevent supply interruption and cascading system fault which may be caused by faults on the transmission lines from major power supply sources.

Considering the current power source structure, the kW and kWh shortages of the Paute power plant during the dry season will sharply lower the system's supply reliability.

It is necessary to analyze past river discharge data on the most dry year during the dry season, the 3-day average dryness (L3), etc., and set the minimum water reserve of the Paute reservoir, and include it in the operation rules. Although it may be not economical, it is also necessary to study and improve operation of existing thermal power plants such as Estero Salado and Esmeraldas, and include them in the base power source soon in order to retain the water reserve of Paute reservoir.

2.4.2 Protective Relay Facilities

The mission of protective relay facilities is to quickly and accurately detect trouble in its territory and eliminate the trouble, and also to prevent the expansion of the trouble by not reacting to trouble outside its territory.

With the expansion of the power system and the system structure becoming more complex it may be necessary to study a new protective relay method in order to improve protective relay reliability. For the operation of existing facilities, the followings are recommended.

(1) Grasping system failure

Use automatic system recorder (OSC), etc., to grasp what the trouble is and analyze the phenomenon to evaluate the protective relay facility and to prevent failures of power facilities such as the transmission line.

(2) Measure to prevent reoccurrence of protective relay failures

Failures due to defects of the protective relay facility will prevent it from doing its work. Therefore it is necessary to systematize the investigation for the cause and take measures to prevent the reoccurrence of similar failures.

(3) Protective relay facility maintenance

Protective relay failures due to protective relay or operation setting defects will affect the power system greatly.

Therefore, it is necessary to prevent failures caused by protective relay facility defects before it happens. To do this we must grasp its operation status by daily inspections, and perfect maintenance by periodically conducting operation characteristic and sequence tests to confirm and maintain the function of the protective relay.

2.5 Power Facilities Expansion Plan

2.5.1 Power Generating Facilities

In order to meet future increase of power demand it is necessary to construct new power sources as planned in the Power Generating Facility

Expansion Plan (JICA plan). But the commissioning time must be delayed considering the current status of construction fund procurement and the progress of the construction. Therefore we expect that between 1994 - 1998 there will be a shortage of energy supply against increased power demand that will continue for a long period of time. Therefore it is necessary for electric power related institutions and the government to immediately take the following measures to smoothly carry out electric power development plans.

(1) Procure funds and speed up construction of Machala gas turbine power plant planned to be commissioned in December, 1994.

(2) Procure construction funds for Trinitaria steam turbine power plant planned to be commissioned in December, 1995.

(3) Make procurement of funds definite so that Daule Peripa hydro power plant planned to be commissioned in December, 1996, will be constructed in the planned period.

(4) Construct a new steam turbine thermal power plant (125 MW) to be commissioned in December, 1997, in addition to the INECEL expansion plan to keep the energy (kWh) balance during droughts.

(5) Make construction fund procurement definite for the San Francisco hydro power plant project. In order for this power plant to be commissioned and incorporated into SNI by December, 1999, it is necessary to start construction by the end of 1994.

(6) Make procurement of funds for the execution design of the Mazar and Toachi hydro project concrete, and start the execution design early.

2.5.2 Transmission and Substation Facilities

(1) Concerning the projects in the transmission line and substation expansion plan, the construction project of SNI Phase D2, Paute-Pascuales-Trinitaria Transmission Line must be completed as soon

as possible due to the following reasons.

a) Although Paute Power Plant has a capacity of 1,075MW, this power plant can not be operated at an output near rated capacity because of the limit of transmission capacity.

The result of power system analysis indicates that the power plant can not be operated over 870MW with the current transmission line.

For this reason, the transmission lines between Paute-Milagro-Pascuales must be expanded (its capacity enlarged) at an early opportunity in order to effectively utilize the installed capacity of Paute Power Plant.

b) This transmission line is also required because the output of Trinitaria Thermal Power Plant (125MW), which is scheduled for commissioning in December of 1995, will be transmitted via Trinitaria Substation and Pascuales-Trinitaria Transmission line.

(2) In addition to the transmission line and substation expansion projects, the financing schedules and construction schedules for all projects in SNI or Subtransmission Plan which are related to the power plant facility expansion plans must be formulated, so that work schedules of the transmission line/substation projects are completely coordinated with the related power plant development projects.

2.5.3 Inspection and Maintenance of Existing Power Facilities

(1) Power plants

Aged power plants are increasing every year. Prolonging power plant life is a measure taken not only because closing existing plants or constructing new plants are difficult, but because it is more economical to repair and maintain existing power plants rather than building new ones. Although this measure is taken for reasons like equipments must be used longer than its designed life, conducting inspections and maintenance, and preventing failures will make the power supply more stable.

Currently, during the wet season the supply capability is sufficient if hydro power plants such as Paute are operating at rated output. But during droughts, if the base thermal plant fails, the energy supply (kWh) will become short. It is necessary to inspect and maintain the facilities carefully so that they will operate normally. To maintain a stable power supply it is essential to allot operation and maintenance expenses and keep spares ready.

Deterioration examination, preventive maintenance and facility improvement measures for power plants are explained in Table A-1-1 - A-1-5.

(2) Transmission and Substation Facilities

Unlike power plants it is difficult to stop transmission and substation facilities for a long period and conduct an overhaul. For stable operation of transmission and substation facilities, and to improve power supply reliability, it is necessary to monitor the equipment while in operation and prevent outages and prolong life using the collected data.

According to the INECEL outage statistics, the number of power supply outages per year is 8.7 for 230kV and 26.3 for 138kV transmission facilities, and 9 for 230/138kV and 12 for 138/69kV substations.

To improve power supply reliability of these transmission and substation facilities it is necessary to carefully inspect and maintain the equipments to prevent outages and make maintenance and control complete.

Measures to improve substation facility reliability are explained in Table A-1-7 ~ A-1-9 and transmission facility inspection chart is shown in Table A-1-10 ~ A-1-14.

(3) Spare Transformer

Concerning the spare transformers to be installed in major 230 kV substations of SNI, one unit of single phase spare transformer each is required at Milagro, Sto. Domingo and Quevedo Substations as the power demand increases in future. 3 phase transformer is recommended in adopting a spare transformer for 138kV substation, and this transformer must be used as a spare transformer which is common to several substations.

(4) The followings may be observed from analyzing outage statistics of transmission and substation facilities

a) Of the 230kV loop trunk line, the number of outages between Paute - Milagra is extremely high. It is necessary to find out the cause and take measures.

b) 138kV Pascuales - Santa Elena line and Pascuales - Posorja line, as mentioned earlier are highly polluted areas. Although the lines were shutdown often for scheduled maintenance between 1990 - 1991 the number of outages recorded was high. But although scheduled shutdown time decreased greatly in 1992, the number of outages also decreased greatly. This is due to the improvement of maintenance.

c) In high temperature heavy rainfall tropical climate areas such as around 138kV Santo Domingo - Esmeraldas line and Milagro - Machala line, the vegetation growing under the transmission line, like creepers, grows very fast. Banana, Abaka (Manila hemp) and coco palm which grow under transmission lines in large high-profit plantation area also grow very fast. The high temperature and these vegetation cause the lines to droop causing grounding failures. Lines also droop when airplanes spraying agricultural chemicals touch the lines. The outage rate is high. It is necessary to look into the causes and take measures to prevent them.

As explained, the type of outages and the method of maintenance differ depending on the area. As SNI transmission lines extend from substations in the mountain region to the tropical rain forest area in the east, it will become necessary to set new measures against accidents caused by animals and vegetation.

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CHAPTER 1 INTRODUCTION

1.1 Background of Study

Generally speaking, an electric power utility is one of the essential infrastructures of a nation, for social and economic development, it is necessary to inexpensively supply high quality and high reliability electric power according to the needs of electric energy consumers.

The electric power industry of the Republic of Ecuador (to be termed Ecuador hereinafter) is being operated by INECEL (INSTITUTO ECUATORIANO DE ELECTRIFICACION) under Ministry of Energy and Mine, the 19 local electric utility companies, and electric utility services managed by some local governments. (refer to Fig. 1-1)

INECEL maintains and operates the national interconnected system of Ecuador (Sistema Nacional Interconectado, to be termed SNI hereinafter). The development of SNI's major power generation, power transmission and substation facilities is also the major commitment of INECEL. INECEL owns, as of January of 1993, 74% of the total power generation facilities amounting to 2,278.2 MW, 100% of 230 kV trunk transmission lines that extend 820 km, 93% of 138 kV trunk transmission lines that extend 1,170.5 km, and 5,833 kVA (Include for stepup transformer for Generations) of substations of the Republic of Ecuador, and supplies power to local electric power companies.

These facts clearly indicate that INECEL plays an important role for the social and economic development of Ecuador by means of SNI.

When we examine SNI from the point of view of power supply/demand balance and the features of power system, we can find the following conditions.

(1) The load centers are locally concentrated. (The two large cities of Quito and Guayaquil account for 70% of the total power demand.)

(2) The large power sources are locally concentrated. (Paute Hydroelectric Power Plant only accounts for 47% of the total installed capacity.)

(3) The load centers are separated from power sources by a great distance. (The power transmission distance between Paute and Quito is approximately 310 km, and between Paute and Guayaquil approximately 180 km.)

(4) The power transmission system is physically large in comparison to the load to be supplied. (The total extension of the 230 kV ring system is 820 km.)

(5) The large power source of Paute Hydroelectric Power Plant has an excessive output capacity in comparison to the dam reservoir capacity, thereby having insufficient regulating capacity, and its output is affected by the variation of river flow.

These characteristics of SNI described above can be identified by a macroscopic power system analysis, and the following problems can be pointed out.

(a) Power demand/supply balance problem (unstable power supply capability).

(b) Transmission line capacity problem. (Paute-Milagro-Pascuales)

(c) Power system stability problem.

These problems would impose particular constraints on the operation of individual power plants, substations and transmission lines.

These problems lying behind SNI are the impediments in realizing a reliable, high quality power supply. Therefore, it is required to immediately evaluate the reliability of the current and future SNI Power System quantitatively as well as qualitatively, with the objective of improving the quality of power supply.

Under the circumstances as described above, the Republic of Ecuador has requested the Government of Japan for the technical assistance in the Study on Service Reliability Improvement Project of National Interconnected System (SNI) of Ecuador.

1.2 Objective of Study

The objectives of this Study are defined as below.

(1) The on-site survey and the study works in Japan shall be implemented to establish the methodology of evaluating the reliability of SNI.

(2) The reliability levels of existing power facilities and future plan shall be evaluated to identify the improvements to be applied to the existing power facilities and to review the future plan, and a recommendation on the project priority order and other items shall be presented.

(3) In the Recommendation, the preliminary designs of the projects which need to be implemented and the related project costs shall be included.

In addition, a set of Reports shall be developed on the subjects of study referred to above, to transfer technology to the counterparts of Ecuador through the process of this Study.

1.3 Scope of Study

The following factors are the elements which represent the quality of the power to be supplied by the electric utility industries to the consumers.

(1) The supply of electric power is not interrupted. (There is no blackout.)

(2) The quality of electric power supplied is high. (The voltage and frequency of the supplied power are constant, and no high harmonic is included.)

Item (1) above is the continuity of service, which, in other words, is the elimination of blackout. The factors that create power supply interruption at the customer ends are as listed below, in macroscopic terms.

(a) The absolute amount of supply capacity is insufficient in comparison to the demand. (The supply to some customers is interrupted by the intention of the supplier.)

(b) The supply capacity is somehow sufficient to meet the demand, but the supply falls short of demand under certain cases when the characteristics of the supply sources are taken into account. (Power supply to some customers is interrupted.)

(c) The power supply is constrained by the performance of power transmission system. (Power supply is constrained by transmission line capacity, voltage regulation limit, etc.)

(d) The power supply is interrupted by transmission line faults. (Power system stability.)

(e) Power supply is interrupted by other events caused by human actions or natural disaster. (Collapse of transmission line towers, floods, etc.)

The power supply reliability can be expressed by the measure of supply reliability. This measure can be evaluated by the frequency of supply interruptions or duration of interruption at the customer ends, or evaluated statistically in terms of the variation of supply capability and the load variations in reference to Item (b) above.

The subjects of this Study are the transmission lines of 138 kV or higher voltage which constitute the National Interconnection System of SNI, and the substations and generators having 5 MVA or larger capacity which are connected to SNI. **The reliability measure dealt with in this Study Report is the reliability level at supply end (transmission bus of power plants) which is obtained by a statistical methodology by treating the supply capability reference to the demand, to evaluate the supply interruption of item (b) above.**

1.4 Site Survey

JICA Team started to study this task from Feb., 1993 and dispatched the site survey mission to Ecuador as follows;

<Local survey>

1st: Feb. 17 - Mar. 16, 1993;	Inception report, electric facility survey
2nd: Jul. 27 - Aug. 10, 1993;	Submission and explanation of progress report
3rd: Oct. 18 - Nov. 1, 1993;	Simulation of supply reliability software
4th: Jan. 10 - Jan. 27, 1994;	Submission and explanation of interim report, seminar
5th: Mar. 11 - Mar. 25, 1994;	Submission and explanation of draft final report

1.5 Member of Survey Team

The Study Mission for this survey consisted following 8 experts, who worked on their respective areas of expertise.

Leader/Coordiantion	Katsuhiko Yamamoto
Power System Planning	Toshimasa Fujiuchi
Power System and Operation Planning	Makio Suzuki
Generating and Substation Equipment	Hisao Sudo
Protective Relay System	Tomoyoshi Hasebe
Transmission Line Equipment	Hiroshi Katsukawa
Power System Analysis	Hiroshi Kagami
Reliability Analysis	Ryuichi Abe

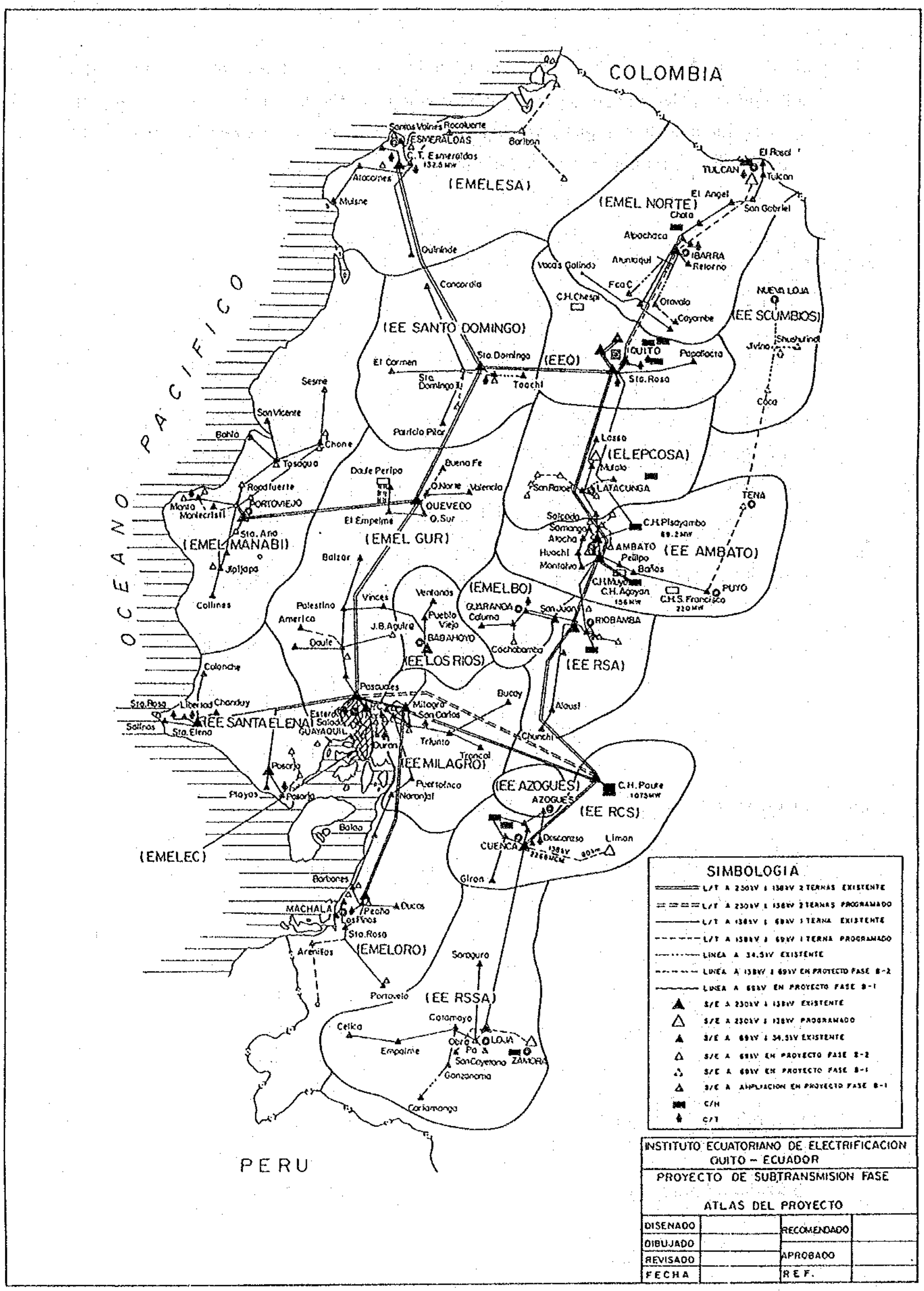

Fig. 1.1 Section of Regional Power Companies

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CHAPTER 2 GENERAL DESCRIPTION OF REPUBLIC OF ECUADOR

2.1 Geography

The Republic of Ecuador is located in the northwestern part of the South American Continent, just on the ecuador. The country borders Colombia to the north, Peru to the east and south, and the Pacific Ocean to the west. The Galapagos Island in the Pacific Ocean are the territory of Ecuador. The land area is approximately 280,000 km^2, and is the fourth smallest nation in the South America, next to French Guiana, Uruguay, and Guyana. The Andes Range, which runs from Colombia crosses the middle of this nation down to Chile in the south, and this mountain range is split to the eastern range and the western range, thereby creating a basin of 1,800 to 3,000 m elevation. Much of the national population is found in this basin area. The two mountain ranges include Chimborazo Mountain (6,310 m), the highest mountain of the nation, as well as more than 30 volcanoes. Active volcanoes include Cotopaxi Mountain (5,897 m), which is known as the highest active volcano in the world, and two other volcanoes.

The land of Ecuador can be geographically classified into three areas, the coastal zone along the Pacific Ocean, the plateau between Andes Ranges, and the eastern tropical jungle zone that extends from the source of Amazón River.

2.2 Climate

Although the land of Ecuador is located just on the equator, the diverse geography and the tidal currents of Humboldt Current (cold current) and Middle American Current (warm current) create a variety of climate. That is, a northern part of Pacific coast and the western half of Amazón basin have high temperature, high humidity climate (with the annual average temperature of 25°C and annual precipitation of 3,000 to 6,000 mm), and the inland side of the Pacific coast plain has a tropical, high temperature, high humidity climate (with average temperature of 14°C to 26°C, with relatively little rain and humidity of around 80%), the high lands with elevation of 3,000 m or so have a tropical mild climate (with distinctive dry and wet seasons), and mountain lands with elevation of more than 3,000 m have tropical, high elevation climate (with precipitation of 1,000 m to 2,000 m, rains every day in the wet season, and humidity of 60% to 80%).

2.3 Population

The total population of Ecuador is estimated to be 10.782 millions as of 1990. The population growth rate in recent years has been 2.8%. The population per 1 km^2 area is 39. A 49% of the population lives in major cities, such as Quito, Ambato, Ibarra, Riobamba and Cuenca, which are located in the central plateau among Andes Mountain Ranges. Another 48% lives in the Pacific coast area such as Guayaquil, and 3% lives in the eastern, Amazón River basin.

2.4 Economy and Energy Resources

2.4.1 Economy

Ecuador was originally an agricultural nation, and its tropical agricultural products such as banana, cacao and coffee have been the major export commodities. However, the oil field discovered in the eastern area by the end of 1960's has been successfully put to production, and when the export of crude oil was started in 1972, a boom of oil well discovery occurred, although the production from each well was not very large. The crude oil export increased with time, and the nation achieved a remarkable economic growth in 1970's which has been leveraged by the income from oil wells. The Government initiated a 5-year economic development program based on this oil income, to accomplish the construction of infrastructures, electric power development, and industrialization.

The economic growth declined, however, in 1980's due to the depressing international oil market. After evaluating this economic difficulty thereby encountered, the Government has introduced barter systems one by one into the international trade, and strengthened its restrictions on unnecessary import commodities. The domestic currency was devaluated in 1982 and 1983, and the Government was busy in negotiating out the extension of public loans. These efforts were rewarded, and together with the successful recovery of the production of major agricultural export commodities as well as the increase of oil production and export, the international trade surplus in 1984 reached 1.1 billion dollars. Also, the negotiations of the extension of public loans turned out favorably. The oil production as well as its transportation from the wells in the northeastern area to the coastal zone continued to increase, amounting to 300,000 barrels per day, thereby marking the record since the starting of crude oil production in 1972.

In recent years, the fish processing industry is remarkably growing. In 1992, the export of non-traditional products, such as tuna, fishes, flowers and shrimps, accounts for 60% of the total export.

The population, population growth, gross national products, and the gross national products per capita during period 1970-1990 are illustrated in Table 2-1.

2.4.2 Energy Resources

(1) Oil

Ecuador is an oil-exporting nation. The oil production was started in 1972, and the nation produces 300,000 barrels per day in 1985. The production cost is relatively high, because most of the production wells are located in the eastern area, and the oil has to be transported to the port of Esmeraldas in the Pacific coast by means of pipelines across the Andes. The confirmed reserve is 1.5 billion barrels as of 1982, and it is estimated there is a total reserve of 3 billion barrels including the unconfirmed reserves.

(2) Natural Gas

The natural gas fields have been discovered in Guayaquil Bay and Shushunfindi of Amazon Basin. The reserve in Guayaquil is estimated to be 377.7 billion cubic feet.

(3) Hydroelectric Power

There are abundant water power resources of high head along the rivers that flow from the eastern and western Andes ranges to the Pacific Ocean to the West and Amazon River to the east. (Hydro-potential: 21,520 MW, Amazon basin: 90%, Pacific coast: 10%)

Table 2-1 Economic Indices

Year	Population (1,000)	Growth Rate (%)	GDP ($ million)	Income per Capita (Dollars)
1970	6,060.5	3.17	1,629	269
1971	6,239.5	3.12	1,602	257
1972	6,432.2	3.09	1,874	291
1973	6,628.8	3.06	2,489	375
1974	6,829.5	3.03	3,711	543
1975	7,034.5	3.00	4,310	613
1976	7,242.9	2.96	5,317	734
1977	7,454.5	2.92	6,655	893
1978	7,670.8	2.90	7,654	998
1979	7,893.3	2.90	9,359	1,186
1980	8,123.4	2.92	11,733	1,444
1981	8,361.3	2.93	13,946	1,668
1982	8,606.1	2.93	13,354	1,552
1983	8,857.4	2.92	11,114	1,255
1984	9,114.9	2.91	11,510	1,263
1985	9,377.9	2.89	11,890	1,268
1986	9,647.1	2.87	10,515	1,090
1987	9,922.5	2.85	9,450	952
1988	10,203.7	2.83	9,129	895
1989	10,490.2	2.81	9,972	951
1990	10,781.6	2.78	10,741	996

(Curtesy of the Central Bank)

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CHAPTER 3 POWER DEMAND AND SUPPLY STATUS

3.1 General Description of Power Demand and Supply Status

The concentration of population in the two cities, Quito and Guayaquil is remarkable, and approximately 70% of the total electric power demand is located in these two cities which form two major load centers of the nation.

The total electric energy consumption of the nation was 5,449 Gwh according to a statistics of 1992. The energy consumption in each consumer category consists of 39.4% residential, 30.4% industrial and 14.9% commercial, and 15.3% is consumed by street lighting and other uses. That is, the proportion of the residential load is large. Although the electric energy consumption by non-industrial sectors is high, the electrification rate is still low in the rural areas, being 52%, although this rate is as high as 94% in the urban areas. The national average electrification rate was 75% as of 1992, and the electrification of rural areas must be further advanced in future (see Table 3-2). The power transmission loss of Ecuador, including the distribution system, is high, being approximately 24% or higher.

The peak power demand of a year normally occurs in December, and the load factor in recent years has been approximately 60%. The peak in the daily load curve is observed at 19 to 20 hour in the evening, indicating that the power demands are dominantly non-industrial. An example of daily load curve is presented in Fig. 3-1.

Concerning the electricity tariff, the average unit price as of 1992 was 62.81 sucres/kWh (3.97 US-cents/kWh), which is suppressed to a fairly low value in comparison with neighboring nations.

In the past 10 years, the annual average growth of total demand was 6%. It is anticipated that the electric energy demand will continue to grow steadily in future, unless there is unexpected changes in economic status and other factors.

3.2 Electric Power Utility

The electric power industry in Ecuador is being operated by INECEL under the Ministry of Energy and Mine, the 19 local electric power companies and some local governments.

INECEL maintains and operates SNI, and engaged in the development of power generation, power transmission and substation facilities for this national grid. Specifically, INECEL maintains and operates Paute Hydroelectric Power Plant, which is a representative power plant in Ecuador, Estero Salado Thermal Power Plant and other power stations, 230 kV trunk transmission grid, 138 kV transmission lines, 69 kV sub-transmission lines, and substations connected to these major power systems, to wholesale the power to local power companies.

Among local power companies, EMELEC (Empresa Electrica Ecuador, Inc.) is a corporation controlled by American private capitals, and this company distributes power to Guayaquil City, the largest load city and the largest load center in Ecuador, and also engaged in some power generation business. Local power companies other than EMELEC are controlled by the capital of INECEL, and depend on INECEL for financial and technical assistance.

3.3 Present State of Electric Power Supply Facilities

3.3.1 Power Generation Facilities

As of Jaunary 1993, a total of 2,278.2 MW of power generation facilities are included in SNI, of which 74.26% are owned by INECEL, 25.74% by local power companies. To classify these facilities by the type of primary energy, 64.5% are hydroelectric plants and 35.5% thermal plants.

Owner / Power Plant Type	INECEL		Local Power Companies*)		Total (SNI)	
	MW	%	MW	%	MW	%
Hydroelectric	1,300.2	76.9	169.9	29	1.470.1	64.5
Thermal	391.6	23.1	416.5	71	808.1	35.5
Total: MW %	1,691.8 74.26	100	586.4 25.74	100	2,278.2 100	100

Note: *) The figures of local power companies do not include the facilities of Sucumbios Power Company (hydro 0.4 MW, thermal 11.03 MW) which can not be connected to the National Grid.
Public power facilities in the eastern and Galapagos areas are not included for the same reason as above.

The installed capacity of each ownership and primary energy classification are given in Table 3-1.

The natural river flows in Ecuador decrease during the dry season from November to February in every year. For this reason, the firm output of hydroelectric power plants is 1,209.4 MW as against the total installed capacity of 1,470.1 MW. The output of thermal power plant has been decreased from 808.1 MW to 583.2 MW because the maintenance work has been insufficient. The maximum power capability in the whole SNI is 1,792.6 MW, which is 78.7% of the total installed capacity. The installed capacity and the power capability of hydroelectric and thermal power plants as of January of 1993 are given in Table 3-2.

3.3.2 Substation Facilities

The power systems in Ecuador are being improved to create SNI which is to be comprehensively operated by INECEL. The 230 kV transmission lines will form the backbone transmission grid of double loop lines, and 138 kV lines will function as the interconnection lines to local areas.

There are 7 key substations which form the 230 kV looped transmission system of SNI. The total substation capacity connected to this loop system is 1,451 MVA as of the end of 1992. The total capacity of the 138 kV substations interconnected to this loop system is 1,618 MVA.

Auto-transformers are frequently used in these substations.

The total capacity of step-up transformers in power plants is 2,731 MVA, including both 230 kV and 138 kV transformers. Except for the 230 kV/138 kV interconnection transformer installed at Paute Power Station, three phase transformers are used. The name, voltage, capacity and year of commissioning of each substation are given in Table 3-3. (1/4-4/4)

3.3.3 Transmission Line Facilities

(1) Present Facilities

At present, the main backbone of the transmission system is SNI (see "Key and SNI Location Map). This interconnection system comprises the 230 kV, double circuit loop transmission system extending for approximately 820 km, which connects the hydroelectric and thermal power plants of INECEL, including Paute Hydroelectric Power Plant, to the pacific coast load center including Guayaquil City and load centers in mountain areas including Quito City, and the double circuit and single circuit 138 kV transmission lines, having a total length of approximately 1,170 km and extending radially from the 7 primary substation located on the 230 kV loop system, as well as 11 substations and 5 power plants connected to these radial transmission lines.

(2) Maintenance of INECEL transmission lines

INECEL transmission lines are maintained by transmission line belonging to the four local offices of DOSNI; Paute (southeast), Pascuales (southwest), Santa Rosa (northeast), and Santo Domingo (northwest). These facilities carry out regular patrols, regular inspection/maintenance, fault patrols, recovery, and clearing beneath the lines. However, the differences in the natural environmental conditions prevailing along the transmission lines appear to provide difficulties in providing uniform inspection and in determining the required maintenance standards. Especially, it affects the 138 KV lines. Also, the number of faults is remarkably high in the plains along the Pacific Coast.

Table 3-4 shows the fault statistics of every INECEL transmission line for the periods 1990 and 1992.

Table 3-5 shows the frequency and time of outage (planned outage) for repairs and inspection during the same period.

(3) Statistics and analysis of transmission line faults

Transmission fault statistics can not be used for the study of facility improvement unless analysis results are accumulated for 5 to 10 years. For instance, we use the above described data to calculate the 'number of faults/100km' which indicates the frequency of transmission fault occurrence. The result is described in the following table to be compared with that in Japan.

Number of Faults/100 km

Country	Voltage (kV)	1990	1991	1992	Total Length (km)	Notes
		Faults/100 km				
Ecuador	230 138	0.73 2.40	0.85 2.80	1.46 1.62	820 1,167.5	INECEL INECEL
Japan	More than 7 km	-	0.48	0.79	82 x 1000	10 E.P.Co.

Note: The fault statistics data in Japan includes all the transmission and distribution lines (more than) of 9 electric power companies and EPDC.

Fault ratio according to voltage;

Less than 33KV; 47.47%

44KV - 77KV; 44.78%

110KV - 154KV with 3-phase reclosing device; 7.02%,

More than 187KV with 3-phase reclosing device; 0.74%

(during 1962 - 1967)

The transmission lines providing extremely high fault rates among all SNI transmission lines are shown below.

High Faults Rate T/L in SNI

Name of Transmission Line	Voltage (kV)	1990	1991	1992	Length (km)
Riobamba - Totoras	230	4.76	0	2.38	42
Paute - Milagro	230	2.13	2.13	6.38	141
Milagro - Machala	138	3.88	3.10	6.20	129
Pascuales - Posorja	138	6.12	4.08	1.02	98
Pascuales - Sta. Elena	138	5.61	5.61	0	107
Sto. Domingo - Esmeraldas	138	1.95	3.90	2.60	154
Cuenca - Loja	138	2.96	2.22	0.74	135

(4) Suggestions based on the fault statistics and its analysis result

(a) The number of faults along the 230KV ring trunk line between Paute and Milagro is remarkably high. It is necessary to pursue the causes and provide suitable countermeasures.

(b) The 138KV Pascuales - Santa Elena line and Pascuales - Posorja line are a highly damaged area as described earlier. Despite frequent planned outage for inspection and repair in 1990 and 1991, they showed a high fault ratio. In 1992, however, fault occurrence was greatly reduced despite reduced planned outage time, indicating that the maintenance method has been improved.

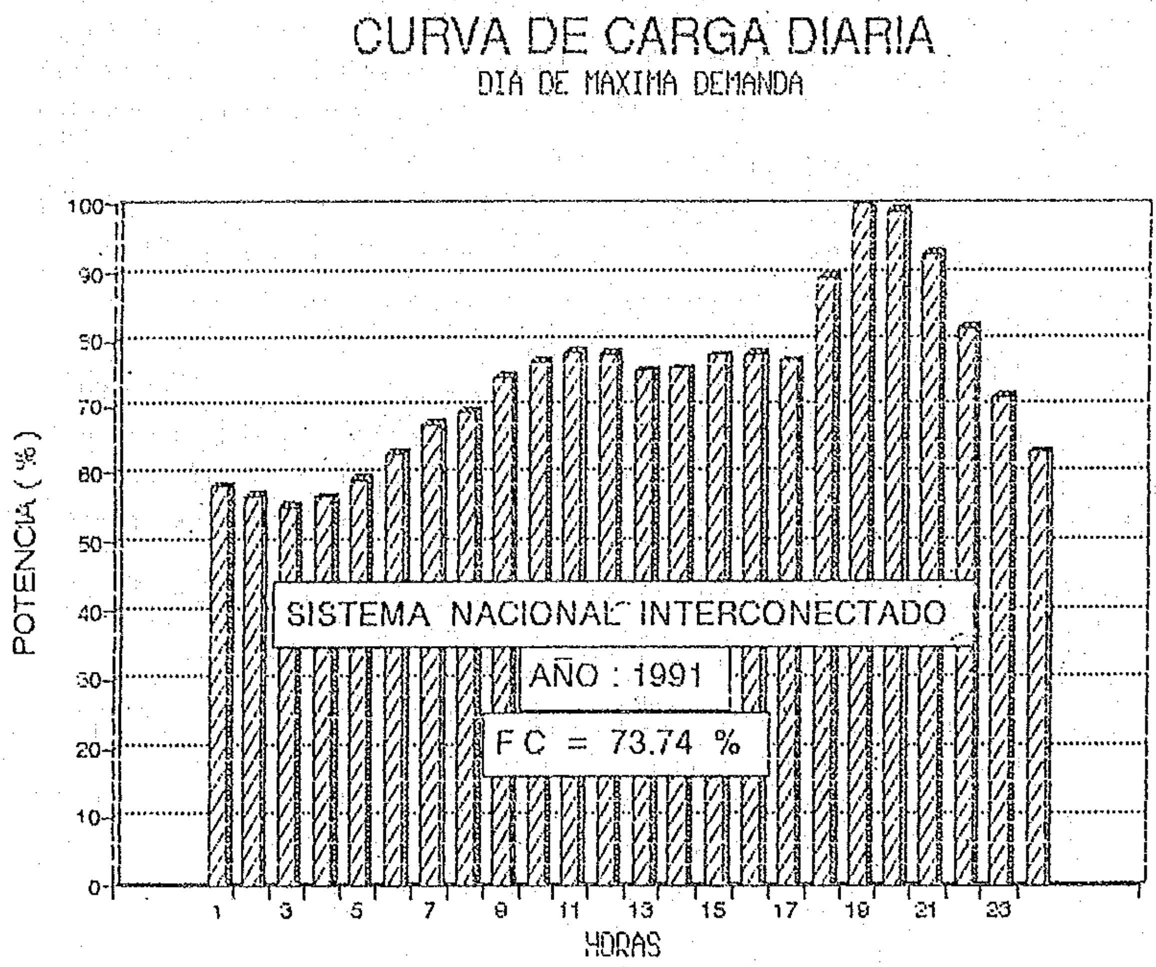
(c) Vegetation, especially the trailing weeds grow extremely fast along the transmission lines such as the 138KV Santo Domingo - Esmeraldas line and Milagro -Machala line which are situated in tropical zones with high temperatures and heavy rainfalls.

Bananas, abaca and palms are planted beneath the transmission lines on large farms and also grow very fast.

The heat also stretches the power lines and causes them to sag to the ground or other conductive structures and plants, there by causing grounding faults.

The high fault ratio is also caused by low flying, light crop dusting aircraft which contact the lines. Another factor which causes grounding fault are aeronautic indicators (two to three 70cm diameter red plastic balls suspended from an overhead earth-wire), which pulls the earth-wire down as rainwater accumulates inside them. (These aeronautic indicators have now been improved.)

These causes must be thoroughly and the appropriate countermeasures provided.



CURVA DE CARGA DIARIA - SNI			
HORA	POTENCIA (%)	HORA	POTENCIA (%)
1	58.04	13	75.50
2	56.64	14	75.89
3	55.25	15	77.78
4	56.41	16	78.07
5	58.92	17	77.03
6	62.80	18	89.53
7	67.39	19	100.00
8	69.27	20	99.03
9	74.65	21	92.89
10	76.91	22	81.84
11	78.36	23	71.41
12	78.01	24	63.01

Fig. 3-1 Daily Load Curve

Table 3 - 1 Installed Capacitry of Power Station
(MW)
As of January, 1993

Enterprise / Type of Generation	S.N.I	Regional System	Municipal Corporation	Orient & Galapagos	Total of Public Service	Independent Service	Total of National Service
Hydroelectric	1,300.20	170.27	1.54	0.15	1,472.16	13.30	1,485.46
Thermal-Electric	391.64	428.09	1.23	10.29	831.25	117.15	948.40
- Vapor (Bunker)	278.50	63.00	0.00	0.00	341.50	0.00	341.50
- Diesel (Diesel)	0.00	169.43	1.23	10.29	180.95	117.15	298.10
- Diesel (Bunker)	31.20	115.91	0.00	0.00	147.11	0.00	147.11
- Gas (Diesel)	81.94	79.75	0.00	0.00	161.69	0.00	161.69
Total	1,691.84	598.36	2.77	10.44	2,303.41	130.45	2,433.86
Z	69.51	24.59	0.11	0.43	94.64	5.36	100.00

Note: Regional System includes capacity of sucumbios power company which cannot operate in parallel to the national power system and small station with the capacity less than 500 kW.

Table 3 - 2 Power Generation of SNI (As of Jan. 1993)

(1) Thermal Generation				
Enterprise	Installed Capacity (MW)	Rehabilitation Capacity (MW)	Operationable Capacity (MW)	Effective Output (MW)
Electric power Companies*	416.5	111.7	304.8	248.9
INECEL	391.6	30.9	360.7	334.3
SUM	808.1	142.6	665.5	583.2
(2) Hydro Generation				
Enterprise	Installed Capacity (MW)	Rehabilitation Capacity (MW)	Operational Capacity (MW)	Guaranteed Output (MW)
Electric Power Companies*	169.9	0	169.9	91.2
INECEL	1,300.2	0	1,300.2	1,118.2
SUM	1,470.1	-	1,470.1	1,209.4
(3) Total of (1)&(2)	2,278.2	142.6	2,135.6	1,792.6

Note: * mark means electric power companies interconnected to SNI, but not included Orient and Galapagos
Power generation at the terminal of generator is applied

Table 3 - 3 Existing Substation (As of December, 1992)

(1/4)

Name of Sub-station	Voltage (kV)	Transformer Rating									Year of Opera -tion
		Capacity (MVA)			Cooling Method	Cap. of Tertiary (MVA)	Type	Units	Connect-tion	LTC	
		OA	FA	FOA							
(1) 230 kV Substaion											
Pascuales	230/138/13.8	225	300	375	OA/FA/FOA	60/80/100	1ϕ/auto	4	YY∆	-	1982
Quevedo	230/138/13.8	100	133	167	OA/FA/FOA	27/36/45	"	4	YY∆	-	1982
Sta.Rosa	230/138/13.8	225	300	375	ONAN/ONAF/ OFAF	60/80/100	"	4	YY∆	-	1982
Sto.Domingo	230/138/13.8	100	133	167	OA/FA/FOA	27/36/45	"	3	YY∆	-	1982
Milagro	230/69/13.8	100	133	167	OA/FA/FOA	27/39/45	"	3	YY∆	-	1983
Totoras	230/138/13.8	60	80	100	OA/FA/FA	20/27/33	"	4	YY∆	-	1987
Riobamba	230/69/13.8	60	80	100	OA/FA/FOA	20/27/33	1ϕ	3	YY∆	Yes	1989
Sum		870	1,159	1,451							
(2) 138 kV Substation											
Vicentina	138/46/13.8	33	44	44	ONAN/ONAF	11/14	3ϕ		YY∆	-	1976
	138/46/13.8	33	44	44	ONAN/ONAF	11/14	3ϕ		YY∆	-	1976
Ambato	138/69/13.8	33	44	44	ONAN/ONAF	11/14	1ϕ/Auto		YY∆	-	1977
Ibarra	138/34.5/13.8	30	40	50	OA/FA/FA	10	3ϕ		YY∆	Yes	1979
Salitral	138/69/13.8	90	120	150	OA/FA/FOA	30	1ϕ/Auto	4	YY∆	-	1980
Sta.Rosa	138/46/13.8	45	60	75	OA/FA/FA	15/20/25	3ϕ		YY∆	Yes	1980
Esmeraldas	138/69/13.8	45	60	75	ONAN/ONAF/ OFAF	15/20/25	3ϕ/Auto		YY∆	Yes	1981
Portoviejo	138/69/13.8	45	60	75	ONAN/ONAF/ OFAF	15/20/25	3ϕ/Auto		YY∆	Yes	1981

Table 3 - 3 Existing Substation (As of December, 1992)

(2/4)

Name of Sub-station	Voltage (kV)	Transformer Rating										Year of Opera-tion
		Capacity (MVA)			Cooling Method	Cap. of Tertiary (MVA)	Type	Units	Connect-tion	LTC	
		OA	FA	FOA							
Quevedo	138/69/13.8	20	27	33	OA/FA/FOA	20	3ϕ		YYΔ	Yes	1981
Reserva	138/69/13.8	(20)	(27)	(33)	OA/FA/FOA	-	3ϕ		YYΔ	Yes	1981
Sto.Domingo	138/69/13.8	60	80	100	OA/FA/FOA	16/22/27	1ϕ/Auto	3	YYΔ	-	1981
Cuenca	138/69/13.8	60	80	100	OA/FA/FOA	16/22/27	1ϕ/Auto	4	YYΔ	-	1983
Babahoyo (mobile)	138/69/46	30	30	30	OA	-	3ϕ		-	-	1985
Pascuales	138/69/13.8	90	120	150	OA/FA/FOA	30/40/50	1ϕ/Auto	4	YYΔ	Yes	1985
Totoras	138/69/13.8	60	80	100	OA/FA/FA	20/27/33	1ϕ/Auto	4	YYΔ	-	1986
Laja	138/69/13.8	40	53	66	OA/FA/FOA	14/18/22	3ϕ/Auto		YYΔ	Yes	1987
Machala	138/69/13.8	60	80	100	OA/FA/FOA	20/27/33	1ϕ/Auto	3	YYΔ	Yes	1987
Milagro	138/69/13.8	60	80	100	OA/FA/FOA	20/27/33	1ϕ/Auto	3	YYΔ	Yes	1987
Posorja	138/69/13.8	20	27	33	OA/FA/FOA	7/9/11	3ϕ/Auto		YYΔ	Yes	1987
Sta.Elena	138/69/13.8	40	53	66	OA/FA/FOA	14/18/22	3ϕ/Auto		YYΔ	Yes	1987
Policentro	138/69/13.8	90	120	150	OA/FA/FOA	30/40/50	1ϕ/Auto	3	YYΔ	Yes	1990
Ibarra	138/69/13.8	20	27	33	OA/FA/FOA	7/9/11	3ϕ/Auto		YYΔ	Yes	1991
Sum		1,004 (20)	1,329 (27)	1,618 (33)							
Total(1)+(2)		1,874	2,488	3,069							
		(20)	(27)	(33)							

Table 3 - 3 Existing Substation (As of December, 1992)

(3) Step-up Substation for Power Station (3/4)

Name of Sub-station	Voltage (kV)	Transformer Rating									Year of Opera-tion
		Capacity (MVA)			Cooling Method	Cap. of Tertiary (MVA)	Type	Units	Connect-tion	LTC	
		OA	FA	FOA							
Guangopolo	6.6/138	15	20	20	ONAN/ONAF	-	3ϕ		ΔY	-	1976
	6.6/138	15	20	20	ONAN/ONAF	-	3ϕ		ΔY	-	1976
Pisayambo	13.8/138	40	40	40	FOA	-	3ϕ		ΔY	-	1977
	13.8/138	40	40	40	FOA	-	3ϕ		ΔY	-	1977
Sta. Rosa	13.8/138	28	28	28	ONAN		3ϕ		ΔY	-	1980
	13.8/138	28	28	28	ONAN		3ϕ		ΔY	-	1980
	13.8/138	28	28	28	ONAN		3ϕ		ΔY	-	1980
E. Salado-V2	13.2/69	52	70	86	OA/FA/FOA		3ϕ		ΔY	-	1980
E. Salado-V3	13.2/69	52	70	86	OA/FA/FOA		3ϕ		ΔY	-	1980
E. Salado-G4	13.8/69	26	35	35	OA/FA		3ϕ		ΔY	-	1980
Esmeraldas	13.8/147.5	90	120	160	ONAN/ONAF/OFAF		3ϕ		ΔY	-	1981
Paute	13.8/138	114	114	114	OFWF		3ϕ		ΔY	-	1983
	13.8/138	114	114	114	OFWF		3ϕ		ΔY	-	1983
	13.8/138	114	114	114	OFWF		3ϕ		ΔY	-	1983
	13.8/138	114	114	114	OFWF		3ϕ		ΔY	-	1983
	13.8/138	114	114	114	OFWF		3ϕ		ΔY	-	1983
	13.8/230/13.8	225	300	375	OA/FA/FOA	60/80/100	1ϕ/Auto	4	YYΔ	-	1983
		225	300	375	OA/FA/FOA	60/80/100	1ϕ/Auto	4	YYΔ	-	1983

Table 3 - 3 Existing Substation (As of December, 1992)

(4/4)

Name of Sub-station	Voltage (kV)	Transformer Rating									Year of Opera -tion
		Capacity (MVA)			Cooling Method	Cap. of Tertiary (MVA)	Type	Units	Connect-tion	LTC	
		OA	FA	FOA							
Agoyán	13.8/145	85	85	85	FOA	-	3ϕ		ΔY	-	1987
	13.8/145	85	85	85	FOA	-	3ϕ		ΔY	-	1987
Paute C	13.8/246.3	134	134	134	OFWF	-	3ϕ		ΔY	-	1992
	13.8/246.3	134	134	134	OFWF	-	3ϕ		ΔY	-	1992
	13.8/246.3	134	134	134	OFWF	-	3ϕ		ΔY	-	1992
	13.8/246.3	134	134	134	OFWF	-	3ϕ		ΔY	-	1992
	13.8/246.3	134	134	134	OFWF	-	3ϕ		ΔY	-	1992
Sum		2,274	2,509	2,731							
Total (1)+(2)+(3)		4,148 (20)	4,997 (27)	5,800 (33)							

Note: Number inside a parenthesis shows the capacity of stand-by facility, the Number is not included in the total capacity.

Table 3 - 4 Interrupted for Origin of - SNI - Line Faults

Name of Transmission Line	1990		1991		1992	
	Nos.	Hours	Nos.	Hours	Nos.	Hours
230 kV Line						
Sta.Rosa-Sto. Domingo	0	0	0	0	1	0.62
Sto.Domingo-Quevedo	0	0	2	0.76	0	0
Quevedo-Pascuales	0	0	0	0	0	0
Pascuales-Milagro	1	0.77	2	1.71	0	0
Milagro-Paute	3	2.40	3	1.03	9	9.54
Paute-Riobamba	-	-	-	-	1	0.44
Riobamba-Totoras	2	0.33	0	0	1	0.39
Totoras-Sta.Rosa	0	0	1	0.65	0	0
Subtotal	6	3.5	8	4.15	12	10.99
138 kV Line						
Pisayambo-Ambato	0	0	0	0	0	0
Pisayambo-Vicentina	0	0	2	0.24	0	0
Vicentina-Ibarra	3	1.11	2	1.97	1	0.35
Guangopolo-Vicentina	0	0	0	0	0	0
Vicentina-Sta.Rosa	0	0	0	0	1	0.83
S.Domingo-Esmeraldas	3	1.75	6	21.65	4	2.73
Quevedo-Portoviejo	0	0	1	0.27	1	0.13
Pascuales-Salitral	0	0	0	0	0	0
Paute-Cuenca	1	0.17	0	0	1	0
Milagro-Babahoyo	0	0	1	0.13	2	0.32
Agoyán-Totoras	0	0	0	0	0	0
Pascuales-Sta.Elena	6	2.95	6	2.83	0	0
Pascuales-Posorja	6	1.93	4	1.77	1	0.15
Milagro-Machala	5	5.30	4	1.19	8	19.17
Cuenca-Loja	4	1.72	3	0.47	1	0.23
Totoras-Ambato	0	0	1	2.65	0	0
Pascuales-Policentro	1	0.20	2	0.68	1	0.15
Subtotal	28	15.13	32	33.85	19	23.91
Total	34	18.63	40	38.00	31	34.9

Table 3 - 5 Programmed Interruption of - SNI - Transmission Lines

Name of Transmission Line	1990		1991		1992	
	Nos.	Hours	Nos.	Hours	Nos.	Hours
230 kV Line						
Sta.Rosa-Sto. Domingo	0	0	0	0	0	0
Sto.Domingo-Quevedo	0	0	0	0	0	0
Quevedo-Pascuales	0	0	0	0	0	0
Pascuales-Milagro	0	0	0	0	0	0
Milagro-Paute	0	0	0	0	0	0
Paute-Riobamba	-	-	-	-	1	0.55
Riobamba-Totoras	1	6.50	0	0	0	0
Totoras-Sta.Rosa	0	0	0	0	0	0
Subtotal	1	6.50	0	0.00	1	0.55
138 kV Line						
Pisayambo-Ambato	0	0	0	0	0	0
Pisayambo-Vicentina	0	0	0	0	0	0
Vicentina-Ibarra	1	0	2	14.85	0	0
Guangopolo-Vicentina	0	0	0	0	0	0
Vicentina-Sta.Rosa	0	0	0	0	0	0
S.Domingo-Esmeraldas	1	6.97	0	0	2	21.55
Quevedo-Portoviejo	2	37.48	1	1.17	1	1.5
Pascuales-Salitral	0	0	0	0	0	0
Paute-Cuenca	0	0	0	0	1	11.25
Milagro-Babahoyo	0	0	0	0	0	0
Agoyán-Totoras	0	0	0	0	0	0
Pascuales-Sta.Elena	8	65.89	2	16.55	2	14.00
Pascuales-Posorja	6	53.53	8	56.92	2	15.26
Milagro-Machala	0	0	3	5.70	3	16.29
Cuenca-Loja	1	5.05	1	8.75	2	12.40
Totoras-Ambato	2	24.07	0	0	0	0
Pascuales-Policentro	0	0	0	0	0	0
Subtotal	18	168.91	17	103.94	13	92.25
Total	19	175.41	17	103.94	14	92.80

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CHAPTER 4 POWER DEMAND PROJECTION AND SUPPLY PLAN

4.1 Power Demand Projection

4.1.1 Past Trend of Power Demand and Economic Growth

Generally speaking, power demand of a nation grows with the growth of its GDP. The past trend of GDP and power demand in Ecuador have been studied, and their correlation is illustrated in Table 4-1.

In reference to Table 4-1, the economic growth rate has been from 5% to 10% during the recent period from 1990 to 1992. According to INECEL's materials, it is expected that the economic growth of this country continues to exhibit this trend after 1992.

On the other hand, the rate of population growth has been 2.7% in annual average until early 1980's, but it showed a tendency of gradual slow down in 1990's, which was 2.4% in 1990. It is estimated that the population growth rate of 2.4% will continue in the future.

4.1.2 Power Demand Projection Methodology

Generally speaking, there are two methods to project the power demand of a nation. One is the macroscopic method by which the long to medium term power demand is projected based on macroscopic indices such as the growth rate of economic and social activities and the structural changes of industries. Another method is the microscopic method by which the short time projection of power demand is projected by the trend in the business cycle. In this study, the power demand is projected for the period from 1993 to 2010 by the macroscopic method.

4.1.3 Result of Power Demand Projection

The macroscopic projection of power demand as established by this methodology is given in Fig. 4-1 and 4-2.

The values are low as a whole compared the power demand projection of INECEL.

The difference, in 2003, is about 3.5% in terms of energy demand, and there is a relatively good correlation between the two.

The differences in result of power demand projection results of INECEL and JICA are small, but in the demand and supply balance plan, the power demand projection results of INECEL which are on the larger side are to be adopted taking into consideration a margin of safety.

4.2 Power Supply Plan

4.2.1 Electric Power Development Plan

The electric power development plan of INECEL is based on the utilization of this rich water resource, and in its electrification master plan (1993 - 2002) MARZO-1993-3, the development of hydroelectric power plants is the mainstay with the construction of thermal electric plants supplementing the deficit.

4.2.2 Power Demand/Supply Balance

In our present plan, basically, the power demand/supply balance was examined, with the electric power development plan of INECEL taken into consideration.

The power demand/supply balance was examined in both the kW capacity and in the kWh capacity, for the period between 1993 and 2003.

The kW balance was studied for a peak day in the month of December when the power demand peaks and the water supply is most scarce.

On the other hand, the kWh balance was studied for the annual total power demand.

Summary of study results

The results of the study on the electric power development plan from 1993 to 2003 conducted by INECEL and JICA are shown in Fig. 4-3 and Fig. 4-4.

In the kW and kWh balances study for the INECEL plan, the firm output and firm energy are examined, for the hydroelectric power plants.

With respect to the thermal power plants, the effective output and the effective energy are studied for demand-supply balance.

The effective energy in this study is calculated from the gas thermal power station capacities (vapor and diesel) with annual plant utilization factor of 90% and 85% respectively for vapor and diesel. The plant utilization factor for the peak stand-by thermal power station (gas) is assumed to be 40%.

In the JICA's proposal, the annual plant utilization factor for the base thermal power plant output (vapor and diesel) is assumed to be 70%. This annual plant utilization factor of 70% is the long-term utilization factor in which annual inspection (15 - 20%) and the power loss resulting from load adjustment (5%) is taken into consideration.

In other respects, the concept is the same between the INECEL plan and the JICA plan.

As a result, it is possible that the kWh balance will not be satisfied until 1995 with the JICA plan. (Without a new power source, the energy shortage will be brought about in case of water shortage.) For this reason, new thermal power plants are required to deal with this supply shortage. However, it would be difficult to construct new thermal power plant in time in view of the construction lead time of such power plants, and the best we can hope for is that Paute Power Plant is provided with sufficient river runoff during this period.

INECEL is planning gas thermal power plants which can be constructed quickly for the purpose of resolving the kWh shortage during this period. In view of little time available, such a plan would be excusable.

Daule Peripa Hydropower Station (130MW) and Manta Thermal Power Station (140MW) are scheduled to be commissioned in 1996. The kWh balance will be satisfied in this year, however, energy will be shortened again in 1997. Therefore, an addition of 125 MW (Vapor) base thermal power generation facility to the plan of INECEL will be required. Instead, however, this JICA adjustment makes the 30 MW (gas) thermal power plant planned for 2003 in the INECEL scenario superfluous, but requires all the other thermal power plants to advance their operation start by one year.

With respect to the kW balance, in the INECEL plan, as well as in the JICA's adjustment proposal, the total capacity is so large that even when both the largest hydroelectric unit and the largest thermal power unit fail on the peak demand day, there will be no power shortage and no possibility of kW imbalance.

Since the newly to be built hydroelectric power plants are large ones in SNI, scheduled to assume vital roles in both kW balance and kWh balance, their delay in operation start would possibly cause power deficit again as in 1992, so that their development strictly on schedule is very important.

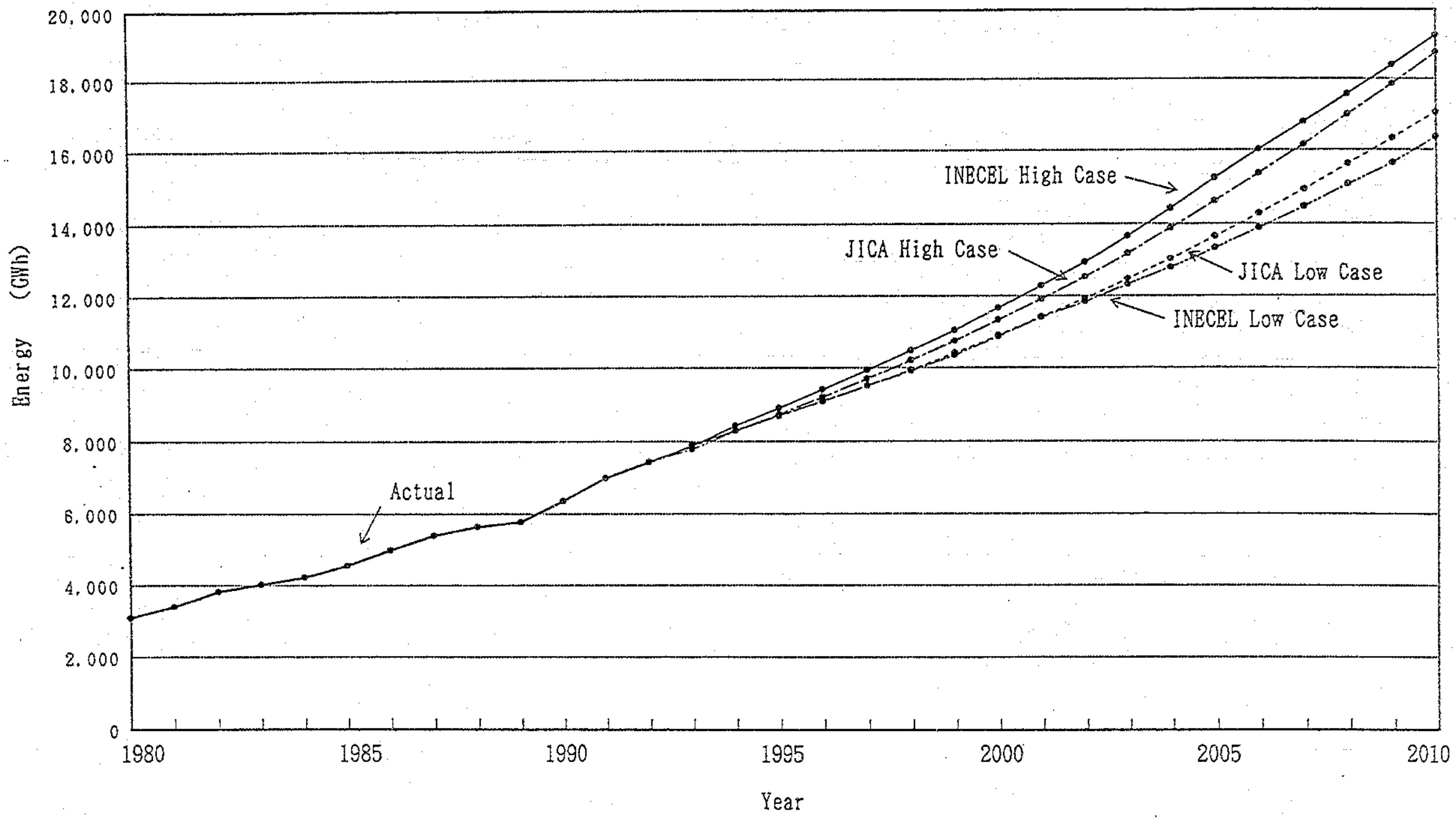

Fig. 4-1 Demand Forecast of Ecuador (1980-2010)

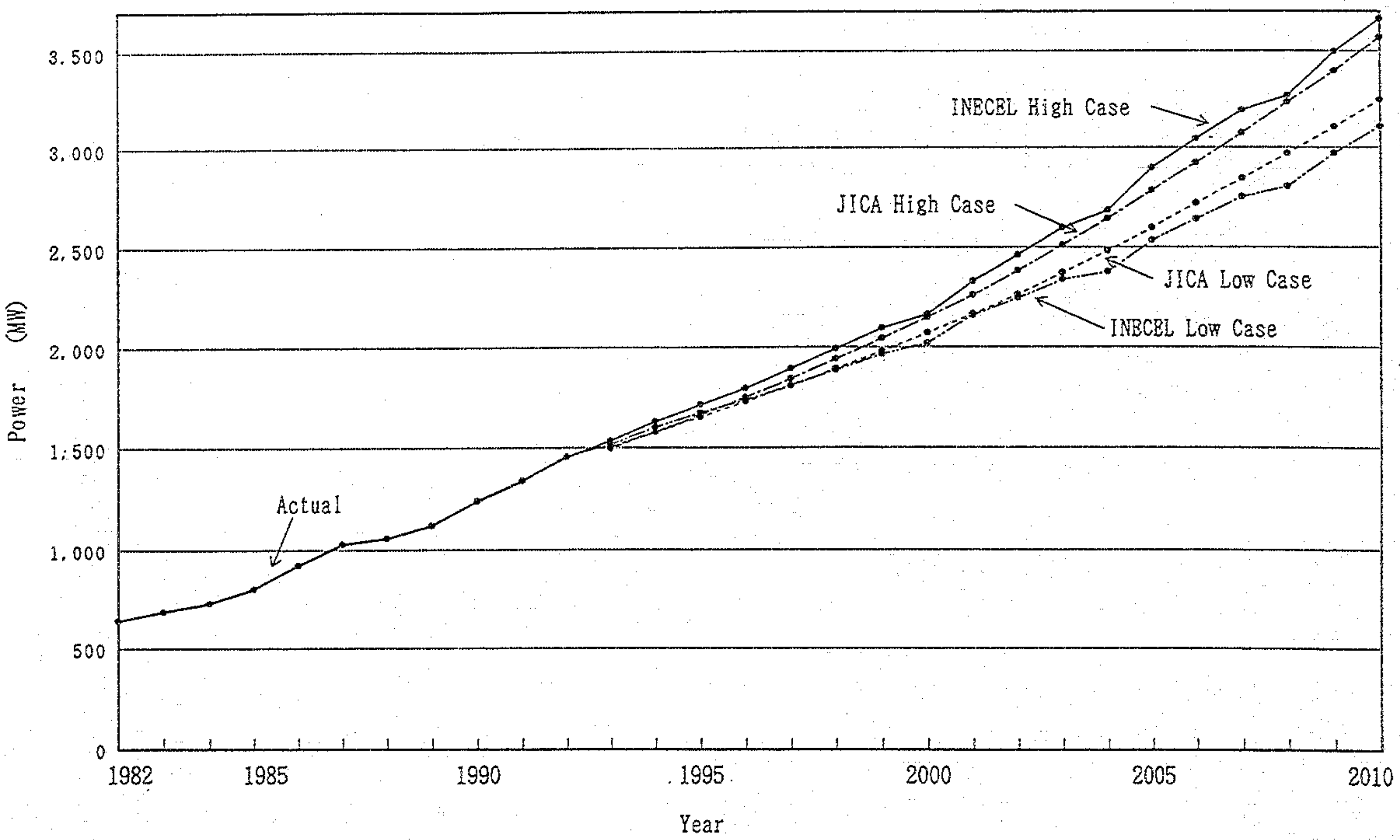

Fig. 4-2 Peak Power Forecast (1982-2010)

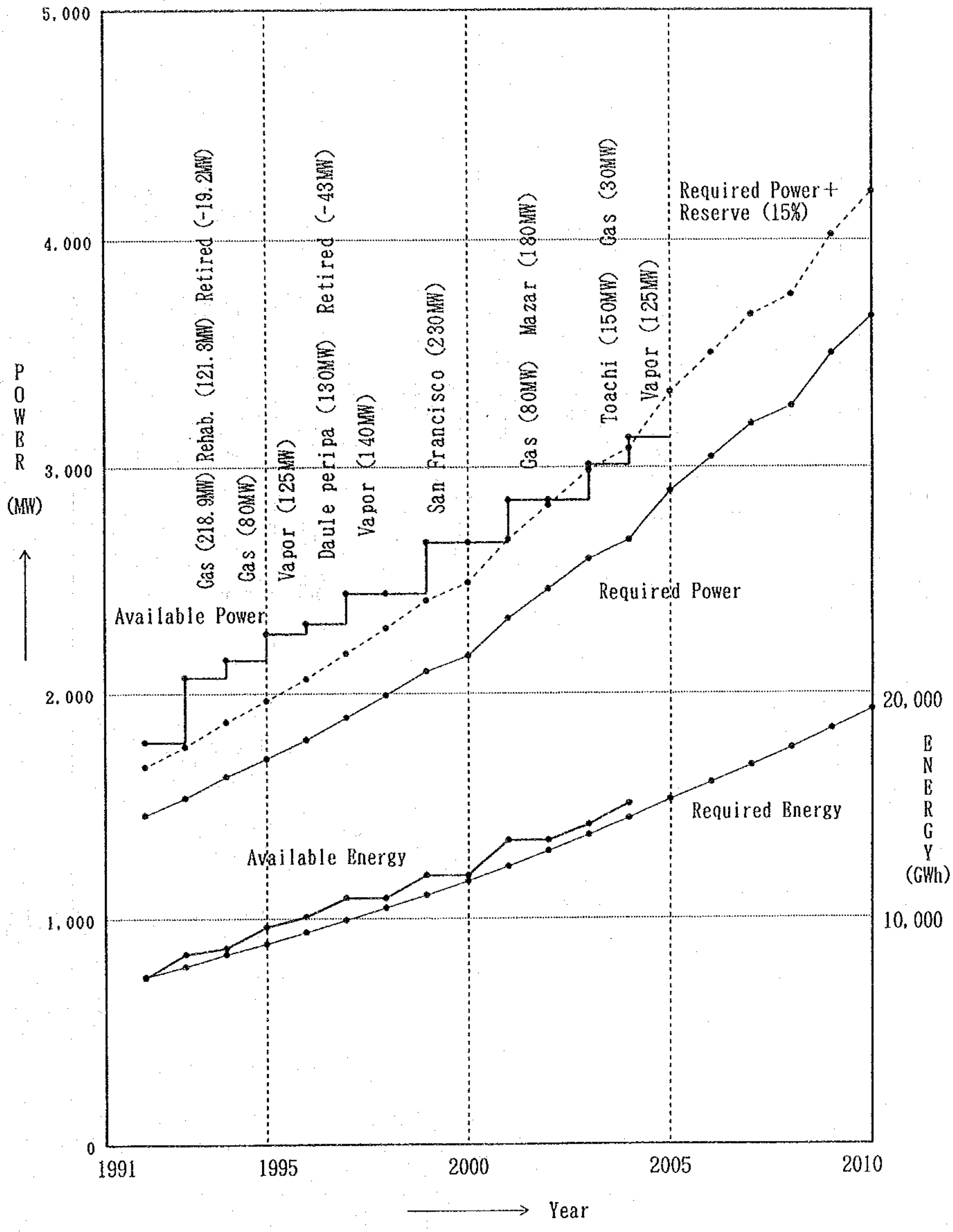

Fig. 4-3 Power Balance and Energy Balance
Alternative I (INECEL Plan)

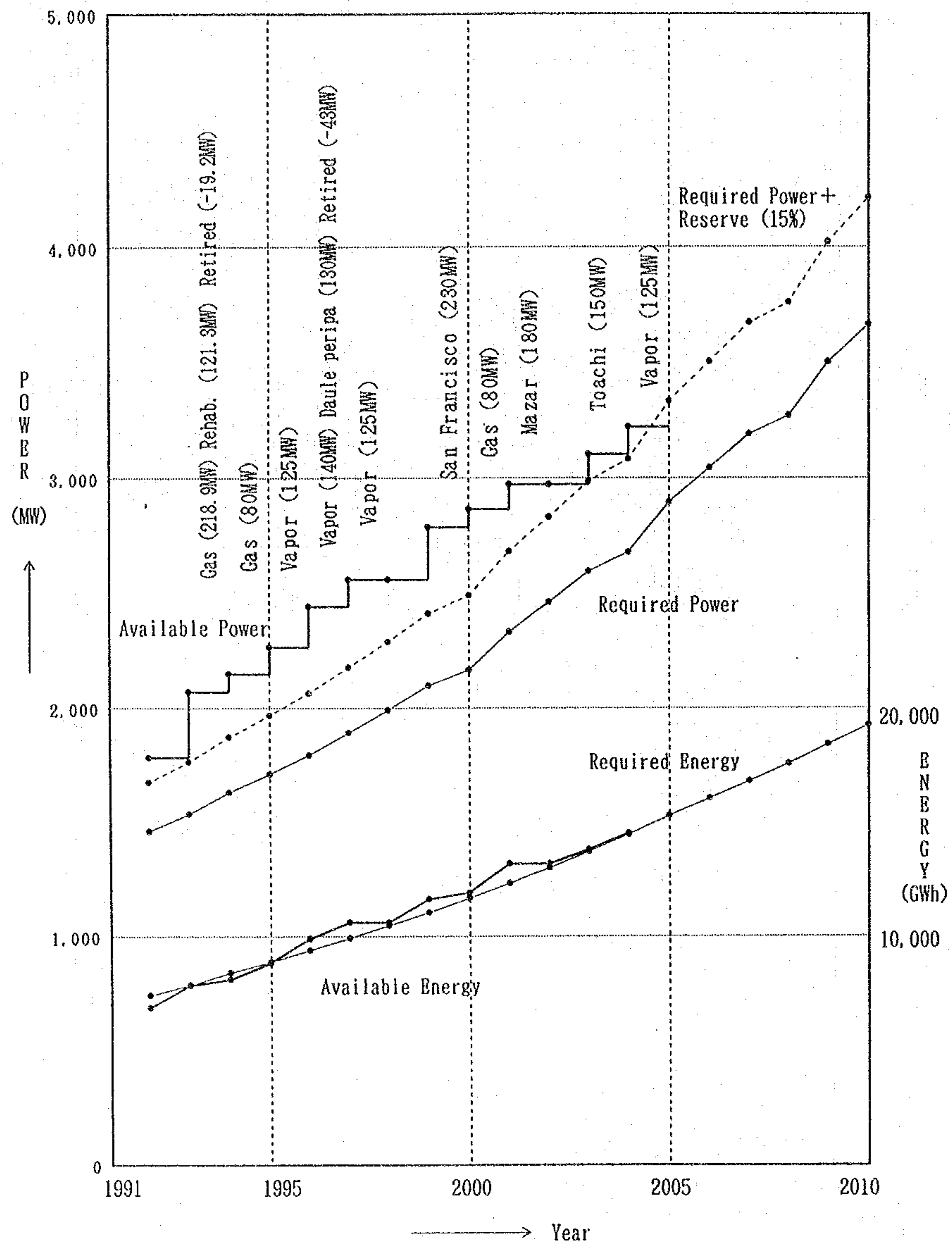

Fig. 4-4 Power Balance and Energy Balance
Alternative 2 (JICA Plan)

Table 4-1 Basic Data for Demand Forecast

(at the price levels and exchange rate of 1980)

	G.D.P (US$)		Energy Demand		Population		G.D.P./Capita		Energy/Capita		Power
Year	(Million)	Rate (%)	(GWh)	Rate (%)	(thousand)	Rate (%)	(US$)	Rate %	(kWh)	rate (%)	(MW)
1970	1,681.2		786		5,969.92		281.6		131,700		
1971	1,586.1	-5.66	865	10.05	6,146.60	2.96	258.0	-1.91	140,700	3.40	
1972	1,855.8	17.00	957	10.64	6,328.51	2.96	293.2	5.75	151,200	3.59	
1973	2,491.2	34.24	1046	9.30	6,515.80	2.96	382.3	11.57	160,500	3.14	
1974	3,718.0	49.25	1221	16.73	6,708.64	2.96	554.2	16.64	182,000	5.65	
1975	4,318.2	16.14	1423	16.54	6,907.19	2.96	625.2	5.45	206,000	5.59	
1976	4,888.3	13.20	1663	16.87	7,106.22	2.88	687.9	4.58	234,000	5.85	
1977	6,155.2	25.92	1977	18.88	7,311.00	2.88	841.9	8.99	270,400	6.55	
1978	7,217.8	17.26	2351	18.92	7,521.67	2.88	959.6	5.99	312,600	6.57	
1979	8,639.7	19.70	2718	15.61	7,738.41	2.88	1,116.5	6.84	351,200	5.42	
1980	10,804.3	25.05	3081	13.36	7,961.40	2.88	1,357.1	8.69	387,000	4.63	
1981	12,505.8	15.75	3393	10.13	8,176.90	2.71	1,529.4	5.82	414,900	3.74	
1982	12,187.5	-2.55	3819	12.56	8,398.24	2.71	1,451.2	-0.94	454,700	4.64	638
1983	6,732.4	-44.76	4015	5.13	8,625.57	2.71	780.5	-16.54	465,500	1.90	684
1984	8,771.0	30.28	4217	5.03	8,859.05	2.71	990.1	11.19	476,000	1.86	726
1985	11,502.0	31.14	4546	7.80	9,098.85	2.71	1,264.1	11.50	499,600	2.88	800
1986	11,207.5	-2.56	4972	9.37	9,320.81	2.44	1,202.4	-1.05	533,400	3.84	922
1987	10,495.4	-6.35	5388	8.37	9,548.18	2.44	1,099.2	-2.60	564,300	3.43	1,027
1988	9,776.4	-6.85	5632	4.53	9,781.11	2.44	999.5	-2.81	575,800	1.86	1,057
1989	9,538.1	-2.44	5770	2.45	10,019.71	2.44	951.9	-1.00	575,900	1.00	1,120
1990	10,522.3	10.32	6360	10.23	10,264.13	2.44	1,025.2	4.23	619,600	4.19	1,240
1991	11,457.0	8.88	6988	9.87	10,514.52	2.44	1,089.6	3.64	664,600	4.05	1,340
1992	12,016.3	4.88	7422	6.21	10,771.01	2.44	1,115.6	2.00	670,300	2.55	1,442

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Chapter 5 Power System Analysis

5.1 Study Conditions

The power systems were studied based on the power system expansion plan formulated by INECEL. The study was conducted for the following years.

Years Studied: 1993, 1998, 2003

The studies on years 1998 and 2003 were conducted on two typical time sections of wet season (June) and dry season (December).

The standard voltage at load side during steady state operations and under faulty conditions are stipulated by INECEL as follows.

Normal Condition ; 97 - 103% Faulty Condition ; 90 - 105%

A single failure (n - 1) criterion was adopted for the evaluation of power system stability. The faults condition assumed was an occurrence of permanent 3-phase short circuit on one circuit of transmission line, with successful clearing and no reclosing operation. In this report, Paute-Milagro 230 kV transmission line was selected as the faulted line. The fault clearing time was set at 5-cycle clearing operation, which is being applied to the 230 kV systems of INECEL. In addition, 2-circuit faults were also assumed on Paute-Milagro line for the studies of 1998 and 2003, although the frequency of such fault would be rare.

5.2 Study of 1993 Time Section

(1) Power Flow

The power flow calculation result, which was calculated in reference to the real power flow in March, 1993, is presented in Fig. 5-1. The operating voltage values at load ends fell within the standard band, except at several locations such as Selva and Alegre Substation. There was no transmission line or transformer that was overloaded.

(2) Short Circuit Current

The short circuit current values at 230 kV busses and 138 kV busses did not exceed the rated rupturing current.

(3) Power System Stability

The power system stability calculation results, which were calculated for 1 circuit, 3LG-3LO faults on Paute-Milagro 230 kV transmission line under the power flow conditions described in Paragraph (1), are given in Fig. 5-2. The power system stability was maintained.

5.3 Study of 1998 Time Section

(1) Power Flow

The power flow calculation results are presented in Fig. 5-3 and Fig. 5-4.

The power flow in Fig. 5-3 is on the time section of June, while that of Fig. 5-4 is on the time section of December when Paute Power Plant is in the dry season. The power generation of Paute Power Plant is reduced from 1,008 MW to 915 MW, and the power flow between Paute and Pascuales is light.

In both cases, the operating voltage values at load ends fell within the standard band, and there was no transmission line that was overloaded.

(2) Short Circuit Current

The short circuit current values at 230 kV busses and 138 kV busses did not exceed the rated rupturing current value.

(3) Power System Stability

(a) June Time Section

The results of power system stability calculations for single circuit, 3LG-3LO and double circuit, 3LG-3LO on Paute-Milagro 230 kV transmission line are presented in Fig. 5-5 and Fig. 5-6, respectively. As the power system was unstable under the power flow condition of Fig. 5-3, the power flow condition of Fig. 5-7, in which the power generation of Paute-C was reduced to 954 MW, was used. The results of these calculations were stable in both cases.

(b) December Time Section

The results of power system stability calculations for single circuit, 3LG-3LO and double circuit, 3LG-3LO on Paute-Milagro 230 kV transmission line are presented in Fig. 5-8 and Fig. 5-9, respectively. The power swing was less severer than in the case of Paragraph (a), and the power system was stable in both cases.

5.4 Study of 2003 Time Section

(1) Power Flow

The power flow calculation results are presented in Fig. 5-10 and Fig. 5-11. The power flow in Fig. 5-10 is the case where Pascuales Power Plant is in the wet season, or the June time section, and the power flow in Fig. 5-11 is for the dry season of December time section. In the dry season, the output of Paute Power Plant is reduced from 972 MW to 798 MW, and the power flow between Paute-Pascuales is lighter.

In both cases, the operating voltage values at load ends fell within the standard band. There was no transmission line or transformer that was overloaded.

(2) Short Circuit Current

The short circuit current values at 230 kV busses and 138 kV busses did not exceed the rated rupturing current value.

(3) Power System Stability

(a) June Time Section

The results of power system stability calculations for single circuit, 3LG-3LO and double circuit, 3LG-3LO on Paute-Milagro 230 kV transmission line are presented in Fig. 5-12 and Fig. 5-13, respectively. As the power system was unstable when a double circuit fault occurred under the power flow of Fig. 5-10, the power generation at Paute was reduced to 915 MW and power flow condition of Fig. 5-14 was used. The power system was stable in both cases.

(b) December Time Section

The results of power system stability calculations for single circuit, 3LG-3LO and double circuit, 3LG-3LO on Paute-Milagro 230 kV transmission line are presented in Fig. 5-15 and Fig. 5-16, respectively. The power swing was less severe than in the case of Paragraph (a), and the power system was stable in both cases.

5.5 Summary of Analytical Results

Although there was no particular problem with the short circuit current level and the overloading of transmission lines and transformers, concerning the operating voltage conditions in the 1993 time section, the operating voltage at a few substations in the northern region did not fell within the allowable range. Although the power system was stable in the 1993 time section, the system was near the stability limit.

In the study of 1993 time section, analytical studies were conducted on the actual power flow record at March time section. No particular countermeasure has been recommended. The above problems would be alleviated in 1998 and 2003 time sections as the transmission line from Paute to Pascuales is reinforced to 4 circuits, and the power development projects near Guayaquil and in the northern region are implemented according to INECEL's plan. This will enable to operate Paute Power Plant at approximately rated power in the wet season of June.

Year.Month	Paute Output (MW)	Stability Study Result	
		1 cct	2 cct
1988. 6	1,008 954	O O	~ O
1998. 12	915	O	O
2003. 6	972 915	O O	~ O
2003. 12	798	O	O

However, some transformer taps and phase compensating condensers will be required in some substations in the northern region power system in 1998 and 2003 time sections in order to maintain voltage in steady state operations.

5.6 Frequency Drop and Load

The sum of the total changes of the generator output and the total changes of loads for a frequency deviation of 0.1 Hz is call the frequency constant (K) of the power system, and this value represents the performance of generators and loads that constitute the power system. This value is normally in the range given below.

Power System Frequency Constant, K = 1.20 --- 1.55 %MW/0.1 Hz

5.6.1 Load Shedding

INECEL has stipulated in its power supply contracts with each power companies that the frequency relays are installed on the switches of 13.8 kV distribution lines and other feeders to shed the loads in proportion to the magnitude of frequency drop in the event of loss of supply sources int he power system. This arrangement is made to separate sources in the power system. This arrangement is made to separate the circuit breakers at interconnection points to maintain the power system frequency, and even under the worst circumstance, the power system stability is maintained and isolated power systems can survive.

When the power system frequency drops to 58.5 Hz or below, the power systems of EMELEC and EEQ are isolated to independent operations.

5.6.2 Actual Measurement of Frequency Constant (K)

The power system frequency constant (K) can be obtained by examining the past records on the loss of supply events in the power system. In such an attempt, attention must be paid on the total capacity of generators which were connected to the power system, the size of loads, and the frequency drop observed in such an event. If these three variables can be determined, the frequency constant (K) of SNI Power System can be determined.

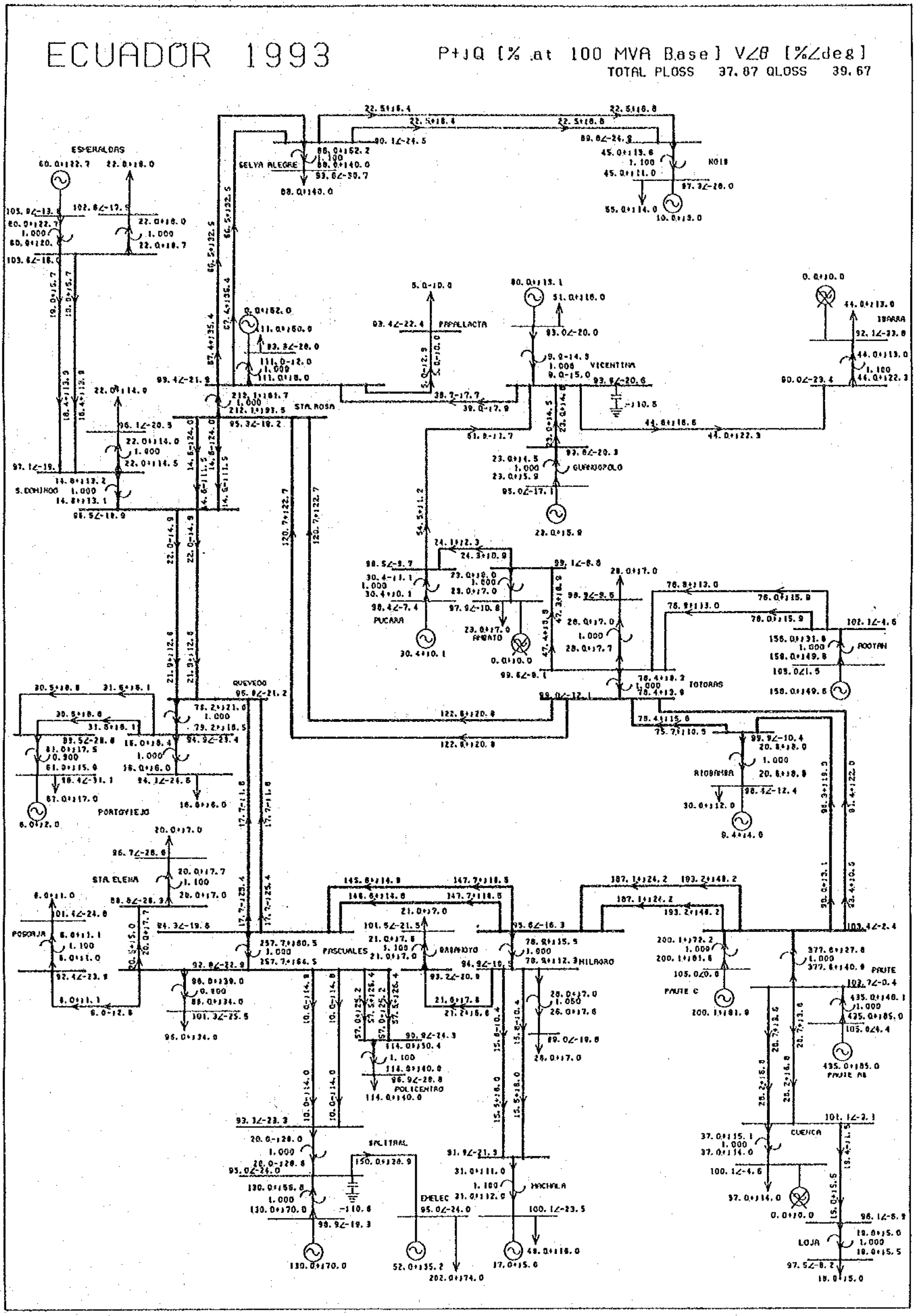
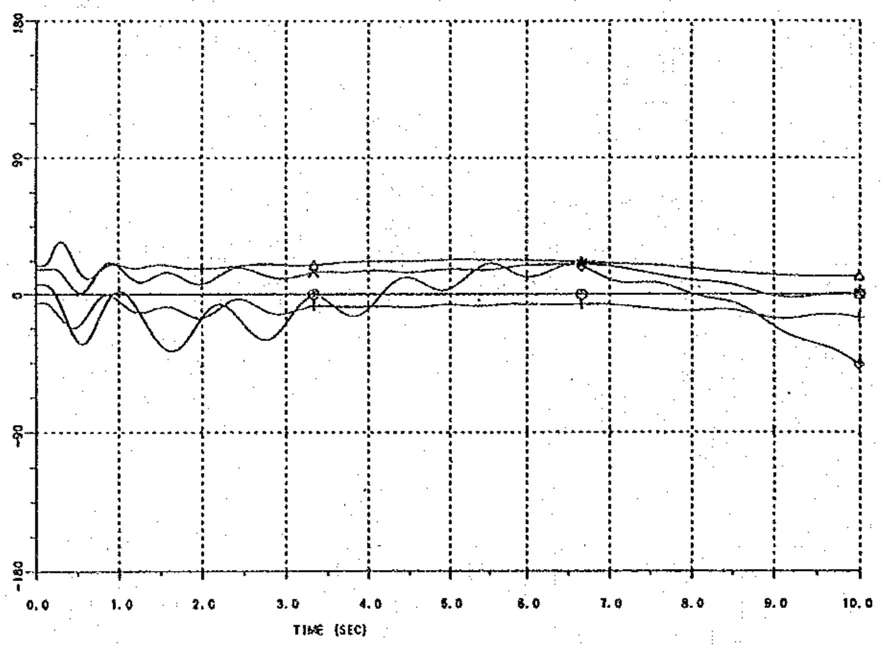


Fig. 5-1 Power Flow 1993

ECUADOR 1993 BR04-1 (PAUTE-MILAGRO) 3LG-0

	Code	Term	Comment	Max	Min	Initial	Final
1	NOG-08	ANG	PAUTE-C	0.00	0.00	0.00	0.00
2	NOG-09	ANG	PAUTE-AB	34.78	10.51	19.44	12.30
3	NOG-14	ANG	PISAYANG	-0.48	-22.18	-5.58	-15.32
4	NOG-13	ANG	AGOYAN	21.27	-2.03	16.81	0.41
5	NOG-05	ANG	SALITRAL	20.70	-46.43	6.67	-46.43



ECUADOR 1993 BR04-1 (PAUTE-MILAGRO) 3LG-0

	Code	Term	Comment	Max	Min	Initial	Final
1	NOG-08	ANG	PAUTE-C	0.00	0.00	0.00	0.00
2	NOG-18	ANG	STA. ROSA	-5.08	-81.01	-39.22	-76.67
3	NOG-07	ANG	MACHALA	-0.82	-47.28	-12.37	-47.28
4	NOG-01	ANG	ESMERALD	30.09	-56.94	-5.57	-50.39

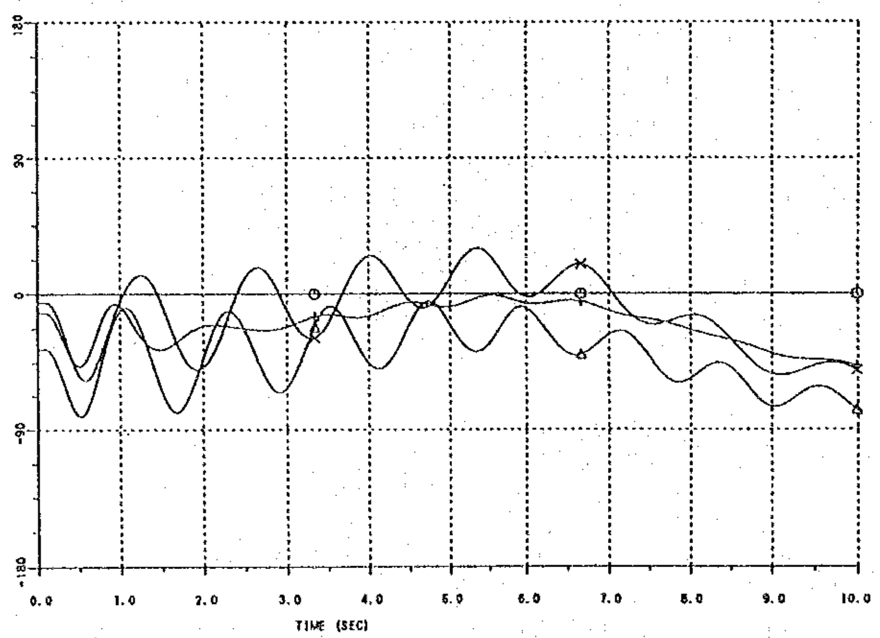


Fig. 5-2 Power System Stability Analisis at 1 CCT Line Fault (under power flow condition of Fig. 5-1)

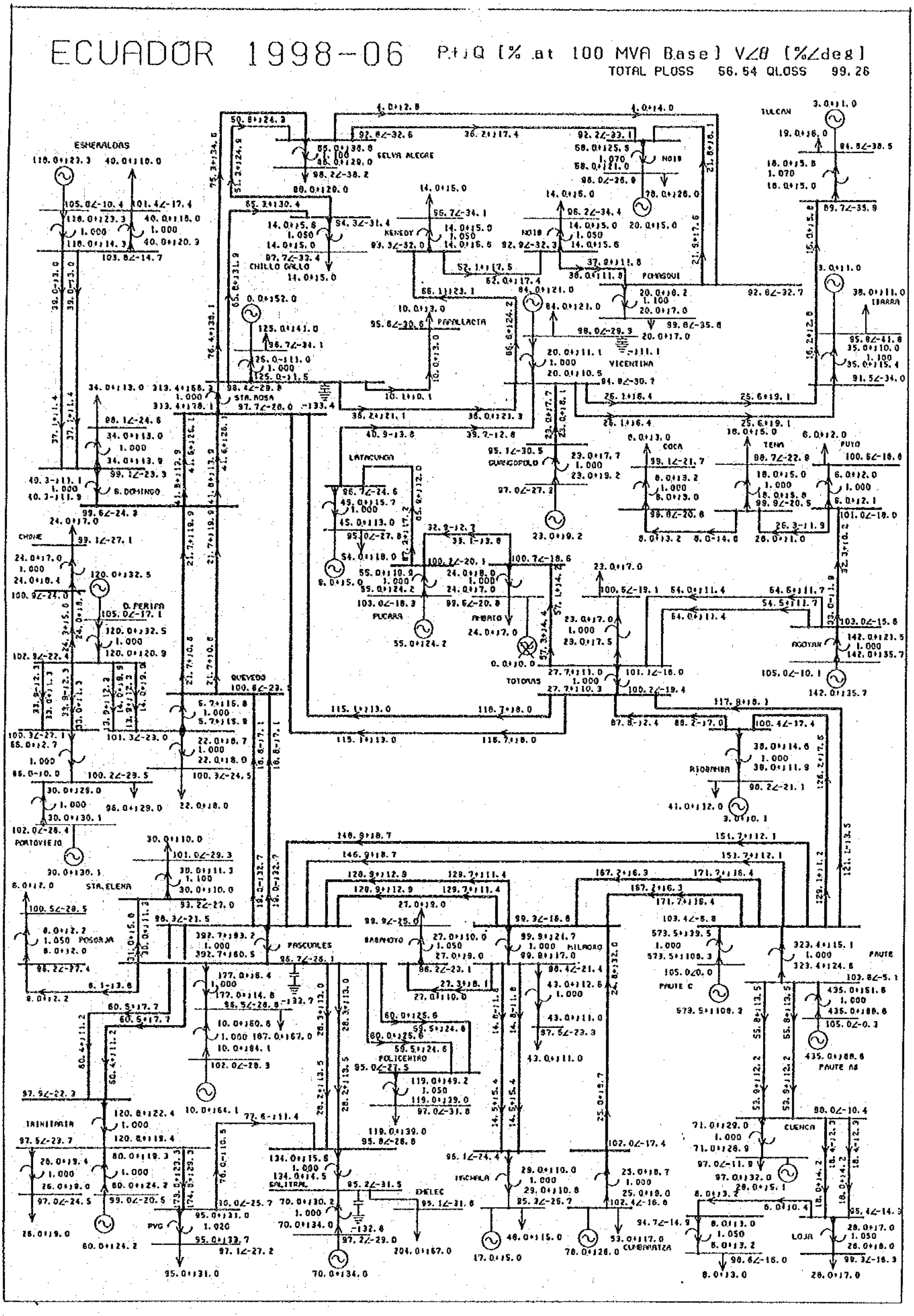


Fig. 5-3 Power Flow in June, 1998

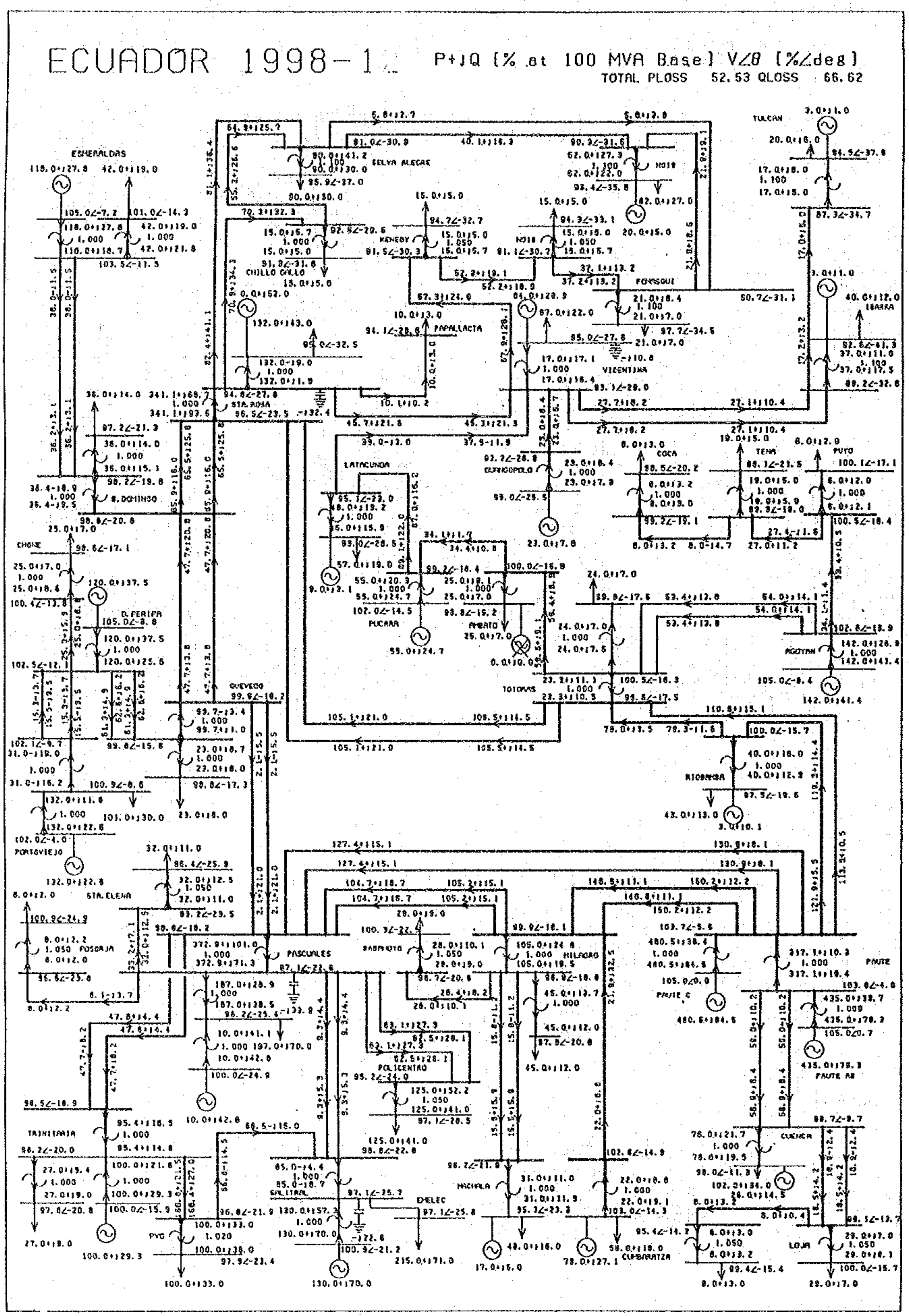
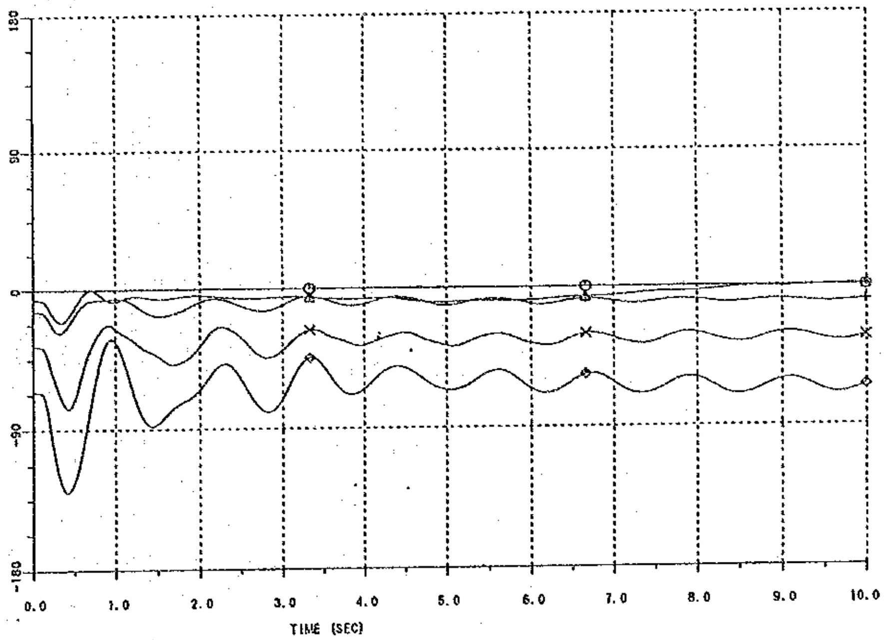


Fig. 5-4 Power Flow in December, 1998

ECUADOR 1998 .6 BR04-1 (PAUTE-MILAGRO) 3LG-0

	Code	Term	Comment	Max	Min	Initial	Final
1 —⊖—	NOG-08	ANG	PAUTE-C	0.00	0.00	0.00	0.00
2 —△—	NOG-09	ANG	PAUTE-AB	0.68	-20.75	-6.34	0.42
3 —+—	NOG-11	ANG	CUENCA	-5.33	-27.73	-13.78	-9.38
4 —×—	NO-60	ANG	LATCUNGA	-22.68	-76.49	-36.45	-32.84
5 —◇—	NOG-16	ANG	IBARRA	-32.02	-129.76	-65.92	-64.74



ECUADOR 1998-06 BR04-1 (PAUTE-MILAGRO) 3LG-0

	Code	Term	Comment	Max	Min	Initial	Final
1 —⊖—	NOG-08	ANG	PAUTE-C	0.00	0.00	0.00	0.00
2 —△—	NOG-05	ANG	SALITRAL	3.85	-119.57	-40.37	-31.38
3 —+—	NO-46	ANG	RIOBAMBA	-29.77	-80.30	-42.07	-38.71
4 —×—	NOG-01	ANG	ESMERALD	44.07	-85.35	-7.92	-6.40
5 —◇—	NOG-15	ANG	GUANGOPL	-24.98	-78.75	-40.37	-37.69

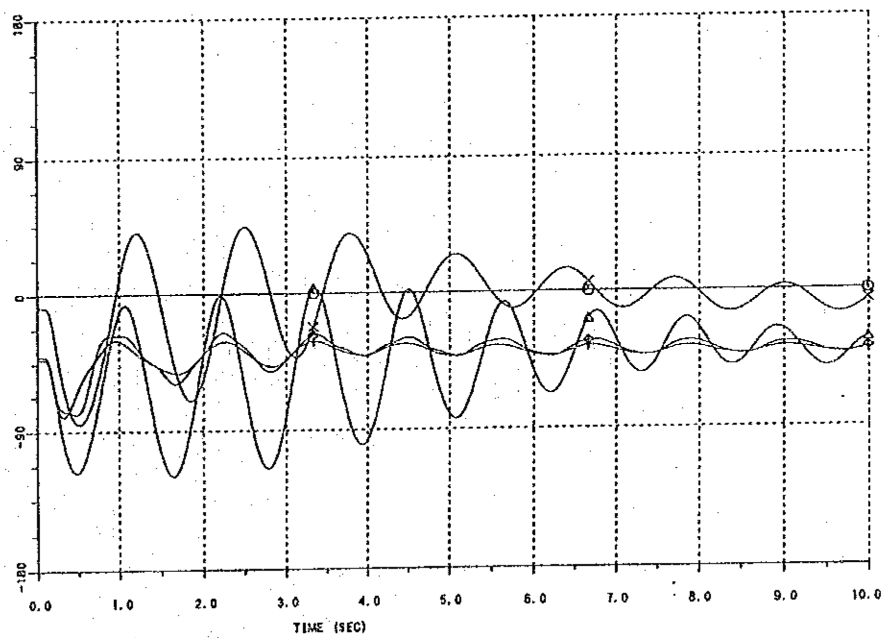
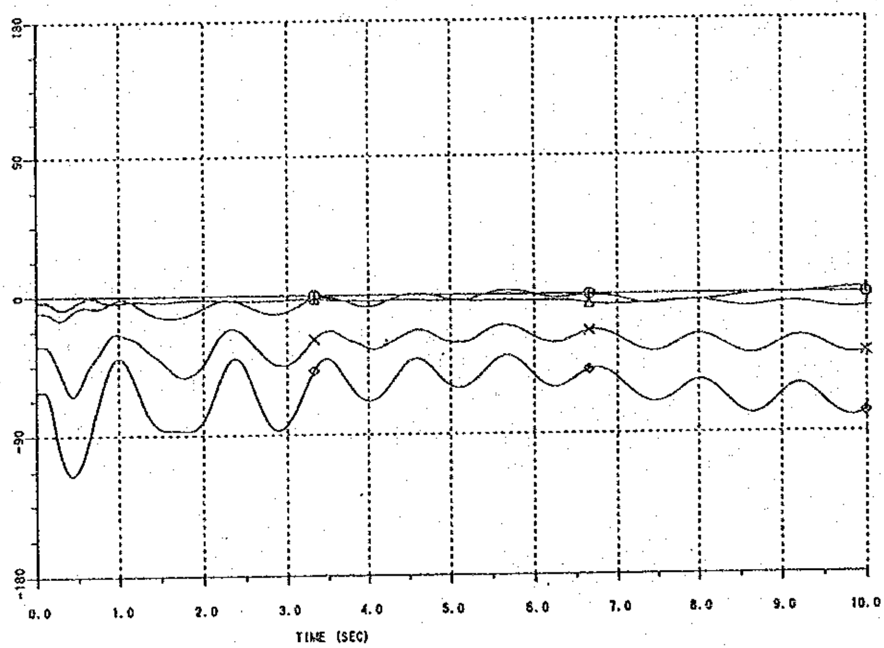


Fig. 5-5 Power System Stability after 1 CCT Line Fault
(under power flow condition of Fig. 5-3)

ECUADOR 1998-06 2CCT (PAUTE-MILAGRO) 3LG-O

	Code	Tera	Comment	Max	Min	Initial	Final
1 —⊖—	NOG-08	ANG	PAUTE-C	0.00	0.00	0.00	0.00
2 —△—	NOG-09	ANG	PAUTE-AB	3.19	-8.10	-3.41	2.93
3 —+—	NOG-11	ANG	CUENCA	2.63	-15.22	-10.45	-9.07
4 —×—	ND-60	ANG	LATCUNGA	-19.94	-64.49	-31.91	-38.18
5 —◇—	NOG-16	ANG	IBARRA	-39.53	-115.09	-61.66	-77.00



ECUADOR 1998-06 2CCT (PAUTE-MILAGRO) 3LG-O

	Code	Term	Comment	Max	Min	Initial	Final
1 —⊖—	NOG-08	ANG	PAUTE-C	0.00	0.00	0.00	0.00
2 —△—	NOG-05	ANG	SALITRAL	11.99	-135.17	-36.54	-72.61
3 —+—	ND-46	ANG	RIOBAMBA	-24.54	-66.14	-38.56	-43.53
4 —×—	NOG-01	ANG	ESMERALD	56.12	-85.04	-3.30	-40.80
5 —◇—	NOG-15	ANG	GUANGOPL	-20.14	-70.08	-35.06	-45.58

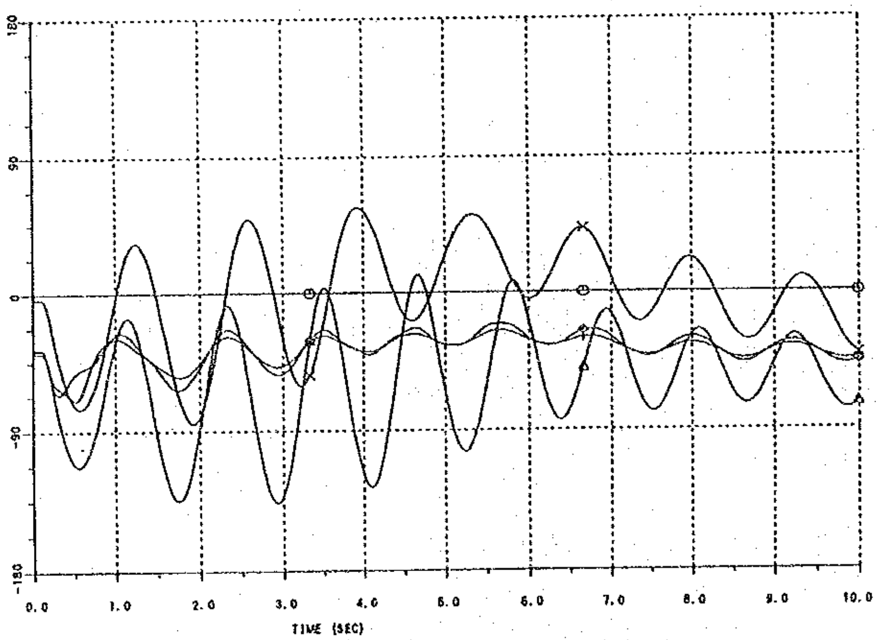


Fig. 5-6 Power System Stability under 2 CCT Line Fault (under power flow condition of Fig. 5-7)

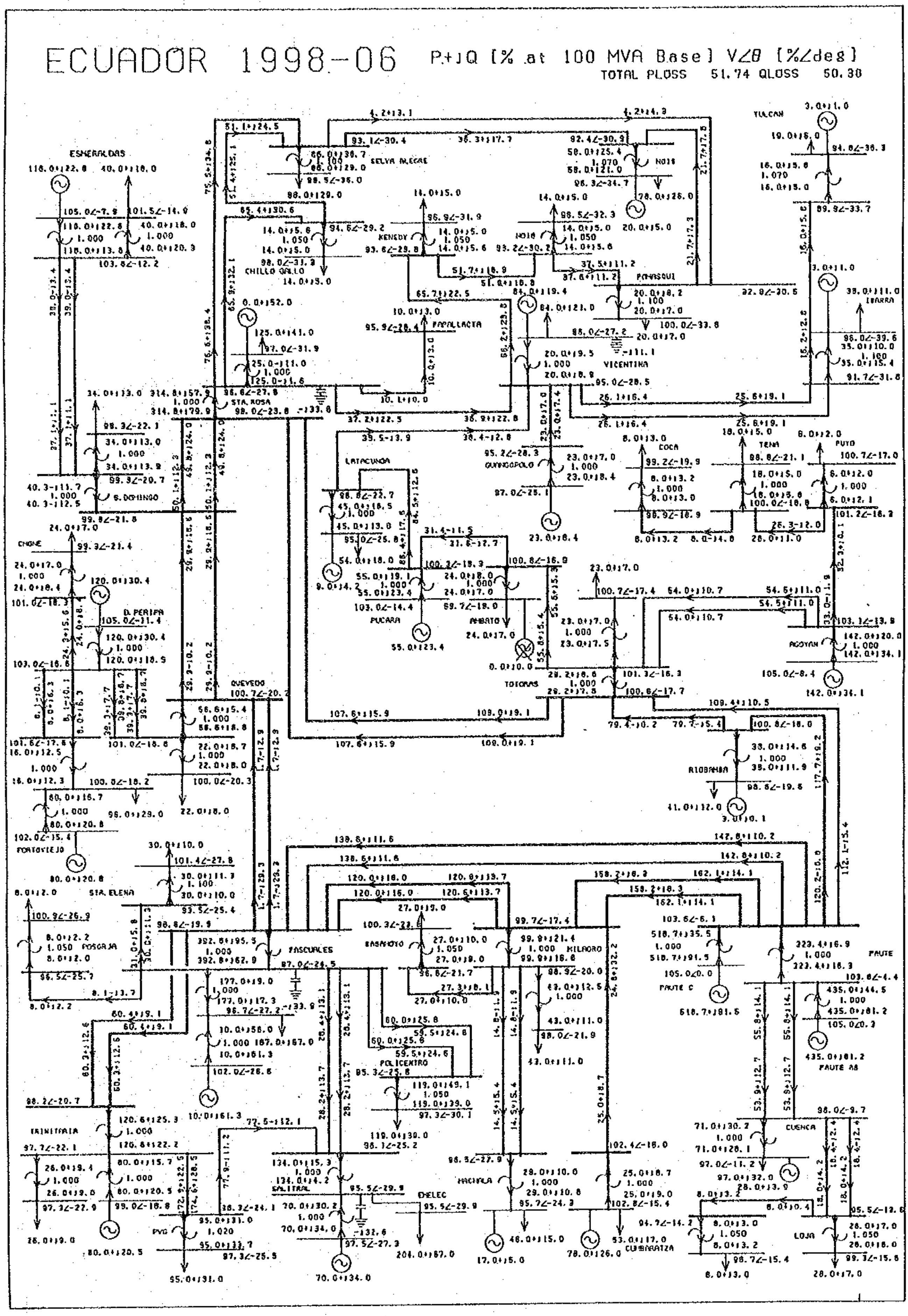
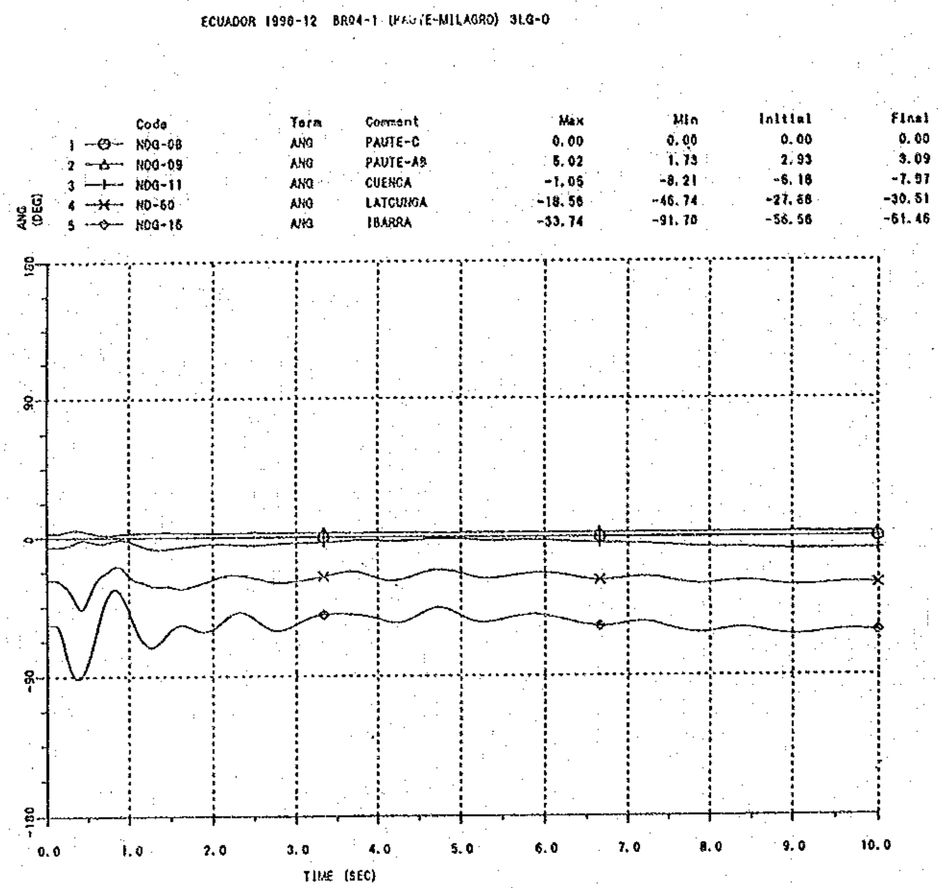


Fig. 5-7 Power Flow in June, 1998 (Case of small output at Paute)



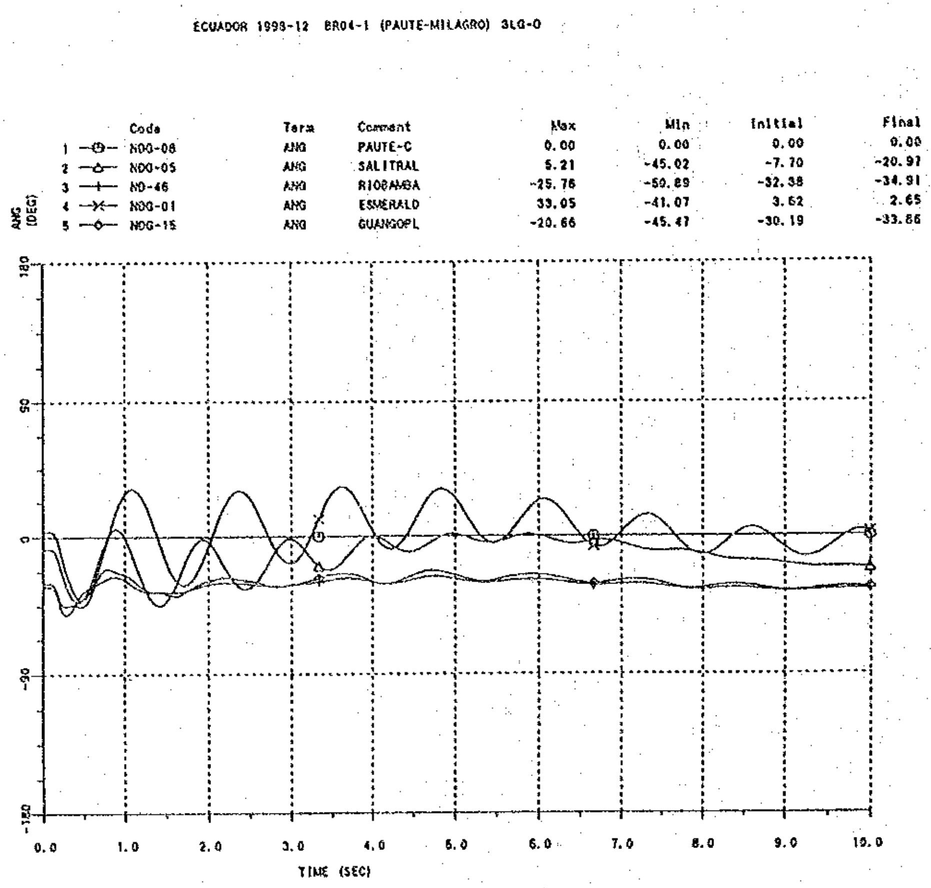


Fig. 5-8 Power System Stability after 1 CCT Line Fault (under power flow condition of Fig. 5-4)