(c) Coordination of insulation

The 150 kV transmission systems in the Province of West Sumatra consists of the following sections between:

- o Maninjau Power Plant - Pauh Limo Substation; and
- o Pauh Limo Substation - Salak Substation.

As shown in Fig. 5.2-2, the insulation level in these two sections varies. In addition, different insulation systems, namely, a line-to-line balanced (standard) insulation system and a unbalanced insulation system, are adopted.

In consideration of these situations, the insulation level and system in the respective sections are determined according to the following reasons under this study.

(i) Insulation level

Any difference in the insulation level of transmission lines, power plant and substations for supplying electric power generated in the Province of West Sumatra to Riau Province will cause a drawback in system operation, reduction of power supply reliability and increase of cost due to excessive insulation design.

Consequently, the insulation level for the transmission lines under this study was determined as shown in Table 5.2-1 to ensure coordination of insulation with the existing equipment because of the reasons explained below.

- o Judging from the number of insulator strings and the efficiency of arcing horn gap of the transmission lines under this feasibility study, an insulation level (impulse flashover voltage) of 750 kV is optimum.

- o Although the insulation level of the Ombilin Power Plant constituting a starting point has not been clarified, the insulation level (impulse flashover voltage) of the 150 kV line between Pauh Limo and Salak connected to the power plant is 750 kV.

- o Although the insulation level of the Padang Luar Substation constituting another starting point has not been made clear, the insulation level (impulse flashover voltage) of its power source line between Maninjau Power Plant and Padang Luar Substation is 895 kV (ten 250 mm dia. suspension type insulators per string without arcing horn).

However, since this area belongs to a frequent lightning occurrence zone, the frequency of power supply failure in transmission line is expected to increase due to frequent damage of insulators resulting from flashover at the time of lightning unless insulators are protected by installing arcing horns. When arcing horns are to be installed to improve power supply reliability while leaving the number of ten insulators per string as it is, the length of arcing horns and insulation level (impulse flashover voltage) become 1,200 mm and 750 kV respectively from the efficiency of arcing horn gap.

(ii) Adoption of balanced insulation system

A balanced insulation system is adopted for the transmission lines according to the following reasons:

- o Although the line-to-line unbalanced insulation system of transmission line is one of the effective means to prevent simultaneous power failure of two circuits, trip-out fault increases additionally in another one circuit on the low insulation side. Therefore, the larger the number of faults due to lightning, the lower the power supply reliability becomes.

Specially under this project, as long as about 350 km transmission line will be constructed between the Payakumbuh Substation to Riau Province to supply electric power to the distribution substations including Pekanbaru Substation and Dumai Substation as a single side power source. In the Minas Substation and Duri Substation to be located halfway between the transmission line, each one circuit out of two circuits will be connected to each other (another one circuit is for standby) balancedly in view of stable system operation. Thereby, the trip-out rate which will become high in one substation and comparatively low in another substation will result in reduction of power supply reliability and restrict smooth power system operation. Meanwhile, from the trip-out rate due to lightning in the Central Sumatra Power System forecast according to the Armstrong-Whitehead Theory, it is clear that the trip-out rate due to lightning increases in the case of the unbalanced insulation system as shown in Table 5.2-2.

Table 5.2-2 Forecast of Trip-out Rate per 100 km per Year

Stroke / To / No. of cct. / Voltage	Standard insulation					Unbalanced insulation				
	Tower		Conductor		Total	Tower		Conductor		Total
	1	2	1	2		1	2	1	2	
150 kV	0.64	1.01	0.67	0.97	3.29	1.98	0.28	1.55	0.22	4.03

o The line-to-line unbalanced insulation system is adopted for the 150 kV line between Maninjau Power Plant and Pauh Limo Substation. As the trip-out records for about two years after commissioning of the line are indicated in Table 5.2-3, it is impossible to clearly evaluate the effect of the unbalanced insulation design.

Table 5.2-3 Trip-out Records of 150 kV Transmission Line between Maninjau and Pauh Limo (Aug. 1983 - Aug. 1985)

Trip-out Condition	Causes of faults					
	Human work	Climate		Animal & tree	Unknown	Total of faults
		Bad weather	Lightning			
Trip-out of 1 circuit	13	0	0	0	18	31
Trip-out of 2 circuits	2	0	0	2	4	8
Total	15	0	0	2	22	39

(2) Insulation clearance

(a) Standard insulation clearance

The standard insulation clearance is determined to ensure coordination of insulation between insulator string, conductors and tower with respect to external abnormal voltage. In principle, the clearance should be so determined that any flashover be absorbed perfectly into arcing horn.

Generally, the standard clearance is obtained from the following formula:

$$\ell = 1.115Z + 0.021$$

where Z: Gap of arcing horns (Z = 1.2 m).

$$\ell = 1.4 \text{ m}$$

(b) Minimum clearance

The clearance of insulation required to withstand against switching surge and continuous abnormal voltage is adopted as a minimum clearance. Since the switching surge is severer than the continuous abnormal voltage, the clearance withstandable against the switching surge is adopted as a minimum clearance (900 mm).

From "Standard Procedures for Lightning-Proof Design of Transmission Line": Central Research Institute for Electric Power Industry in Japan (1971).

5.3 Conceptual Design of Transmission Towers

The transmission towers applicable to the power system in Central Sumatra shall be of a low cost design matching the natural conditions in Sumatra according to the Japanese Electrotechnical Committee Standard JEC-127 (1965).

5.3.1 Loads Assumed for Design of Towers

Stresses arising in the respective tower members should be calculated on the assumption that the following loads will act to the respective towers:

(1) Vertical load

(a) Weight of tower

(b) Weight of conductors, groundwires and insulators
In case the vertical angle to the line is substantial, the effect of such an angle shall be taken into account.

(2) Horizontal transverse load

(a) Wind pressure to tower

(b) Wind pressure applied to conductor, groundwires, insulators, etc.

(c) Transverse components of assumed tensions of conductor and groundwires in case there is any horizontal angle in the line

(d) Torsional force arising due to break of conductor or groundwires

(3) Horizontal longitudinal load

(a) Wind pressure to tower

(b) Horizontal longitudinal components of unbalanced tensions arising due to anchoring of conductor and groundwires in the case of dead-end tower

(c) Horizontal longitudinal components of unbalanced tensions arising due to break of conductor or groundwire

(d) Torsional force arising due to break of conductor or groundwires

5.3.2 Wind Pressure

(1) Design wind velocity

Whether to adopt an instantaneous wind velocity or a mean wind velocity as a design wind velocity for calculating wind pressure is one of the most important elements in the design of transmission tower.

For reasonable design of tower, it is desirable to properly evaluate the instantaneous wind velocity which causes a maximum load to the tower, and study the relationship between the loads calculated as a design wind velocity and the bearing capacity of the tower.

However, it is impossible to make clear the duration of instantaneous wind velocity causing maximum load to the tower, namely, to which mean wind velocity the instantaneous wind velocity belongs.

According to JEC-127 (1965), however, it is designated to adopt the maximum mean wind velocity for ten minutes as a design wind velocity.

From the observation records of wind velocity in Central Sumatra shown in Annex 5-5, the values of maximum wind velocity in the respective areas are picked up from the values in the table as listed below:

Pekanbaru	(El.: 31 m)	25 knots (46.3 km/hr.)
Tabing (Padang)	(El.: 3 m)	35 knots (64.9 km/hr.)
Rengat	(El.: 18 m)	16 knots (29.7 km/hr.)
Sukaraml	(El.: 928 m)	11 knots (20.4 km/hr.)

From 35 knots (64.9 km/hr.), the largest value among those in the above, the mean wind velocity per sec. is calculated to be 18.0 m/sec.

Considering that natural wind fluctuates hourly or momently and is affected by topographical conditions, the maximum mean wind velocity of 25 m/sec. is adopted as a design wind velocity.

Meanwhile, according to the records of wind velocity observed for the Asahan Project in the Province of North Sumatra on the same Sumatra Island, though this area is somewhat distant from this project area, the maximum values in each area are as shown in Table 5.3-1. When compared with these records, the design wind velocity of 25 m/sec. adopted under this project is considered justifiable.

Table 5.3-1 Observation Records of Maximum Wind Velocity

Observation areas	Elevation (m)	Maximum wind velocity (m/sec.)	Observation period
Medan	5	17.0	1949 - 1976
Pintsu Pohan	898	18.0	1963 - 1976
Simangkuk	1,106	25.0	1969 - 1976

(2) Calculation of wind pressure

The wind pressure to tower, insulators, conductors, groundwires, etc. is calculated according to the following formula:

$$P = 1/2 \rho c V^2 A \quad \cdots\cdots \quad (5.3\text{-}1)$$

where P: Wind pressure (kg)

ρ: Air density (kg sec.^{2}/m^4)

c: Coefficient of drag

V: Design wind velocity (m/sec.)

A: Wind receiving area (m^2)

Meanwhile, the air density ρ is obtained from the following formula:

$$\rho = \frac{1.293 \times 273}{T + 273} \times \frac{H}{760} \times \frac{1}{9.8} \text{ (kg.sec.}^2\text{/m}^4\text{)}$$

where T: Atmospheric air temperature (°C)

H: Atmospheric air pressure (mmHg)

According to the past records of atmospheric air temperature in Pekanbaru shown in Annex 5-6 and 5-7, the air density ρ becomes as follows from a mean lowest air temperature = 21.0°C and mean atmospheric air pressure = 1,010 MBar = 758 mmHg in the tables:

$$\rho = \frac{1.293 \times 273}{21.0 + 273} \times \frac{758}{760} \times \frac{1}{9.8} = 0.1222$$

(3) Wind pressure to tower

(a) Drag coefficient of tower

The drag coefficient of tower varies extensively depending upon the sectional form of wind receiving members. The drag coefficient of an angle tower scarcely varies due to the change of wind velocity if the occupying proportion of material (as calculated from the formula below) of the tower is the same. However, the drag coefficient tends to vary depending upon the occupying proportion of material. Therefore, the drag coefficient of angle tower is determined according to the occupying proportion of material (ψ) calculated from the following formula.

$$\psi = \frac{\text{Area of member occupying } \Sigma \text{ node space}}{\text{Area of } \Sigma \text{ node space}}$$

A relationship between the occupying proportion of material and drag coefficient of square angle tower based upon the results of wind tunnel tests is as shown in Fig. 5.3-1.

Therefore, when the drag coefficient in the diagram is applied to the transmission line in Central Sumatra, then

$$\text{Occupying proportion of material } \psi = \frac{16.1}{107.8} = 0.149 \quad *1$$

Hence, the drag coefficient c = 3.05.

Note *1. The occupying proportion of material is based upon the Type A tower which occupies more than 80% of the total number of towers in this study.

(b) Wind pressure to tower

The wind pressure applied to tower is calculated accoding to the formula (5.3-1) above.

$$\begin{aligned} P &= 1/2\rho cV^2A \\ &= 1/2 \times 0.1222 \times 3.05 \times 25^2 \times 1 \\ &= 116.5 \ (\text{kg/m}^2) \end{aligned}$$

Therefore, 120 kg/m² shall be adopted as a value of wind pressure to the angle towers for 150 kV transmission lines in Central Sumatra with some additional margin for safety.

Meanwhile, the wind pressure in the following cases should be calculated based upon the above-mentioned procedures depending upon the respective conditions:

- o In case the standard wind velocity is changed in special regions.
- o In case the height of tower is very large.

(4) Wind pressure to conductor and groundwire

(a) Drag coefficient of conductor and groundwire

Although the drag coefficient of conductor and groundwires may vary depending upon their surface roughness, namely, their outside diameters and configuration of stranded wires, the following coefficient values have been obtained roughly by wind tunnel tests of such conductor and groundwire:

Conductor size	Drag coefficient
ACSR 240 mm^2 - 410 mm^2	0.965 - 0.980
AS/AW 55 mm^2	1.165

(b) Wind pressure to conductor and groundwire

The wind pressure applied to conductor and groundwire is calculated according to the formula (5.3-1) above similarly as in the case of that to tower as follows:

(Conductor)

$$P = 1/2 \rho c V^2 A$$
$$= 1/2 \times 0.1222 \times (0.965 \sim 0.980) \times 25^2 \times 1$$
$$= 36.9 \sim 37.4 \ (kg/m^2)$$

(Groundwire)

$$P = 1/2 \rho c V^2 A$$
$$= 1/2 \times 0.1222 \times 1.165 \times 25^2 \times 1$$
$$= 44.5 \ (kg/m^2)$$

Therefore, the wind pressure to the conductors and groundwire for the transmission lines in Central Sumatra shall be determined as follows with some safety margings:

Conductor	:	40 (kg/m^2)
Groundwire	:	45 (kg/m^2)

(5) Wind pressure to insulators and fittings

(a) Drag coefficient of insulators (250 mm dia. suspension type insulators) and fittings

When a suspension insulator device receives wind, the insulator string is inclined and the wind receiving area of insulator changes. In case there is a horizontal angle or insulator is subjected to oblique wind, moreover, the wind receiving surface of tension insulator device also varies. A drag coefficient of 1.4, which is largest among those based upon the results of wind tunnel tests carried out by taking into account this effect, is adopted for this project.

Since fittings come into miscellaneous complex forms, it is difficult to determine standard values of drag coefficient of fittings. Still more, there is no record of wind tunnel test. However, in consideration that the ratio of wind pressure to fittings to the total design load is very low, the same drag coefficient of insulator is adopted as that for fittings.

(b) The wind pressure applied to insulators and fittings is obtained from the formula (5.3-1) above as follows:

$$P = 1/2\rho cV^2A$$
$$= 1/2 \times 0.1222 \times 1.4 \times 25^2 \times 1$$
$$= 53.5\ (kg/m^2)$$

Therefore, 55 kg/m^2 shall be adopted respectively as the wind pressure to insulators and fittings for the transmission lines in Central Sumatra with some safety margins.

(6) Summary

The values of wind pressure calculated in Paragraphs (3) through (5) are summarized in Table 5.3-2. Moreover, the design values of wind pressures to the existing 150 kV transmission lines in Central Sumatra and East Java are also given in the table for reference.

Table 5.3-2

Wind pressure \ Consultant	Central Sumatra	Electrowatt & Nippon Koei (Maninjau ∿ Pauh Limo)	Lahmeyer (Salak ∿ Padang)	Newjec (East Jawa I ∿ III Stage)
Tower (kg/m^2)	120	120	140	110
Conductor (kg/m^2)	40	40	53	40
Groundwire (kg/m^2)	45	40	53	40
Insulator and Fittings (kg/m^2)	55	80	-	60

5.3.3 Construction of Tower

Transmission towers are classified into the following types according to their uses.

Standard tower
- Straight tower (Type A)
- Light angle tower (Type B)
- Sharp angle tower (Types C & K)
- Dead-end tower (Type D)

Special tower (Type S) (Used for long span crossing river, etc.)

The shapes of these types of towers are so determined as to permit easy construction and maintenance at low cost based upon:

(1) The conditions in the area along the transmission line route;
(2) Insulator devices, and
(3) Insulation design, etc.

while comprehensively taking into account the cost of tower, foundation and materials for conductors as well as construction and land cost.

(1) Width of lower and upper tower structures

The wider the lower and upper tower structures, the greater the weight of a tower becomes. Whereas, the narrower the lower and upper tower structures, the lighter the tower body can be made. However, too narrow lower and narrow tower structures can cause distortion and other problems. When the width of lower tower structure is made small, the load to foundation is enlarged. Thereby a large foundation becomes necessary, and results in the increase of construction cost.

Therefore, the width of lower and upper tower structures should be determined based upon the results of overall comparative study regarding the cost of materials for tower and foundation as well as construction, land and other cost. Based upon the results of this study, the width of the lower tower structures is indicated in Figs. 5.3-2, 5.3-3 and 5.3-4, and that of the upper tower structures in Fig. 5.3-5.

(2) Arrangement of conductor and groundwire

Since the power transmission system in Central Sumatra is required to be interconnected through two circuit transmission lines, the two circuit tower system is adopted as a result of study regarding:

- o Restriction in selecting appropriate routes across mountain zone (it is difficult to select two or more routes near the ridges on Andalas)
- o Economic advantage of two circuit line (compared with an alternative one circuit two route plan), etc.

Moreover, since the overhead groundwire will be constructed in frequent lightning occurrence zone, and long distance single terminal power source transmission line will be constructed, the overhead groundwire shall be of two lines configuration and the shielding angle be 0° to further improve power supply reliability.

(3) Types of towers to be used

The towers to be used for the power transmission system in Central Sumatra will be designed on the basis of the six types of towers shown in Table 5.3-3 according to the loads and shapes of towers assumed in (1) and (2) above, and constructed through economically optimum combinations according to the topography in the areas along the route.

Table 5.3-3

Types of towers	Horizontal angle (°)	Load span length (m)	Type of insulator device
Type A	3	350	Suspension device
Type B	15	350	Tension device
Type C	30	350	"
Type D (K)	Dead-end (60)	350	"
Type S	3	600	"

Tower Type A	:	Annex 5-8
Tower Type B	:	Annex 5-9
Tower Type D (K)	:	Annex 5-10
Tower Type S	:	Annex 5-11

5.4 Conceptual Design of Tower Foundation

For design of tower foundation for transmission line, the scale of towers, loads applied to towers, ground conditions and other requirements should be clarified sufficiently in advance. Then, the tower foundation should be so designed as to ensure reliability and safety of construction work with minimum cost in order to safely support the tower structure without causing any differential settlement which would exert an adverse effect upon the structural members.

Although six types of towers are used for the power system in Central Sumatra, conceptual design is carried out with respect to the following three types, namely, Types B, K and D under this basic design.

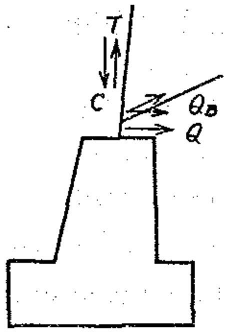
(1) Design conditions

(a) Load of tower foundation

The loads transmitted to the foundation from tower are as listed below:

Tower types	C (t)	T (t)	Q (t)	Q_B (t)	tan θ	L (mm)	ℓ (m)	Remarks
Type B	21	16	2.1	1.5	0.126	100	6.5	
Type K	47	41	4.7	3.3	0.139	150	7.0	
Type D	85	85	8.5	6.0	0.139	200	7.0	

C: Compressive force; T: Uplifting force; Q: Horizontal force; Q_B: Horizontal component of force applied in the direction of brace; tan θ : Inclination; L: Size of main leg members; ℓ: Width of leg



(b) The following foundation types are selected respectively according to the ground conditions:

a.	Favorable ground	:	Inverse T-shape type spread foundation	Type I
b.	Slightly soft ground	:	Mat type spread foundation	Type IV_1
c.	Soft ground	:	Pile foundation	Type IV_2

(c) Ground conditions

(i) Favorable ground (corresponding to the results of cone penetrometer tests in Annexes 5-13 and 5-15)

	C (t/m²)	ϕ (°)	γ (t/m³)	WL (m)
Upper layer	3	0	1.5	None
Lower layer	4.5	0	1.3	None

C: Cohesion; ϕ: Angle of internal friction;
γ: Unit weight of soil; WL: Ground water level

The cohesion C was estimated from the following formula based upon the results of cone penetrometer tests:

$$C = \frac{1}{10} q_c$$

q : Cone index (kg f/cm²) (Refer to Annex 5-12 ∿ 15)

(ii) Slightly soft ground (corresponding to Annex 5-12)

	C (t/m²)	ϕ (°)	γ (t/m³)	WL (m)
Upper layer	1.0	0	1.3	GL±0
Lower layer	3.4	0	1.5	

GL: Ground level

(iii) Soft ground (corresponding to Annex 5-14)

	Soil properties	Thickness of layer (m)	Characteristics of strength	WL (m)
Upper layer	Clayey soil	25	q_u 3.3 (t/m^2)	
Lower layer	Sandy soil	5	N value: 10	GL±0
Bearing layer	Sandy soil	-	N value: 30	

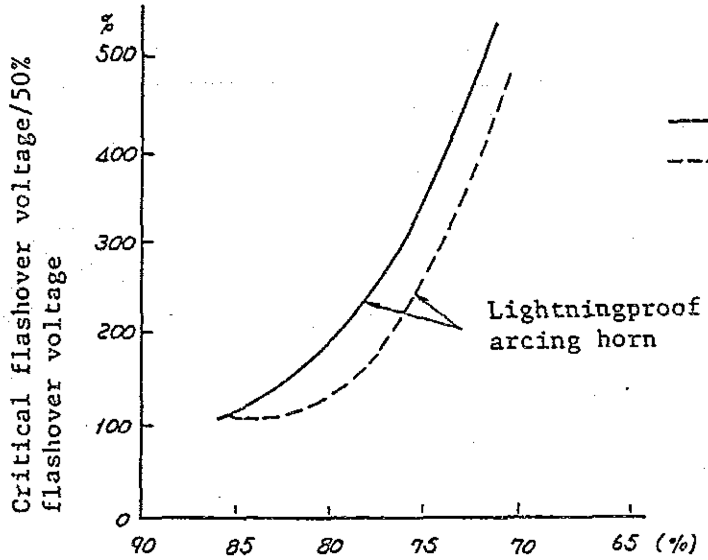
q_u: Unconfined compressive strength

N value: Results of standard penetrometer test expressed in terms of N value.

GL: Ground level

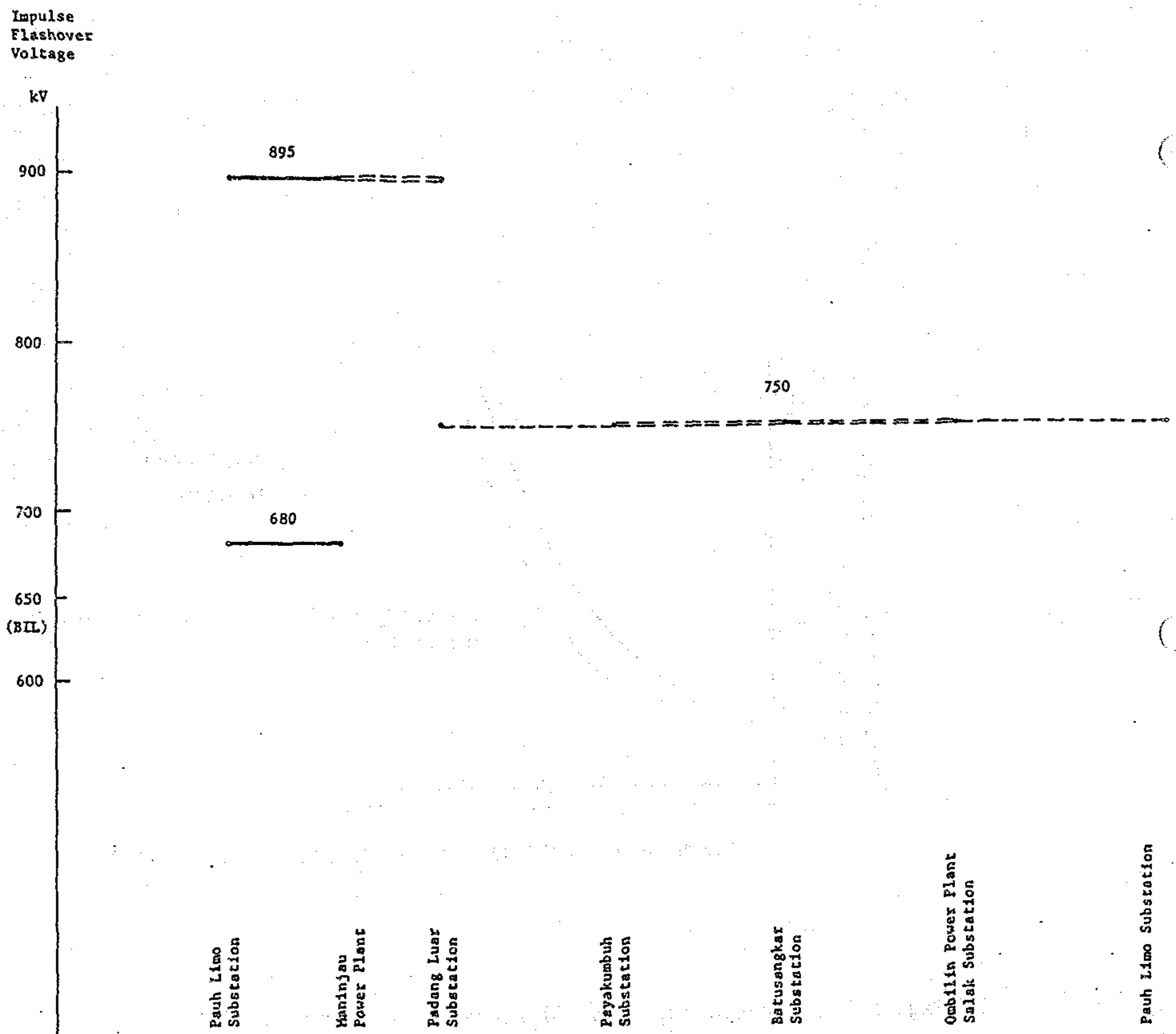
(2) Results of design

The results of design about the shape and dimensions of tower foundations based on the above design conditions are shown in Annex 5-16, Annex 5-17, Annex 5-18.



[Arcing horn gap (Z)]/[length of insulator string (Zo)]

Fig. 5.2-1 [Arcing horn gap (Z)]/[Length of insulator string (Zo)] and Critical Flashover Voltage



Arcing horn gap	Existing	Under design	Designed under this study	Designed under this study	Designed under this study	Under construction
High insulation circuit	1,485 mm	None	1,200 mm	1,200 mm	1,200 mm	1,200 mm
Low insulation circuit	1,115 mm	None	1,200 mm	1,200 mm	1,200 mm	Two circuit design, with one circuit being overhead line

Fig. 5.2-2 Insulation level of 150 kV transmission lines

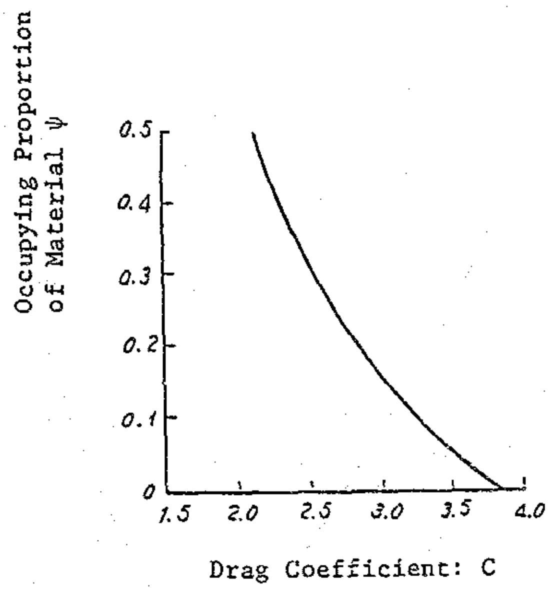


Fig. 5.3-1 Relationship between Occupying Proportion of Material Drag Coefficient of Angle Tower

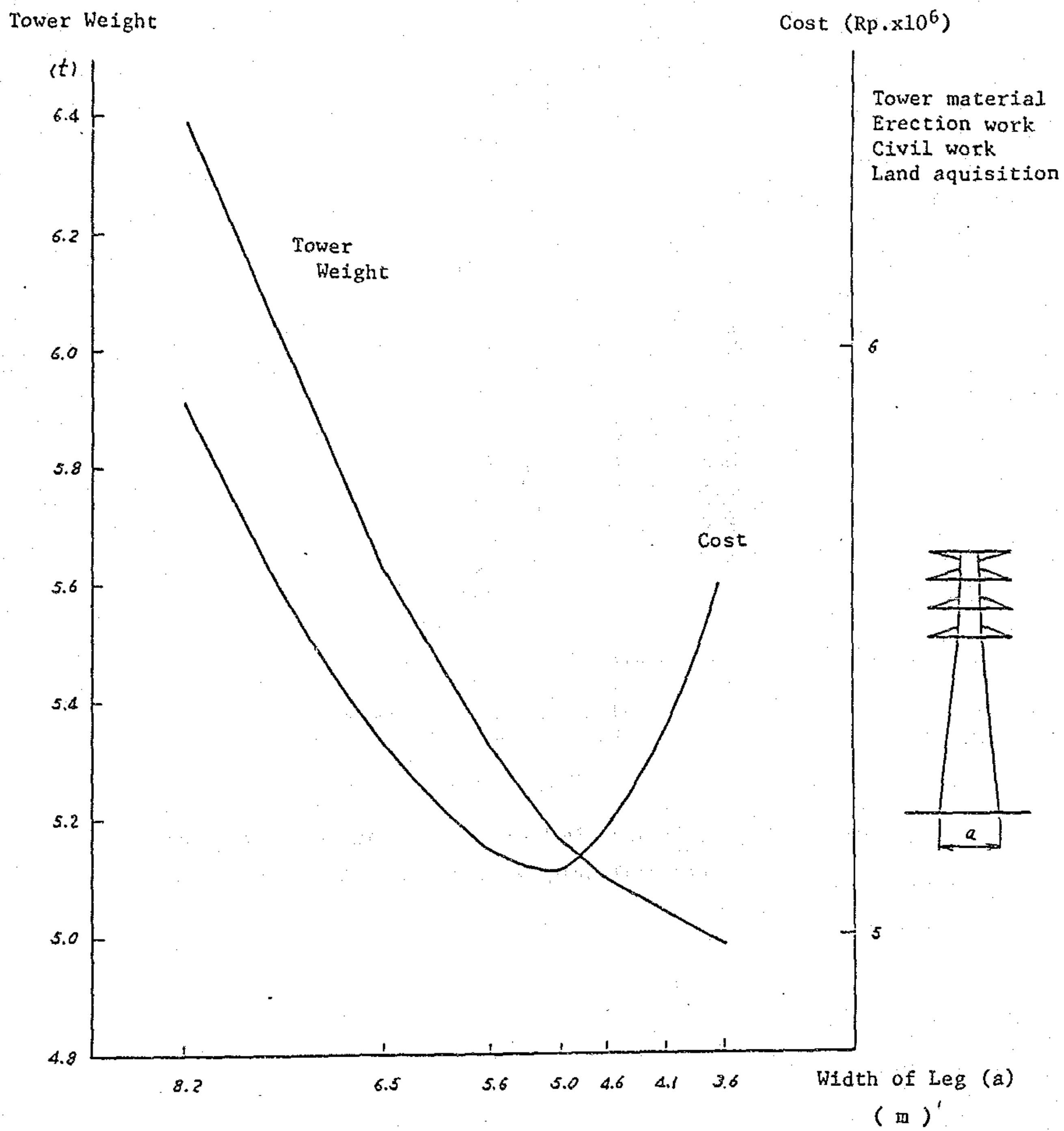


Fig. 5.3-2 Width of Leg and Cost for A Type Tower

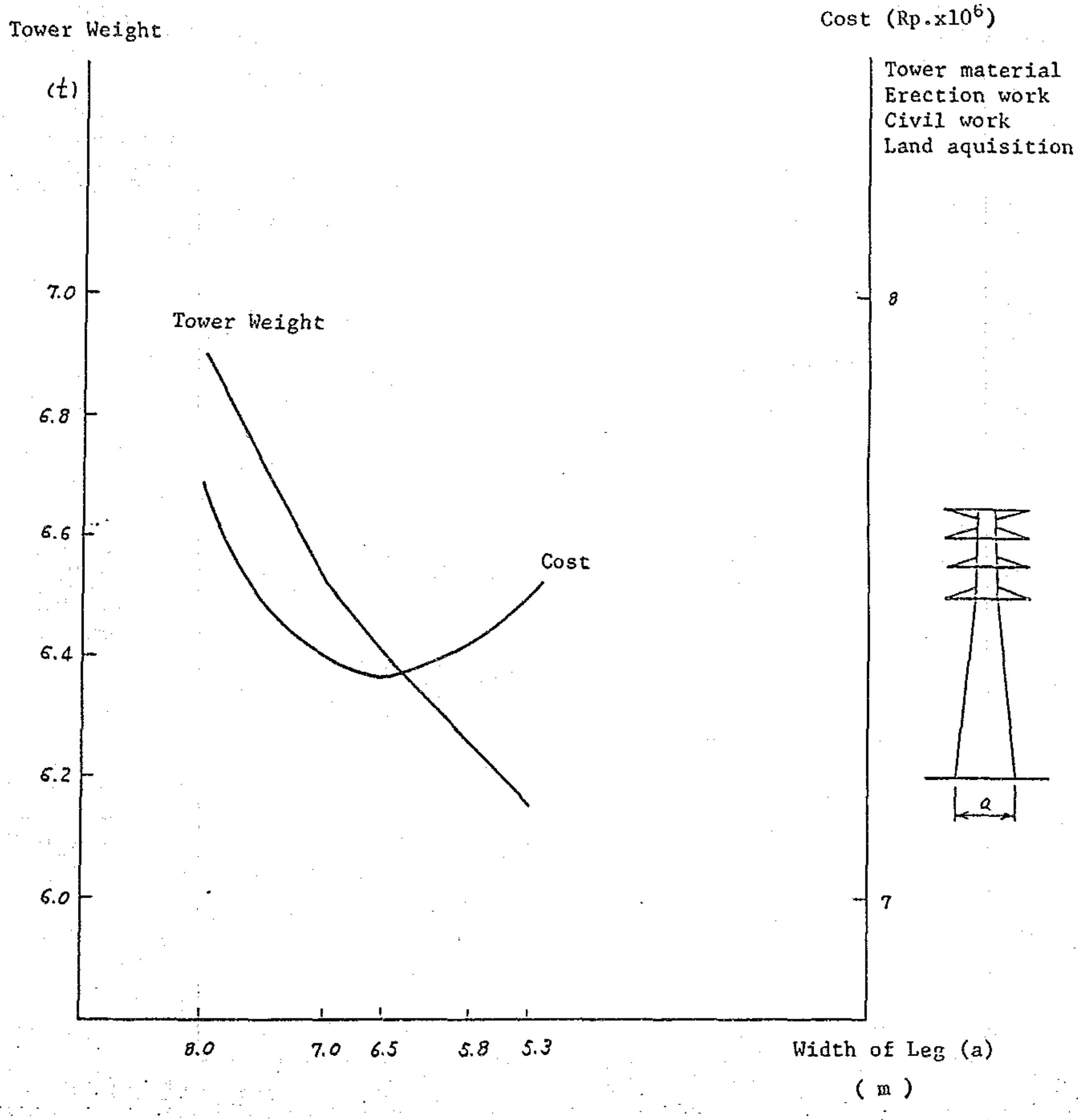


Fig. 5.3-3 Width of Leg and Cost for B Type Tower

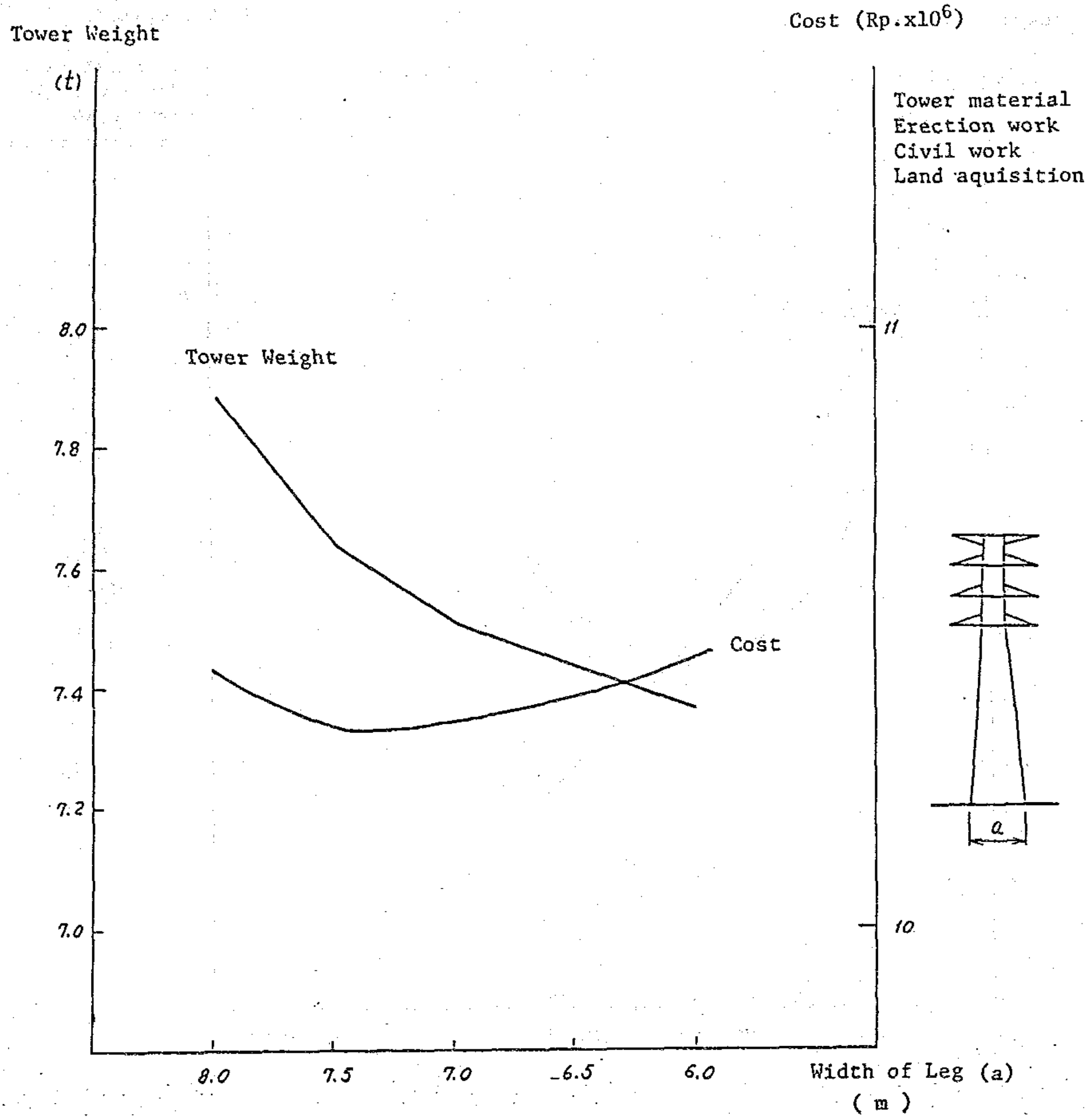


Fig. 5.3-4 Width of Leg and Cost for C Type Tower

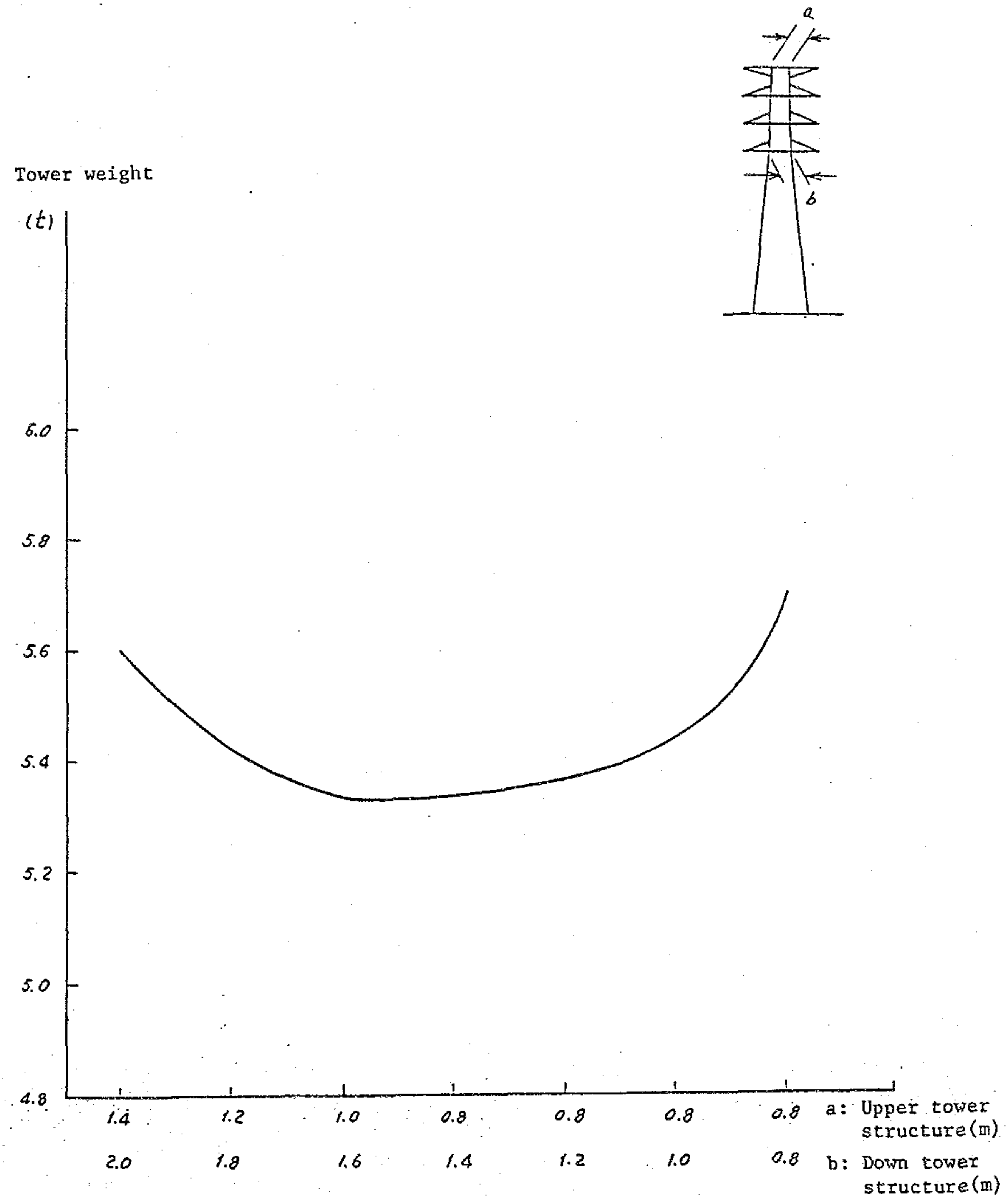


Fig. 5.3-5 Upper Tower Structure and Tower Weight

SECTION 6

SUBSTATION FACILITIES

SECTION 6 SUBSTATION FACILITIES

6.1 Selection of Optimum Sites of Substations to be Interconnected to the Existing and Proposed Power System

6.1.1 City Plans Related to Proposed Substation Sites and Investigation of the Sites

To ensure effective utilization of substation and coordination with surrounding environment over a long period, it is essential to select a site which is in harmony with the city plan in the corresponding region.

From this view point, the city plans in major cities were investigated first of all.

(1) Padang area (Refer to Fig. 6.1-1)

The study team visited BAPPEDA and carried out investigation on the city plan in Padang.

At present, the Padang bypass road construction project is implemented according to the city plan, and a part of the bypass road toward the Padang Port at the southern part of the city and Teluk Bayur has already been completed. The route from the eastern part to the northern part of the city is now under planning stage so as to start construction of the route within several years.

Completion of the bypass road is expected to bring about substential changes in the regional distribution of power demand followed by construction of industrial plants along the road.

At the northern part of the city, an airport construction project is planned, with its feasibility study having already been carried out by JICA.

Subsequent to completion of the new airport, the existing Tabing Airport is scheduled to be used for the Air Force without abolition.

As for selection of the proposed substation site, field investigation was carried out taking into consideration two plans listed below.

1 Construction of 150 kV substation in the Simpangharu Diesel Power Plant

2 Construction of new 150 kV substation near the new bypass road and along the existing the 150 kV transmission line route in Tabing at the northern part of the city.

(a) Simpangharu Power Plant

A part of generators at the existing power plant have already been deteriorated and are going to be dismantled, while other generators which can be used will be moved to other power plant site. About half the power plant site can be used for a substation site after rearranging the existing power plant equipment.

A general layout in case this site is used as a substation site is as shown in Annex 6-1 (a), (b). It is evaluated to be possible to install outdoor general type equipment in this site.

(b) Tabing area

At present, this area is a paddy field zone where it will be possible to freely select a substation site along the transmission line. However, the access way is too narrow to permit traffic of large vehicles. It is considered advantageous to select an optimum site after it has become possible to confirm the regional development plan associated with construction of a bypass road in the future.

(c) Boosting the Capacity of Pauh Limo Substation

In the space for installation of additional transformers allotted initially at the time of constructing this substation, the transformers for gas turbine power plant have already been installed. Therefore it will be necessary to take some measures to boost the capacity of this substation.

(d) As a result of study regarding the countermeasures for reinforcement of power facilities in Padang area as described in 6.3.3, it was evaluated to be advantageous to boost the Simpangharu Substation to 150 kV.

(2) Pekanbaru area (Refer to Fig. 6.1-2)

The JICA study team collected data and information on city plans from BAPPEDA, PLN CHABAN, etc. Mainly in the central part of the city, an urbanization project is implemented, and the city is expected to undergo remarkable development in the future. In the field of power supply, construction of five 6 MW diesel power units in addition to existing diesel power plant is promoted. Moreover, modernization of associated distribution networks is also promoted.

A 150 kV substation construction site had already been selected during the feasibility study for Kotapanjang Hydro-Power Plant and reinforcement of distribution system is now going to be brought to realization. Therefore, the trend of power demand in the surrounding area, development of the city and other conditions were investigated under this investigation.

Although the proposed substation site is by about 12 km distant south-west from the central part of the city, this substation is expected to play a key role in the future power system in Riau Province. Moreover, along with remarkable introduction of a radio broadcasting station, universities, etc. according to the Pekanbaru City Development Plan, power demand is also expected to grow at a substantially high rate.

However, considering that the proposed site is distant from the city center area and the transmission line from Pekanbaru toward Dumai is planned to be routed along the west side of the city, it would also be desirable to construct this transmission line as close as possible to the city and select a proposed substation site on the west side of the present city area. Then the substation site is recommended to be selected after adequately clarifying the distribution of power demand later in the execution stage.

(3) Dumai area (Refer to Fig. 6.1-3, Annex 6-11)

The JICA study team visited WALIKOTA, a branch of BAPPEDA, and conducted survey and investigation in Dumai where, together with promotion of the Dumai Port modernization project, city development projects are energetically promoted. Although various city development plans including road construction and city modernization plans are steadily studied and worked out in a semi-circular form mainly around the Dumai Port, these plans are still in an initial planning stage.

In selecting an optimum substation site in this area, it is very important to accurately catch the trend of the growth of future power demand for general consumers since a large portion of the city is occupied by the oil-related facilities of CALTEX and PERTAMINA.

By combinedly taking into account the relationship between these oil facilities and future trend of city development, a substation site was selected at the southwestern part of the city.

To meet recent growth of power demand, a diesel power plant (20 MW) construction plan is promoted, and 50,000 m^2 of land has already been acquired along a road toward Pekanbaru 18 km south from the central part of the city. Therefore, it will become increasingly important to work out an integrated distribution network modernization plan covering diesel power plants and substation.

Although the site selected under this study is located within the city plan area, this site is still as distant as about 10 km from the present city center. Although the JICA study team exchanged views with pertinent administrative authority in the investigation stage, it was evaluated to be difficult to construct the substation further adjacent to the city center area.

However, since the city plan has not been made concrete, it is also considered possible to construct the substation further adjacent to the city center area after sufficient discussions with the city authority.

(4) Payakumbuh area (Refer to Fig. 6.1-4)

This area is expected to become a base of the power system connecting West Sumatra and Riau Provinces. By taking into account the relationship with distribution lines for regional power supply, and the river running on the southern side of the city including construction of incoming transmission lines in three directions, a substation construction site has been selected about 3 km northwest from the central part of the city.

There is a marble production plant adjacent to this area, where an industrial power plant is operated. In this area, power demand including that for these mining-related industries is expected to undergo substantial growth.

Although there is about 2 ha of land on the south side of the city area acquired by PLN in 1972, this area was not selected as a proposed site since a river runs between the city area, and this area is not desirable geologically for a transmission tower site as well.

(5) Duri area (Refer to Fig. 6.1-5)

Since a wide area is occupied by the oil facilities of CALTEX, it is required to exclude this area in selecting a substation site. Therefore, the substation site was selected near a new road west from the central part of the city, in consideration of the geographical conditions of the site where the transmission line toward Bagan Siapiapi is scheduled to be branched in future.

Since this site is near the existing diesel power plant, it is evaluated to be a desirable site permitting easy connection with existing distribution lines.

(6) Batusangkar area (Refer to Fig. 6.1-6)

Although a small scale substation is considered to be sufficient for the time being, this area is considered to play a key role as a base of the power system which is scheduled to be connected to a power system interconnected with Singkarak Power Plant in the future. Thus, a substation site was selected at the northern part of the central part of the city where easy construction of incoming transmission line would be ensured.

Since the southeastern part of the city area faces a mountain zone, this area is evaluated to develop in the northwestern direction in the future.

(7) Bangkinang area (Refer to Fig. 6.1-7)

Bangkinang is a small city where there is a route of transmission line from Payakumbuh to Pekanbaru. Since its northern side faces a river, a substation site was selected along the transmission line route on a hill zone on the southern side of the city.

This area has a slender land form where a paddy field zone has been cultivated along the river and there is a housing area parallel to the paddy field zone.

The area selected under this study is a newly developing housing zone and therefore evaluated to be an optimum substation site.

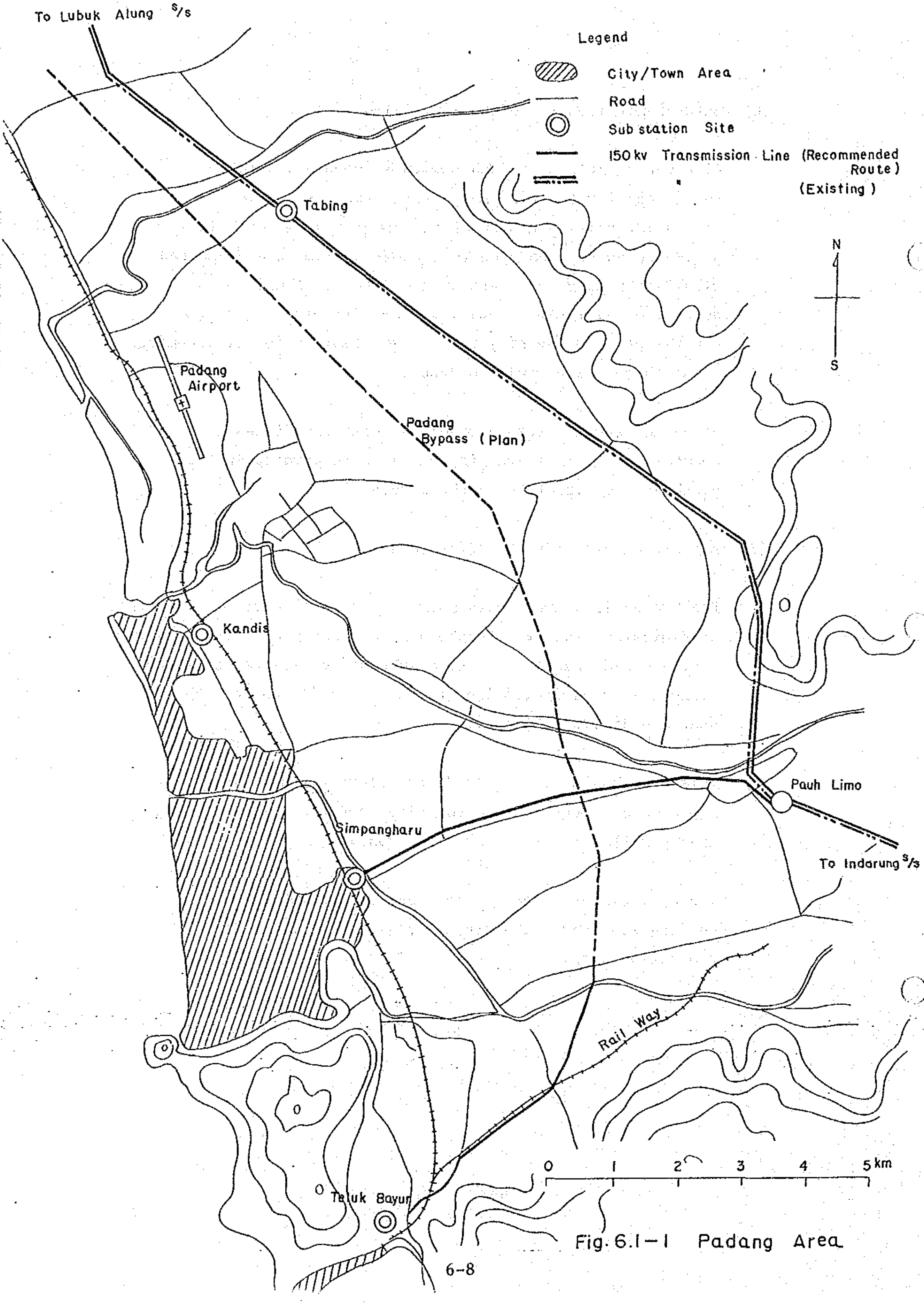


Fig. 6.1-1 Padang Area

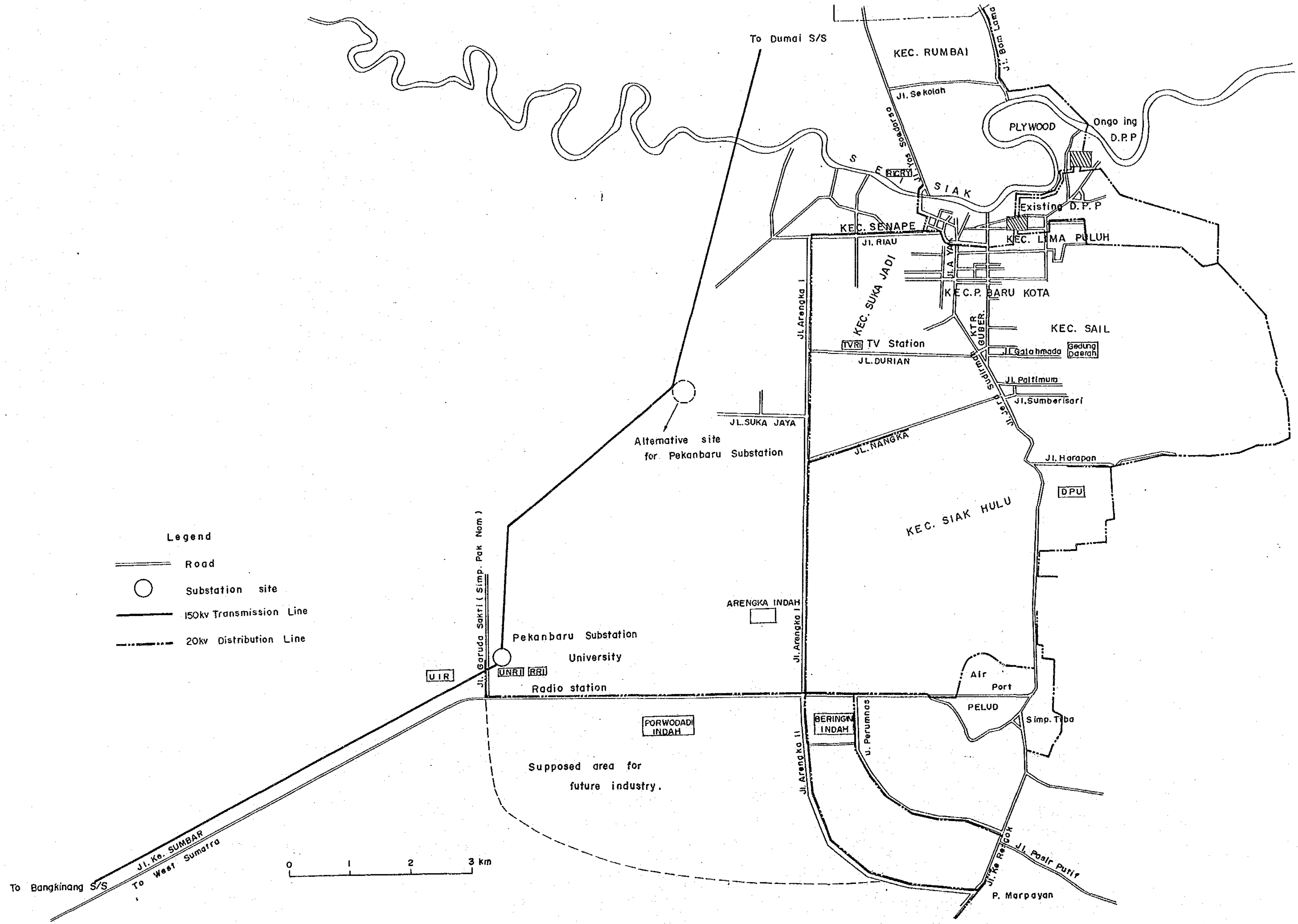


Fig. 6.1 - 2 Pekanbaru Area

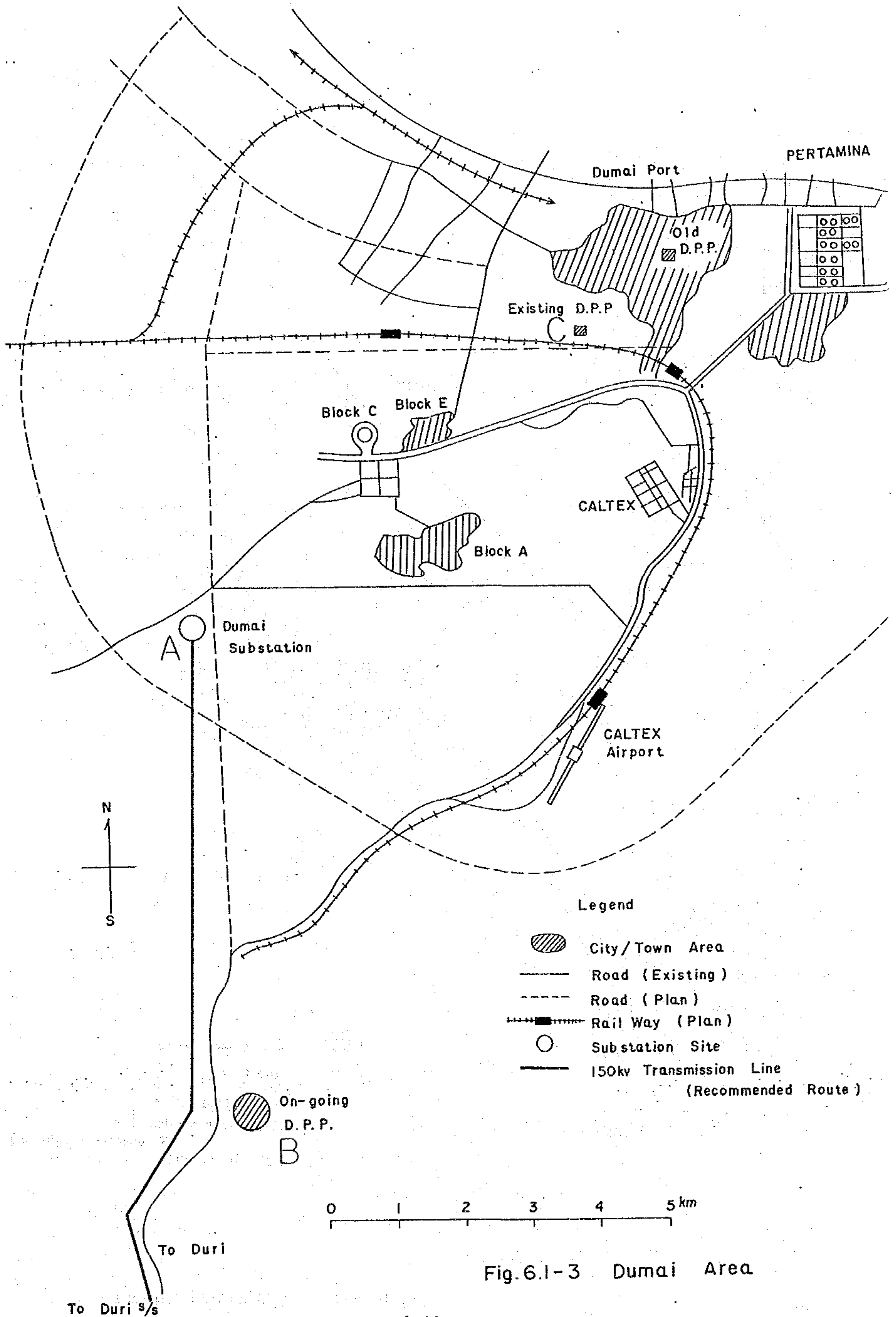


Fig. 6.1-3 Dumai Area

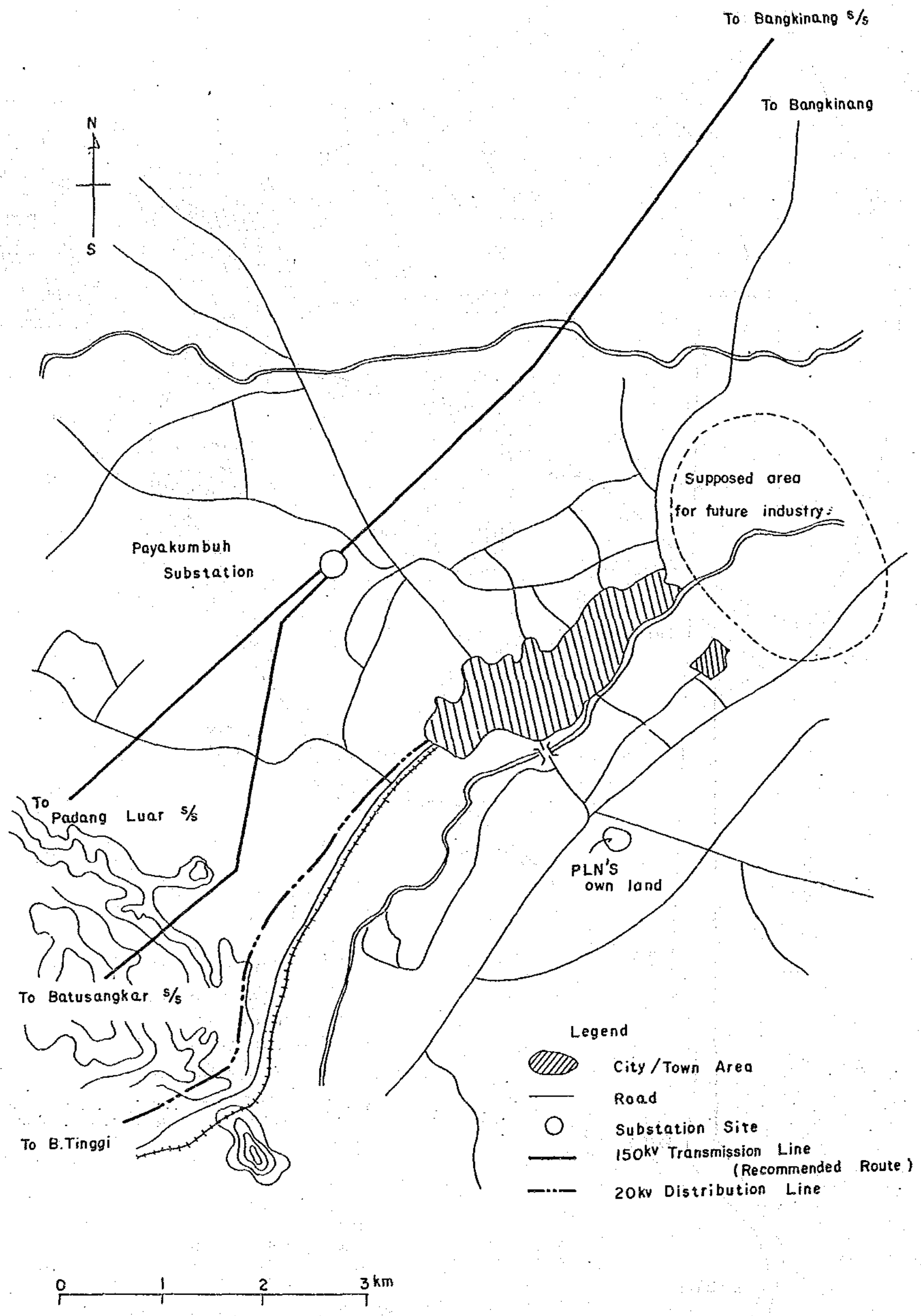


Fig. 6.1-4 Payakumbuh Area

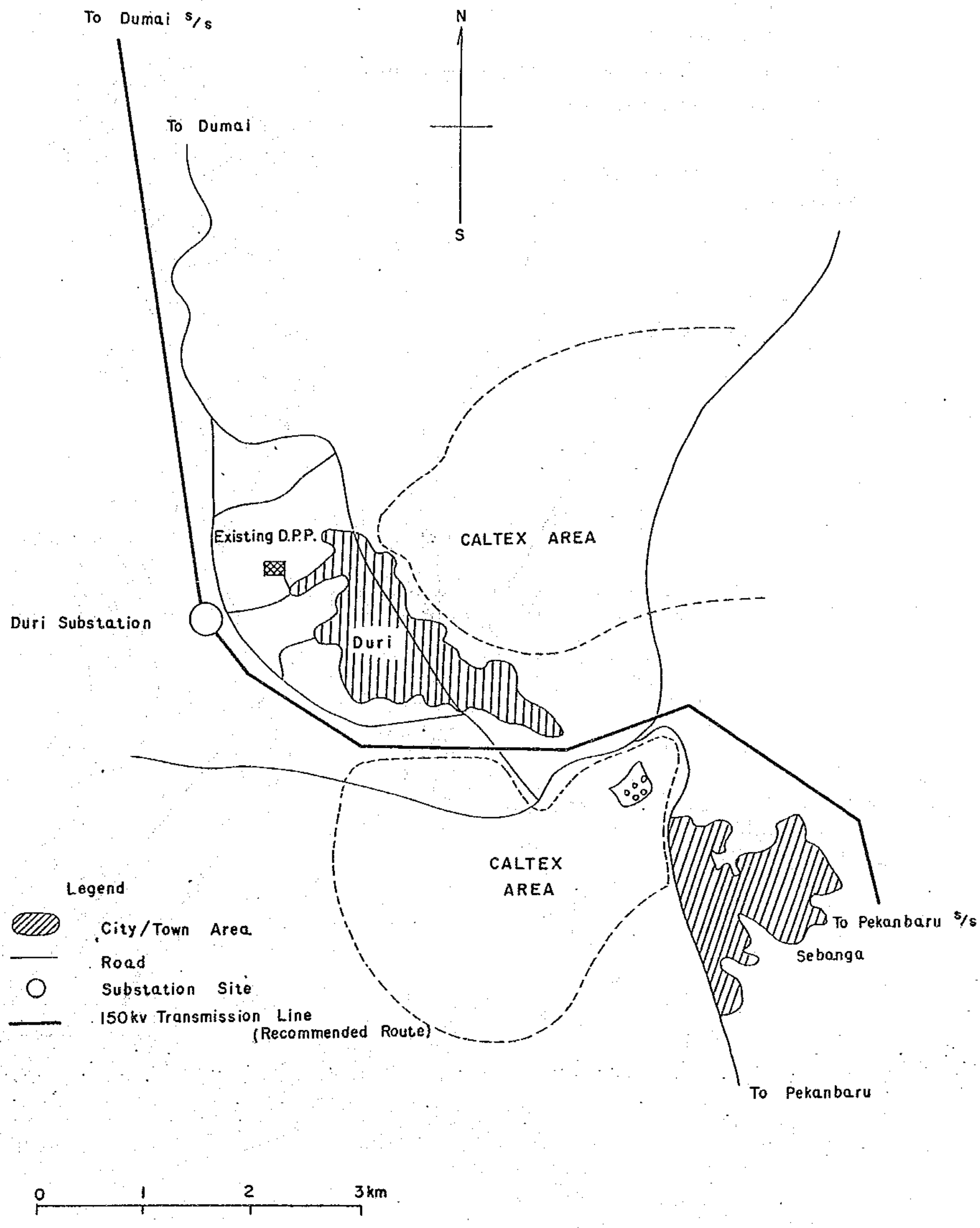


Fig. 6.1-5 Duri Area

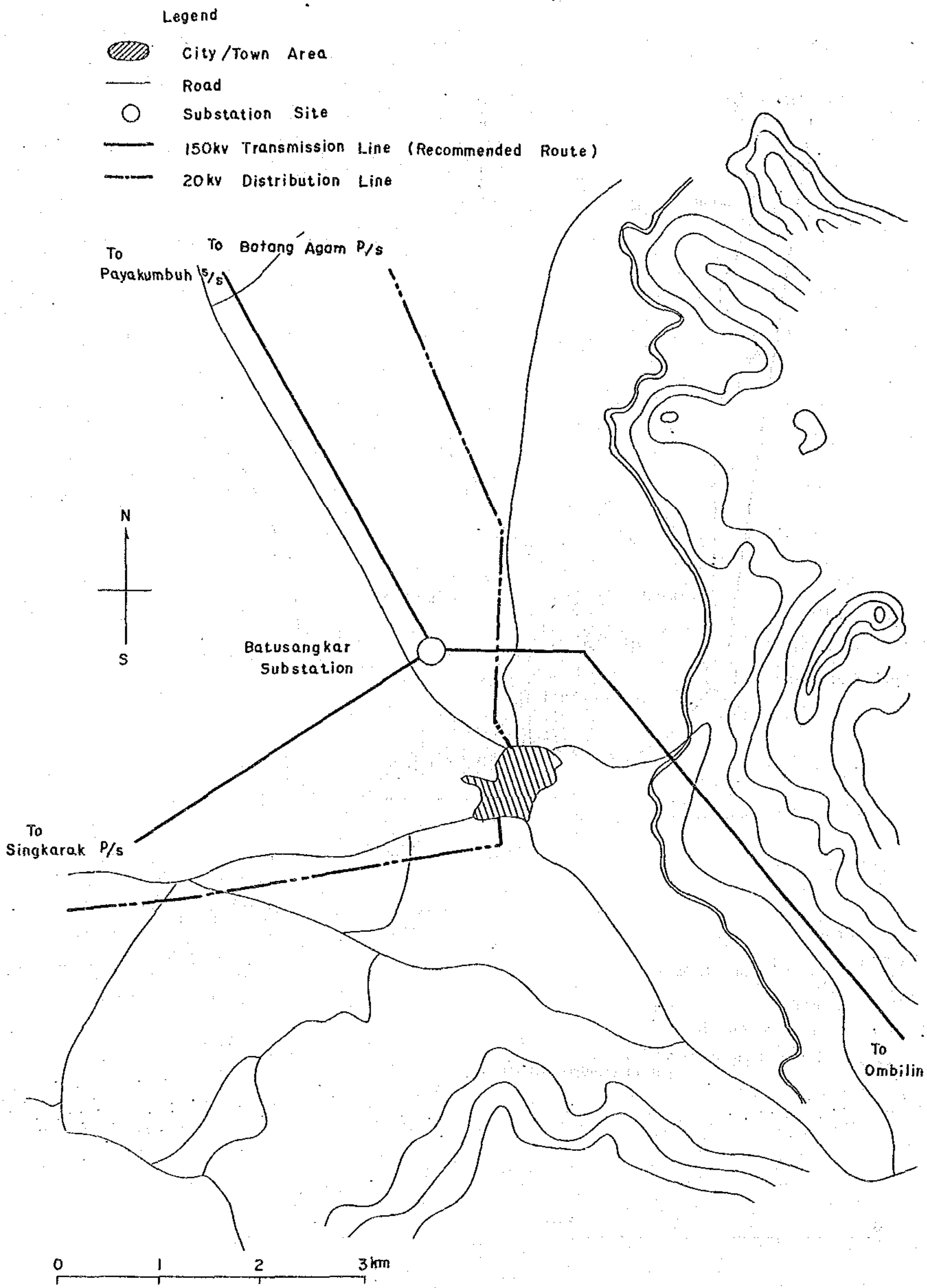


Fig. 6.1-6 Batusangkar Area

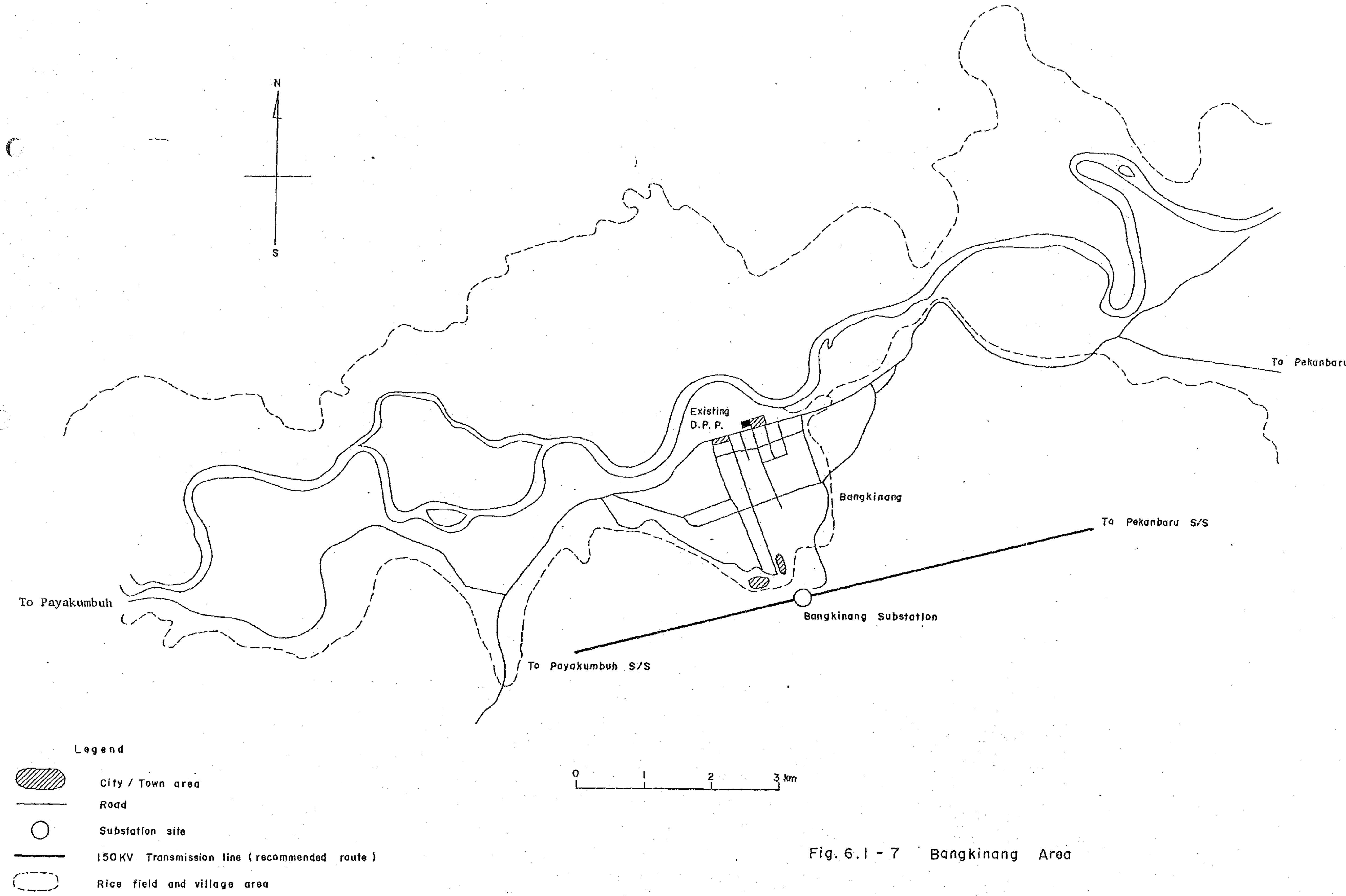


Fig. 6.1 - 7 Bangkinang Area

6.1.2 Comparison of Costs for Transmission Line and Distribution Line pertaining to Selection of Small Scale Substation Sites

(1) Generally, it is desirable to construct a substation as close as possible to a load center. Actually, however, it is difficult to construct a high voltage overhead transmission line in a city area.

Presented hereunder is the cost comparison including power loss in transmission and distribution lines in order to obtain the target values for selecting small scale substation sites in small towns where the land for substation site can be acquired easily in adjacent area in case the distance of distribution line is not so long as to cause a problem of voltage drop.

As a result it is advantageous in terms of cost to construct a substation right under a transmission line route in case the initial power demand is roughly 5,000 kW or less (Refer to Fig. 6.1-8).

(2) Items assumed for cost comparison

o For the purpose of regionally dispersed power supply, three circuit distribution lines will be constructed.
20 kV 95 mm^2, ¥3,000 x 10^3/km/1 cct

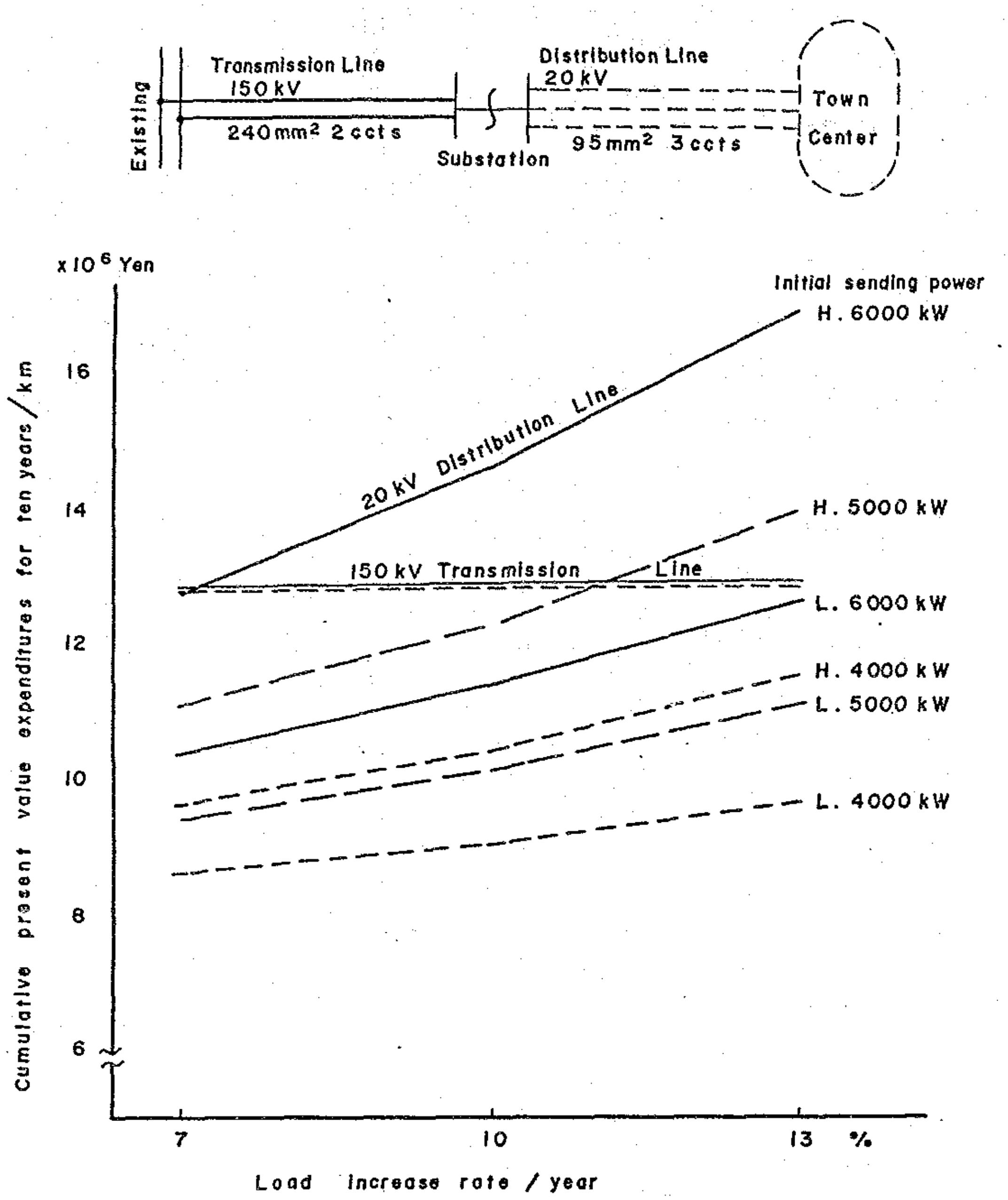
o A two circuit transmission line will be constructed.
150 kV 240 mm^2, ¥16,100 x 10^3/2 ccts

o Ratio in terms of annual expenditures
Annual interest rate : 10%
Service life : 25 years
Maintenance cost : 1.5%
Ratio in terms of total annual expenditures: 12.42%

- Discount rate : 12%

- Evaluation of transmission loss in terms of monetary value (Refer to 4.4 (d))

- The construction cost of substation will not vary depending upon each substation site.



Note : H 6000 kW Initial sending power 6000 kW in case of high evaluated loss cost

L 6000 kW Initial sending power 6000 kW in case of low evaluated loss cost

Fig. 6.1 - 8 Conparison of Annual Expenditure between 150 kV Transmission Line and 20 kV Distribution Line

Description of Fig. 6.1-8

1. By assuming a connection system as shown in the upper diagram, the cost is compared in case the transmission line is made longer and the distribution line is made shorter and vice versa.

2. The annual cost per km of transmission line corresponds to a nearly horizontal line at the center portion of the diagram where the cost does not make any remarkable change even if the sending power is changed since the effect of transmission loss is minor.

3. The annual cost per km of distribution line increases due to the effect of loss along with increase in the sending power.

4. The oblique lines in this diagram indicate the total expenditures for ten years calculated in terms of present values in case the load increase rate is changed from 7% to 13% as a result of commissioning a substation with respect to the three cases where the load is 4,000 kW, 5,000 kW and 6,000 kW.

5. The curves in the diagram indicate the total expenditures for ten years calculated in terms of present values in both cases where the cost of transmission loss is evaluated at a high level (¥8.7/kWh or Rp.47.9/kWh) and at a low level (¥4.3/kWh or Rp.23.7/kWh equivalent to an additional fuel cost for coal firing). The respective curves are denoted by H and L.

6. For example, in case the initial load is 5,000 kW and annual increase rate of load is 10%, the cost of transmission line is higher than that of distribution line even if power loss is evaluated at a low level. However, the cost of distribution line becomes higher than that of transmission line at around the level where the annual increase rate of load exceeds 11%.

6.2 Standardization and Coordination of Design and Equipment

6.2.1 Standard Equipment Layout

Based upon the results of site survey and investigation of literatures regarding actual design conditions of existing Pauh Limo and Lubuk Alung Substations as well as those of Solok and Salak Substations under construction, and by taking into account the actual design conditions of Kurian Substation in East Java, the following standard equipment layout drawings of the proposed substations have been prepared (For further detail, refer to Annex 6-2 - 6-4:

Related substations	Capacity of substation	No. of outgoing transmission line circuits	Bus system	Phase modifiers
Pekanbaru	50 MVA x 2* Future addition 1	4 Future addition 2	Double bus with tie	SC 20 kV 15 MVAx2+1
Bangkinang and others	10 - 30 MVA x 1 Future addition 1 or 2	2	Single bus	Space for installation

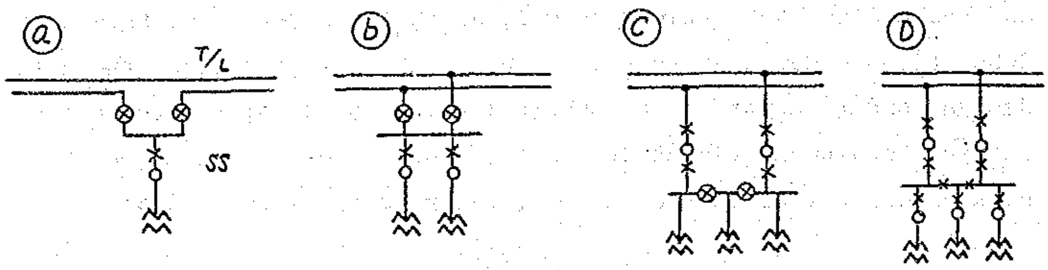
*: Attention to Table 6.3-4

6.2.2 Design Considerations for Omitting Circuit Breakers Primary Transformers

Although various efforts have been directed for simplifying the design of substations, design considerations are given here for omitting the circuit breakers of transformer primary circuit for small scale distribution substation with its high voltage circuit being designed solely for power receiving.

(1) Various connection systems

There are a variety of connection systems as illustrated below:



(i) Features of the respective systems

(a) This system is adopted for a very small scale substation, and power is received from one circuit transmission line. Since power is received after making a long detour when one circuit of transmission line has been shut down, as much transmission loss occurs, though the equipment is of the simplest configuration.

(b) Since transmission line is shut down similarly as in the case of trouble in the transmission line when a trouble has occurred in a substation bus, this system can possibly cause power failure to occur at other substations.

(c) As circuit breakers are provided on the power receiving side, it becomes easier to eliminate a trouble within the substation. If this system is used in parallel receiving the substation is free from any line fault. In case this system is used in single receiving, it is required to suspend power supply once due to line fault. However, changeover to other sound line is easy.

Even if the number of transformers has been increased, only two circuit breakers are sufficient, although complex operation is necessary to stop transformers.

ⓓ Although the range of power failure can be reduced at the time of trouble, a larger number of circuit breakers are required, and the cost required becomes considerably high.

(ii) The respective connection systems are selected after taking into consideration the scale, power supply reliability and other requirements of individual substations.

According to statistics, a considerably large number of faults have occurred in substations. Hence, it is desirable to install circuit breakers on the power receiving side as described later in Paragraph (6).

Thereby, it will be possible to perform prompt switchingover operation of power receiving circuit.

(2) Effect of omitting transformer primary circuit breaker

(a) When the connection systems ⓒ and ⓓ which are adopted for comparatively large scale substations of three banks configuration are compared among various connection systems mentioned above, the system ⓒ makes it possible to eliminate the necessity of as many as three circuit breakers.

If a cost of more than 10 million yens required per circuit breaker can be saved, the resultant economic effect upon reduction of cost and saving of space is greatly significant.

(b) Should a trouble occur in a transformer, power supply must be suspended once. However, it is possible to isolate the equipment in trouble and restore power transmission after a short time. Since the probability of transformer trouble occurrence is extremely low, omission of circuit breakers will not cause a major problem for practical operation except in the case of specially important key substations.

(c) At the time of conducting switching operation of transformer, it becomes necessary to perform switching operation of exciting current and loop current with a disconnecting switch. Although it is possible to make and break the transformers of about 150 kV, 30 MVA class, such switching operation can cause damage on the contact surface. Thus, frequent switching of transformer is not desirable. For this reason, frequent stoppage of transformer should preferably be avoided to minimize power loss at low load.

(3) Comparison between the effect of omitting circuit breaker and that of reducing power loss by shutting down transformers at the time of low load

As mentioned above, the effect of omitting circuit breakers brings saving of construction cost equivalent to more than 10 million yens.

On the other hand, the effect of reducing power loss by shutting down transmormers at the time of low load is converted into an order of 100,000 yens or more per year in terms of money amount.

Therefore, it cannot be said to be advantageous to omit circuit breakers for attaining the effect of reducing power loss as explained later in Clause 6.6.

(4) Switching operation by disconnecting switch

In case no circuit breaker is provided in the transformer primary circuit as shown in the connection system ⓒ above, it is required to make and break exciting current with a disconnecting switch at the time of on-off operation of transformer.

The switching capability of disconnecting switch for exciting current recommended in Japan is as shown in Table 6.2-1. With this capability, there will not be any particular problem in switching of exciting current (roughly 1% of the rated current) in 150 kV, 30 MVA class transformers for standard outdoor substations.

However, since switching operation of exciting current will cause damage of the portion of contact surface, sufficient maintenance and inspection should be carried out periodically.

(a) On-off operation of transformer with disconnecting switch should be carried out by taking the following precautions:

i. Motor-driven switching operation should be adopted to eliminate uneven switching speed by manual operation.

ii. The isolation distance from main live part to other structures should be larger than the phase-to-phase center distance, and any structure should not be placed particularly above the live part.

iii. To prevent damage of contacts, arc horns, etc. should be attached.

iv. The contacts should be kept in satisfactory conditions through periodical maintenance and inspection.

(b) The standard intervals of periodical maintenance and inspection of disconnecting switches adopted by an electric power company T in Japan are given for reference as follows:

General inspection : Once every two years
Detailed inspection: Once every six years

Although on-off operation of disconnecting switch is not carried out in most cases, the contact part of disconnecting switch designed for switching of loop current and other small current is damaged due to switching operation. Therefore, such disconnector should be inspected tentatively even prior to the inspection period per every six years.

The standard interval of tentative inspection is as shown in the table below:

	Cycle of temporary inspection	Remarks
Loop current or exciting current switching disconnector	200 times	Temporary inspection of disconnecting switch with current switching duty shall be carried out every 200 times of switching operation.
No-load switching disconnector	2,000 times	

(5) When the conditions described in Paragraphs (2) through (4) above are comprehensively evaluated, there will be no particular problem if transformer primary circuit breakers are omitted in the case of distribution substations using 30 MVA class transformers.

Table 6.2-1 Standard ultimate switching capability of outdoor disconnecting switches

Rated voltage (kV)	Minimum phase-to-phase center distance (mm)		Lagging current (A)	Leading current (A)
	Horizontal one point switching disconnecting switch	Other types of disconnecting switches		
7.2	800 or more	400 or more	4	2
12	800 ditto	600 ditto	4	2
24	1,000 ditto	750 ditto	2	2
36	1,000 ditto	900 ditto	2	2
72	1,500 ditto	1,500 ditto	2	1
84	1,800 ditto	1,700 ditto	2	1
120	2,500 ditto	3,200 ditto	3	1
168	3,000 or more		3	1
204	3.500 ditto		3	0.5
240	4,000 ditto		2	0.5
300	5,000 ditto		2	0.5
550	8,000 ditto		-	0.5

(6) Records of troubles in substations

According to the statistics of substation troubles in Central Sumatra, protective relays were actuated four times at the Pauh Limo and Lubuk Alung Substations, and such troubles resulted in power supply failure for 59 minutes in total.

At the substation in Indarung Cement Plant for 20 kV system, protective relays were actuated four times, thereby resulting in 130 minutes of power supply failure in total.

The breakdown of the troubles is as follows:

Trouble causing actuation overcurrent relay	:	1 time
Actuation of overcurrent ground relay	:	2 times
Actuation of undervoltage relay	:	4 times

However, none of these troubles did not result in long time power supply failure.

Meanwhile, the number of troubles in substations and transmission lines occurred in Java Island are as listed below:

Fiscal year	1982	1983	1984
No. of substation troubles	55	79	129
No. of transmission line troubles	334	343	747

Although a considerably large number of troubles had occurred in substations, the number of those occurred in transmission lines ranges from four to six times the total number of substation troubles.

6.3 Scale of Substation

6.3.1 Selection of the Capacity of Transformer Banks and Concept of Standby Bank Installation

(1) Selection of transformer bank capacity

(a) An optimum bank capacity was selected from the standard capacity of PLN.

An optimum bank capacity is determined after comparing the construction cost and yearly expenditures while taking into account the scale and growth of demand of power to be supplied to the demand area. In comparing the cost and expenditures, the subsequent extension period, standby bank installation, etc. should also be taken into account based upon the following concept:

(b) Concept of standby bank installation and capacity extension period

(i) Expansion of standby bank should be carried out when power supply has become insufficient by receiving power from existing diesel power plant at the time of one bank shutdown. The maximum allowable overload in a sound bank shall be 110% of the rated capacity.

(ii) In the case of substation constructed on the basis of one bank configuration, the second bank shall be installed three years after construction of the substation in consideration that it will become increasingly difficult to shut down the bank due to subsequent increase of load, change of equipment conditions, etc.

(iii) For small scale substations which can't expect supply from diesel power plant and/or distribution line at the transformer bank fault, one spare transformer shall be provided each in West Sumatra and Riau Provinces from the economical view point.

6.3.2 Selection of the Capacity of Transformers for the Respective Proposed Substations

The capacity of transformers for the respective proposed substations was determined based upon the results of comparative study regarding the capacity, construction cost and extension period of the individual substations as well as the results of demand forecast in the individual power supply areas.

The results of comparative study carried out on the capacity of transformers and importance of the respective substations are presented in Table 6.3-1 (a), (b). The respective plans for individual substation construction are compared in the following respective tables and figures.

(1) Payakumbuh : Table 6.3-2, Fig. 6.3-1 and Table 6.3-3
(2) Pekanbaru : Table 6.3-4, Fig. 6.3-2 and Table 6.3-5
(3) Dumai : Table 6.3-6, Fig. 6-3-3 and Table 6.3-7

Concerning the spare bank, one of two banks of 10 MVA in Lubuk Alung can be alocated as a spare as the demand is less than half of the total bank capacity as of 1995 in West Sumatra. For Riau, however, one spare bank of 10 MVA shall be provided in Duri.

6.3.3 Countermeasures for Reinforcement of Power Facilities in Padang

After study on the reinforcement of power facilities in Padang, it is evaluated to be appropriate to boost the Simpangharu Substation to 150 kV by installing one 150/20 kV 3ϕ 30 MVA transformer bank in 1992 and extend the substation by installing another bank for two banks configuration in 1995.

An outline of this study is as follows.

(1) Present situation of power supply

(a) In Padang, electrical power is supplied from or through the following respective key stations:

i. Simpangharu Diesel Power Plant
Actual output in 1985: 14.4 MW

ii. Pauh Limo Substation, 150/20 kV 3ϕ 30 MVA x 2 banks

iii. Kandis Switching Station, 20 kV (Secondary system of Pauh Limo Substation)

iv. Teluk Bayur Substation, 20/6 kV (secondary system of Pauh Limo Substation)

(b) The Simpangharu Power Plant mainly plays a role of power supply during peak hours. During other than peak hours, the generators are shut down and the power to respective demand areas is supplied from the Pauh Limo Substation through distribution lines.

The capacity of the existing power facilities (including that of the distribution lines scheduled to be extended in a few years) is as listed below. In addition, it is expected to become necessary to take new countermeasures for increasing the capacity of power supply in about 1992.

(c) Supply capacity of existing facilities

Pauh Limo : 3ϕ 30 MVA transformers x 2 banks
27 MW (at one bank shutdown)

Simpangharu Diesel Power Plant

6.2 MW x 2	11.2 MW (actual capacity in 1985)
4.3 MW x 1	3.2 MW (actual capacity in 1985)
Total	41.4 MW

(d) Distribution line connecting between Pauh Limo and Simpangharu

Pauh Limo - Simpangharu

240 mm^2 2 cct.	7.5 km	9,600 kW/cct. x 2
150 mm^2 1 cct.		7,500 kW/cct. x 1

(Scheduled to be extended and connecting to existing lines)

Pauh Limo - Kandis

150 mm^2 2 cct.	13.08 km	4,300 kW/cct. x 2

Pauh Limo - Telukbayur

150 mm^2 1 cct.	10.44 km	5,400 kW/cct.

Total 40,700 kW (31,100 kW at one cct. shutdown)

(Calculated where power factor = 0.9 and voltage drop between mutual substations = 5%)

The supply capacity through distribution lines from Pauh Limo has become nearly equivalent to that of one transformer bank.

(2) Study of various countermeasure plans

As countermeasures for increasing the capacity of power supply to this area, the following three plans can be considered:

i. Boosting of the Simpangharu Substation to 150 kV

ii. Construction of a 150 kV substation in Tabin, Northern Padang

iii. Extension of the capacity of Pauh Limo Substation and reinforcement of distribution lines

An outline of study on the respective plans is as follows.

(a) Boosting of Simpangharu Substation to 150 kV and installation of one transformer bank

For boosting of the substation to 150 kV, it was confirmed to be possible to install outdoor general type substation facilities, provided that the portions of the existing deteriorated power plant equipment have been dismantled and the existing auxiliary equipment have been renewed at the same time.

When one bank is tentatively installed and the existing distribution lines and diesel power plants are operated as standby facilities, it is evaluated to be appropriate to install the second bank in about 1995.

Supply capacity through distribution lines

Simpangharu + Kandis: 25,700 kW (At 1 cct. shutdown of distribution line)

Diesel power plant : 11,800 kW (2% of capacity decline every year is considered)

Total 37,500 kW

Where the load in city center is estimated to be equivalent to 70% of the total load, it will become necessary to expand the capacity of these power facilities when the total load has reached 37,500/0.7 = 53,570 kW.

In consideration that the load will become roughly equal to the above value and the surrounding environment will also undergo some changes, it is considered necessary to install the second bank in 1995.

(b) Construction of Tabing Substation

To meet the increase of power demand in North Padang, it will be necessary to construct a substation in Tabing which is expected to develop in future.

Along with completion of a bypass road construction plan, if realized, the power demand growth rate in this area is expected to be raised.

However, construction of this substation prior to boosting of the Simpangharu Substation to 150 kV will require large scale expansion of distribution lines for the time being.

(c) Expansion of the capacity of Pauh Limo Substation

Because of the location of this substation about 8 km from the central part of Padang, increase of load can possibly cause voltage drop in distribution lines. Since the space initially alloted for installation of the second transformer bank is already used for installation of gas turbine power unit, it is required to rearrange the layout of the equipment in this substation.

There are already seven circuits of distribution lines (including those under planning) from Pauh Limo Substation toward the city area of Padang, and it is considered difficult to extend the capacity of Pauh Limo Substation and reinforce the distribution lines corresponding to the additional capacity in view of acquisition of distribution line routes.

(3) Conclusion

The results of study on the above-mentioned respective plans are concluded to be as shown in Table 6.3-8.

Namely,

(i) Extension of the Pauh Limo Substation (Plan C) is lowest in tentative extension cost and somewhat advantageous over other plans. However, it would be difficult to extend both the transformer bank and distribution lines.

(ii) The later the Simpangharu Substation should be boosted to 150 kV, the more difficult it would become to acquire the route of 150 kV transmission line in proportion to the progress of urbanization.

(iii) As for construction of the Tabing Substation, appropriate countermeasures should be taken after observing the progress of bypass road construction and urbanization in Northern Padang.

As a result of overall comparative study, it was concluded to be appropriate to promote boosting of the Simpangharu Substation to 150 kV (Plan A).

Meanwhile, large power demand is not yet expected in Teluk Bayur, a plan to construct a substation here has been proposed in anticipation of the development of this area as an industrial belt along the bypass road. Therefore, construction of substation in this area in future can also be considered appropriate.

Branching of power source from a transmission line between Pauh Limo and Painan should also be taken into account.

(Refer to Figs. 6.1-1, 6.3-4, Tables 6.3-8 and 6.3-9).

Table 6.3-1 (a) Schedule for Construction and Extension of Substations

Stations	Additional output	Commissioning in:	Extension schedule Capacity	Period	No. of transmission line circuits Initial	Extension	Period	Bus system Initial	Final	No. of cubicles for distribution lines	Remarks
Payakumbuh S/S	150/20 kV 20 MVA x 2	1993	20 x 1	1999	4	1(2)	1994	W.Tie		5 units x 2 sets	
Bangkinang S/S	150/20 kV 10 MVA x 1	1993	10 x 1	1996	2			S.		5 x 1	Attention to Table 6.3-4
Pekanbaru S/S	150/20 kV 50 MVA x 2	1993	50 x 1	1999	2	2	1995	W.Tie		5 x 2	CS 15 MVA x 2 1995
Batusangkar S/S	150/20 kV 10 MVA x 1	1994	10 x 1	1997	2	4		S.	W	5 x 1	Extension to double bus system at the time of interconnection with Singkarak P.S.
Duri S/S	150/20 kV 10 MVA x 1	1995	10x1+(1)	1998	2	4		S.	W	5 x 1	Extension to double bus system at the time of extending the out-going line to Bagan Siapi-api
Dumai S/S	150/20 kV 20 MVA x 1	1995	20 x 1	1998	4			W.		5 x 1	CS 6 MVA x 1 1995
Simpangharu P/S	150/20 kV	1992			2			S.			Modification of existing 20 kV diesel power plant to 150 kV substation
	30 MVA x 1										
	30 MVA x 1	1995								5 x 1	

Table 6.3-1 (b) Outgoing Transmission Line Extension Plan

Stations	No. of bays to be extended	Commissioning in :	Terminals to be connected
Ombilin P/S	150 kV 2	1993	Payakumbuh
Payakumbuh S/S	150 kV 1 (2)	1994	Padang Luar
Padang Luar S/S	150 kV 1 (2)	1994	Payakumbuh
Pekanbaru S/S	150 kV 2	1995	Dumai
Pauh Limo S/S	150 kV 2	1992	Simpangharu

Note: The abbreviations 'S, W and Tie' of bus system refer to single bus, double bus and 'with bus tie', respectively.
The number of transmission line circuits: '1 (2)' indicates that the second circuits will be installed in future.

Table 6.3-2 Study for Transformer Capacity : Payakumbuh

unit : 10^6 Yen

Year	Peak MVA	Expectable H.P.P. Output MVA	Plan : A 30 MVA Bank Plan	Cost	Plan : B 20 MVA Bank Plan	Cost	Plan : C 10 MVA Bank Plan	Cost
1991	16.0	7.0						
92	17.0	7.0	New		New		New	
93	18.2	7.0	30 MVA x 2	978	20 MVA x 2	923	10 MVA x 2	875
94	19.5	7.0					Add 10 MVA x 1	207
95	21.0	7.0						
96	23.0	7.0						
97	25.0	7.0						
98	27.1	7.0			Add		Add	
99	29.1	7.0			20 MVA x 1	231	10 MVA x 1	207
2000	31.1	7.0						
01	33.5	7.0						
02	36.0	7.0						
03	38.4	7.0	Add				Add	
04	40.8	7.0	30 MVA x 1	259			10 MVA x 1	207
05	43.2	7.0						
06	45.7	7.0						
07	48.1	7.0						
Total cost				1237		1154		1496
Present value of Cost				1052		1040		1225
Present value of yearly expenditure (15 years total)				1074		1077		1235

Note: Plan B is adopted by the following reason.

: The present value of yearly expenditure of Plan A and B has no so much difference, but the initial investment cost, total cost, and present value of Plan B are cheaper than those of Plan A.

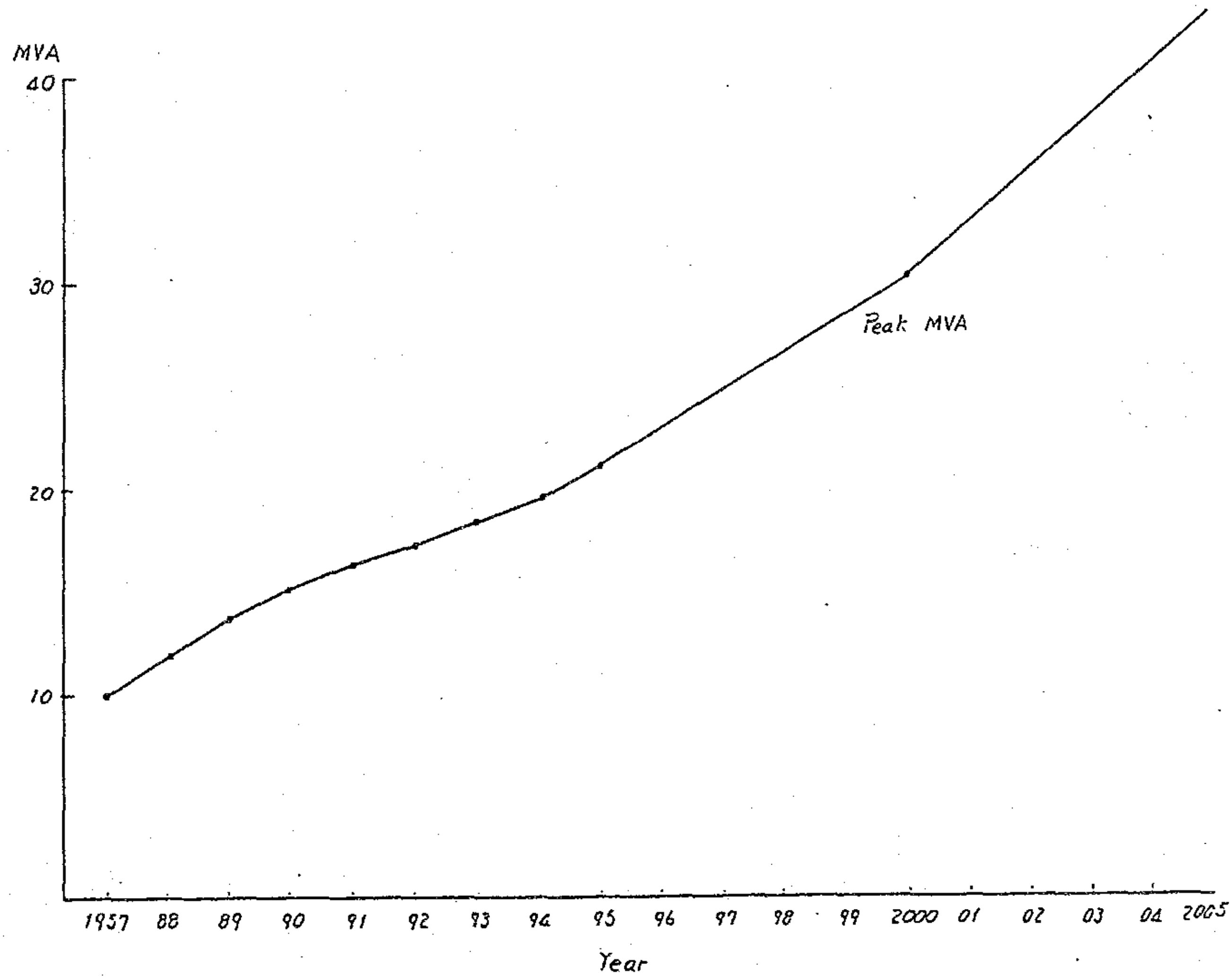


Fig. 6.3-1 Peak Load : Payakumbuh

Table 6.3-3 Break Down of Figures in Table 6.3-2

Unit : 10^6 Yen

**PLAN: A Payakumbuh 30MVA*2 **

YEAR	C.COST	YEREXP	PUYEXP	PUCOST
1993	978.0	136.1	136.1	978.0
94	0.0	136.1	121.5	0.0
95	0.0	136.1	108.5	0.0
96	0.0	136.1	96.9	0.0
97	0.0	136.1	86.5	0.0
98	0.0	136.1	77.2	0.0
99	0.0	136.1	68.9	0.0
2000	0.0	136.1	61.5	0.0
1	0.0	136.1	54.9	0.0
2	0.0	136.1	49.0	0.0
3	0.0	136.1	43.8	0.0
4	259.0	172.1	49.5	74.4
5	0.0	172.1	44.1	0.0
6	0.0	172.1	39.4	0.0
7	0.0	172.1	35.2	0.0
TTL	1237.0	2186.3	1073.7	1052.5
T10	978.0	1361.4	861.5	978.0

**PLAN: B Payakumbuh 20MVA*2 **

YEAR	C.COST	YEREXP	PUYEXP	PUCOST
1993	923.0	128.4	128.4	923.0
94	0.0	128.4	114.7	0.0
95	0.0	128.4	102.4	0.0
96	0.0	128.4	91.4	0.0
97	0.0	128.4	81.6	0.0
98	0.0	128.4	72.9	0.0
99	231.0	160.6	81.3	117.0
2000	0.0	160.6	72.6	0.0
1	0.0	160.6	64.8	0.0
2	0.0	160.6	57.9	0.0
3	0.0	160.6	51.7	0.0
4	0.0	160.6	46.1	0.0
5	0.0	160.6	41.2	0.0
6	0.0	160.6	36.8	0.0
7	0.0	160.6	32.8	0.0
TTL	1154.0	2216.6	1077.3	1040.0
T10	1154.0	1413.4	868.5	1040.0

**PLAN: C Payakumbuh 10MVA*2 **

YEAR	C.COST	YEREXP	PUYEXP	PUCOST
1993	875.0	121.8	121.8	875.0
94	207.0	150.6	134.4	184.8
95	0.0	150.6	120.0	0.0
96	0.0	150.6	107.2	0.0
97	0.0	150.6	95.7	0.0
98	0.0	150.6	85.4	0.0
99	207.0	179.4	90.9	104.8
2000	0.0	179.4	81.1	0.0
1	0.0	179.4	72.4	0.0
2	0.0	179.4	64.7	0.0
3	0.0	179.4	57.7	0.0
4	207.0	208.2	59.8	59.5
5	0.0	208.2	53.4	0.0
6	0.0	208.2	47.7	0.0
7	0.0	208.2	42.6	0.0
TTL	1496.0	2605.0	1235.4	1224.2
T10	1289.0	1592.6	974.0	1164.7

Table 6.3-4 Study for Transformer Capacity : Pekanbaru

Unit: 10^6 Yen

High demand case							Low demand case						
Year	Peak demand (MVA)	Expectable[2] Diesel P.P. Output (MVA)	Plan : A Transformer install. plan	cost	Plan : B Transformer install. plan	cost	Year	Peak demand (MVA)	Expectable Diesel P.P. Output (MVA)	Plan : A Transformer install. plan	cost	Plan : B Transformer install. plan	cost
1991	28.2	35.9					1991	27.1	35.9				
92	30.6	35.2	New		New		92	29.9	35.2	New		New	
93	49.9	25.9	50 MVA x 2 [1]	964	30 MVA x 2	856	93	47.6	25.9	50 MVA x 2	964	30 MVA x 2	856
94	52.3	25.4					94	50.2	25.4				
95	54.9	24.9			Add		95	52.9	24.9				
96	57.8	24.4			30 MVA x 1	259	96	55.7	24.4			Add	
97	60.7	23.9					97	58.4	23.9			30 MVA x 1	259
98	63.7	23.4					98	61.2	23.4				
99	66.7	23.0					99	64.0	23.0				
2000	69.7	22.5					2000	66.8	22.5				
01	73.1	22.1					01	70.1	22.1				
02	76.6	21.6	Add				02	73.4	21.6	Add			
03	80.1	21.1	50 MVA x 1	313			03	76.8	21.1	50 MVA x 1	313		
04	83.6	20.8			Add		04	80.1	20.8				
05	87.1	20.3			30 MVA x 1	259	05	83.5	20.3				
Total cost				1277		1374	Total cost				1277		1115
Present value of Cost				1065		1106	Present value of Cost				1065		1020
Present value of yearly expenditure (15 years total)				1080		1112	Present value of yearly expenditure (15 years total)				1080		1061

1) In case of high demand case which is applied to this study, Plan A (50 MVA unit) has an advantage in economical viewpoint.
However, the difference is very small, which means if the demand varies, the advantage may be easily reversed.
Taking into above situation, the study in Pekanbaru was implemented also in the case of low demand case.
As the above table shows, in the latter case, 30 MVA unit has a little advantage over 50 MVA unit.
In this study, Plan A (50 MVA unit) was adapted based on the high demand case.
However, in the detail design stage, the unit size shall be restudied considering the newest situation at the time along with the flexibility against the load demand variation in future.

2) The new diesel power plant in Pekanbaru is assumed to be remained as a reserver capacity for power source in Central Sumatra, even after the 150 KV T/L is commissioned in 1993. The output of the diesel plant is expected as listed above.
Expectable Diesel P.P. output : Actual output capacity (declining capacity 2%/year) - output capacity of maximum two units
= Power supply capacity under one unit inspection and then one unit faults.

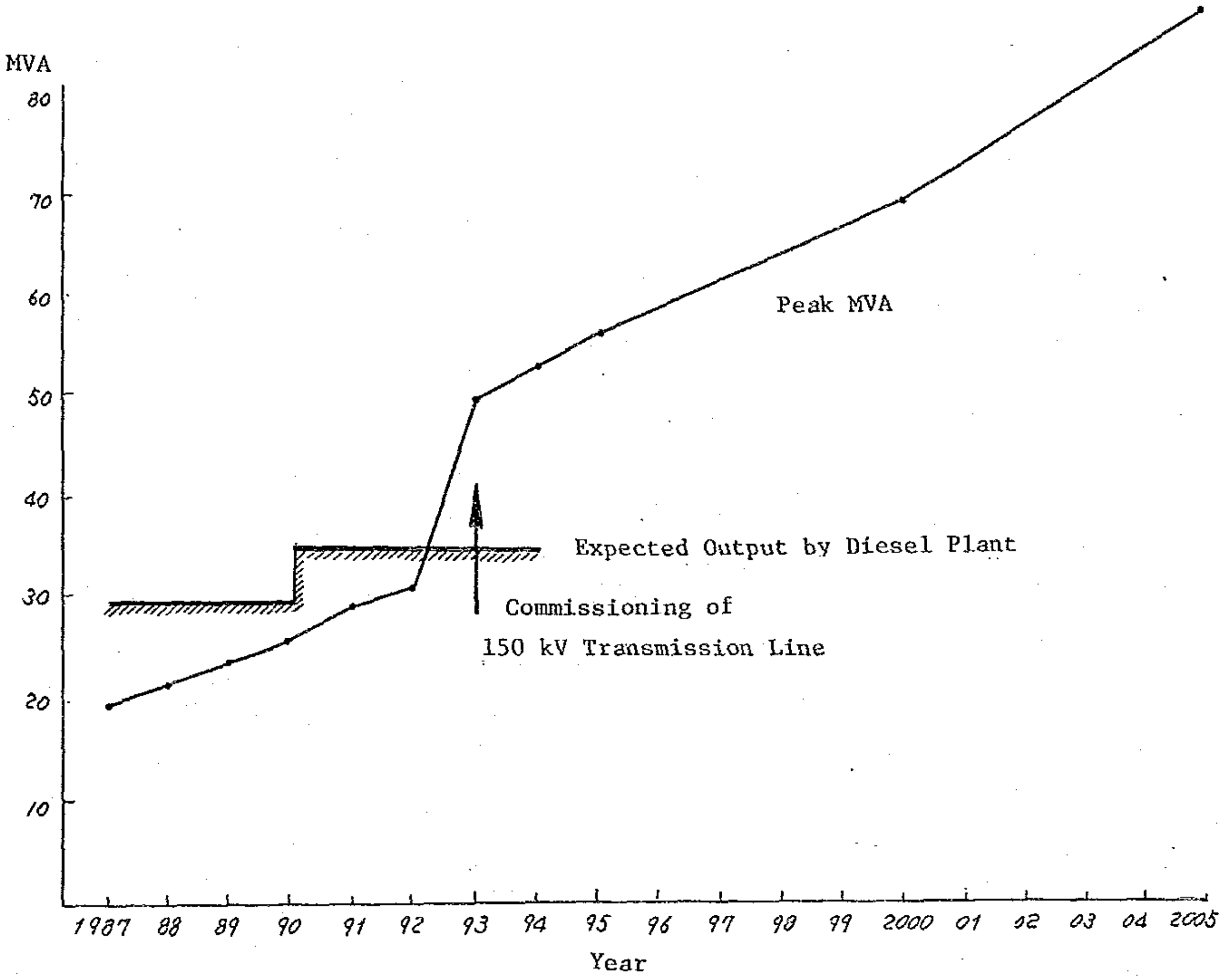


Fig. 6.3-2 Peak Load : Pekanbaru

Table 6.3-5 Break Down of Figures in Table 6.3-4

Unit : 10^6 Yen

High Demand Case

**PLAN: A Pakanbaru 50MVA*2 **

YEAR	C.COST	YEREXP	PUYEXP	PUCOST
1993	964.0	134.1	134.1	964.0
94	0.0	134.1	119.8	0.0
95	0.0	134.1	106.9	0.0
96	0.0	134.1	95.5	0.0
97	0.0	134.1	85.2	0.0
98	0.0	134.1	76.1	0.0
99	0.0	134.1	67.9	0.0
2000	0.0	134.1	60.7	0.0
1	0.0	134.1	54.1	0.0
2	0.0	134.1	48.3	0.0
3	313.0	177.7	57.2	100.7
4	0.0	177.7	51.1	0.0
5	0.0	177.7	45.6	0.0
6	0.0	177.7	40.7	0.0
7	0.0	177.7	36.3	0.0
TTL	1277.0	2230.7	1080.3	1064.8
T10	964.0	1341.9	849.2	964.0

**PLAN: B Pakanbaru 30MVA*2 **

YEAR	C.COST	YEREXP	PUYEXP	PUCOST
1993	856.0	119.1	119.1	856.0
94	0.0	119.1	106.3	0.0
95	0.0	119.1	94.9	0.0
96	259.0	155.2	110.4	184.3
97	0.0	155.2	98.6	0.0
98	0.0	155.2	88.0	0.0
99	0.0	155.2	78.6	0.0
2000	0.0	155.2	70.2	0.0
1	0.0	155.2	62.6	0.0
2	0.0	155.2	55.9	0.0
3	0.0	155.2	49.9	0.0
4	0.0	155.2	44.6	0.0
5	259.0	191.2	49.0	66.4
6	0.0	191.2	43.8	0.0
7	0.0	191.2	39.1	0.0
TTL	1374.0	2328.1	1111.9	1106.8
T10	1115.0	1443.9	885.2	1040.4

Low Demond Case

**PLAN: A Pakanbaru 50MVA*2 **

YEAR	C.COST	YEREXP	PUYEXP	PUCOST
1993	964.0	134.1	134.1	964.0
94	0.0	134.1	119.8	0.0
95	0.0	134.1	106.9	0.0
96	0.0	134.1	95.5	0.0
97	0.0	134.1	85.2	0.0
98	0.0	134.1	76.1	0.0
99	0.0	134.1	67.9	0.0
2000	0.0	134.1	60.7	0.0
1	0.0	134.1	54.1	0.0
2	0.0	134.1	48.3	0.0
3	313.0	177.7	57.2	100.7
4	0.0	177.7	51.1	0.0
5	0.0	177.7	45.6	0.0
6	0.0	177.7	40.7	0.0
7	0.0	177.7	36.3	0.0
TTL	1277.0	2230.7	1080.3	1064.8
T10	964.0	1341.9	849.2	964.0

**PLAN: B Pakanbaru 30MVA*2 **

YEAR	C.COST	YEREXP	PUYEXP	PUCOST
1993	856.0	119.1	119.1	856.0
94	0.0	119.1	106.3	0.0
95	0.0	119.1	94.9	0.0
96	0.0	119.1	84.8	0.0
97	259.0	155.2	98.6	164.5
98	0.0	155.2	88.0	0.0
99	0.0	155.2	78.6	0.0
2000	0.0	155.2	70.2	0.0
1	0.0	155.2	62.6	0.0
2	0.0	155.2	55.9	0.0
3	0.0	155.2	49.9	0.0
4	0.0	155.2	44.6	0.0
5	0.0	155.2	39.8	0.0
6	0.0	155.2	35.5	0.0
7	0.0	155.2	31.7	0.0
TTL	1115.0	2183.9	1061.3	1020.6
T10	1115.0	1407.9	859.5	1020.6

Table 6.3-6 Study for Transformer Capacity: Dumai

Unit : 10^6 Yen

Year	Peak (MVA)	Plan: A Transformer install. plan	Cost	Plan: B Transformer install. plan	Cost
1993	7.4				
94	8.2	New		New	
95	9.5	20 MVA x 1	543	10 MVA x 2	633
96	11.5				
97	13.4	Add			
98	15.4	20 MVA x 1	231		
99	17.3				
2000	19.3			Add	
01	20.6			10 MVA x 1	207
02	22				
03	23.3	20 MVA x 1	231	10 MVA x 1	207
04	24.7				
05	26.0				
06	27.4				
07	28.7				
08	30.1				
Total Cost			1,005		1,047
Present value of Cost		Total	801		822
Present value of Yearly Expenditure		Total	802		819
		10 Years total (1995-2004)	620		629

Installation year of the extention of transformer bank has been determined on the assumption that the output of diesel power plant can be expected until 2002.

Here, Plan: A is adopted because of economic view point.

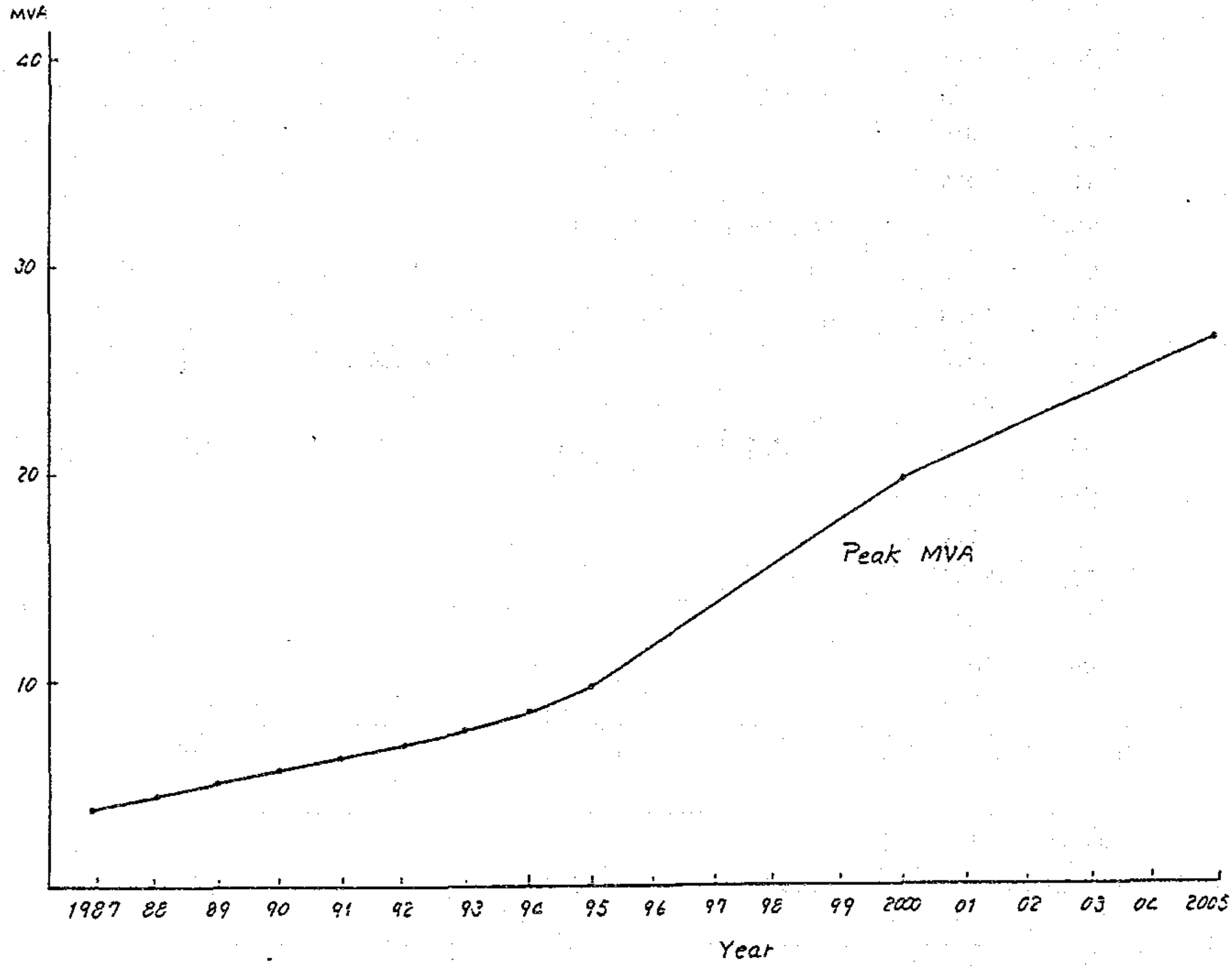


Fig. 6.3-3 Peak Load : Dumai

Table 6.3 - 7 Break Down of Figures in Table 6.3 - 6

Unit : 10^6 Yen

**PLAN:A Dumai 20MVA*1

YEAR	C.COST	YEREXP	PUYEXP	PUCOST
1995	543.0	75.5	75.5	543.0
96	0.0	75.5	67.4	0.0
97	0.0	75.5	60.2	0.0
98	231.0	107.7	76.6	164.4
99	0.0	107.7	68.4	0.0
2000	0.0	107.7	61.1	0.0
1	0.0	107.7	54.5	0.0
2	0.0	107.7	48.7	0.0
3	231.0	139.8	56.5	93.2
4	0.0	139.8	50.4	0.0
5	0.0	139.8	45.0	0.0
6	0.0	139.8	40.2	0.0
7	0.0	139.8	35.9	0.0
8	0.0	139.8	32.0	0.0
9	0.0	139.8	28.6	0.0
TTL	1005.0	1744.7	801.7	800.7
T10	1005.0	1045.3	619.9	800.7

**PLAN:B Dumai 10MVA*2

YEAR	C.COST	YEREXP	PUYEXP	PUCOST
1995	633.0	88.1	88.1	633.0
96	0.0	88.1	78.6	0.0
97	0.0	88.1	70.2	0.0
98	0.0	88.1	62.7	0.0
99	0.0	88.1	55.9	0.0
2000	0.0	88.1	49.9	0.0
1	207.0	116.9	59.2	104.8
2	0.0	116.9	52.8	0.0
3	207.0	145.7	58.8	83.6
4	0.0	145.7	52.5	0.0
5	0.0	145.7	46.9	0.0
6	0.0	145.7	41.8	0.0
7	0.0	145.7	37.4	0.0
8	0.0	145.7	33.4	0.0
9	0.0	145.7	29.8	0.0
TTL	1047.0	1782.7	818.7	821.5
T10	1047.0	1054.0	629.3	821.5

Table 6.3-8 Economical Comparison: Padang Area

Unit : 10^6 Yen

Year	Peak MVA	Plan: A Out line of Plan	Cost	Plan: B Outline of Plan	Cost	Plan: C Outline of Plan	Cost	Remarks
1991	46.9							
92	50.4	Simpangharu 150 kV 30 MVAx1	550	Tabing New 30 MVAx1	517	Pauh Limo Add 30 MVAx1	269	Discount rate 12%
		Pauh Limo 2 cct	141	T/L Branch	18	D/L 4 cct 7.5 km	148	
		T/L 150 kV 7.0 km	114	D/L 4cct 8.5 km	164		417	
			805		699			Yearly expenditure rate
93	54.0							
94	57.9							
95	61.8	Simpangharu 30 MVA	223	Tabing 30 MVAx1	223	Simpangharu 150 kV 30 MVAx1	805	Substation 13.92%
				D/L	164	Pauh Limo 2 cct		
					387	T/L 150 kV 7.0 km		Transmission 12.42%
96	66.0							Distribution 14.92%
97	70.3							
98	74.5							
99	78.8					Simpangharu 30 KVAx1	223	
2000	83	Tabing New 30 MVAx1	517	Simpangharu 150 kV	805			
		T/L	18					
		D/L	164					
			699					
01	87.7							
02	92.4							
03	97.0	Tabing 30 MVAx1	223	Simpangharu 30 MVA	223	Tabing New 30 MVAx1	699	
04	101.7							Total values for 15 years on the basic of those in 1992
05	106.4							
Total Cost			1,950		2,114		2,144	
Present value of Cost		Total	1,310		1,364		1,304	
		10 Years Total	1,246		1,300		1,103	
Present value of Yearly Expenditure		Total	1,229		1,288		1,189	
		10 Years Total	887		911		832	

In addition to the values in the above table, the Plan A is expected to be effective to reduce power loss equivalent to about 3 million kWh in three years when compared with the Plan C. (It is converted about 28 million yen in present value of yearly expenditure. Refer to Annex 6-5)

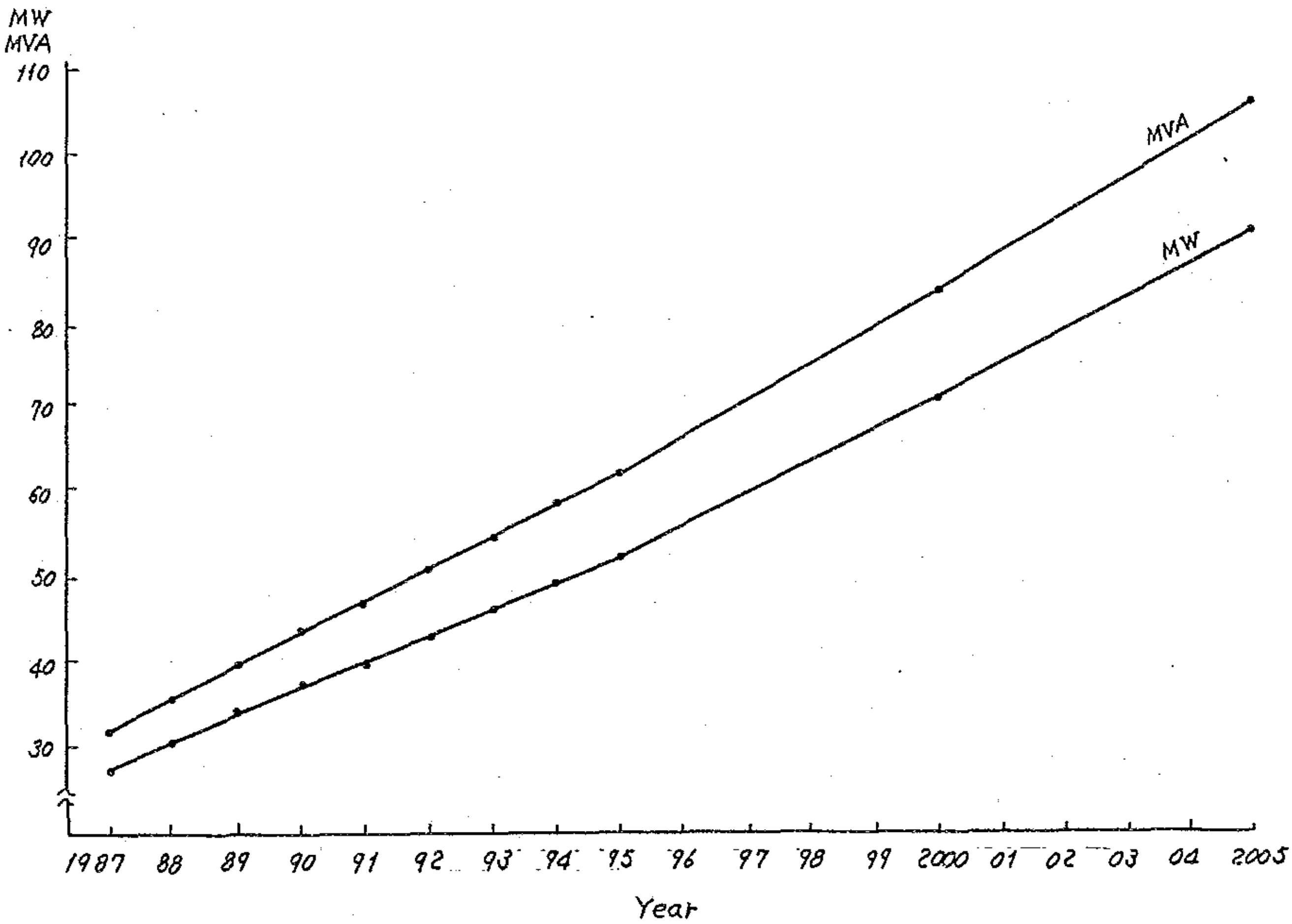


Fig. 6.3-4 Peak Load : Padang Area

Table 6.3 - 9 Break Down of Figures in Table 6.3 - 8

PADANG AREA COST COMPARISON TABLE

Unit : 10^6 Yen

PLAN: A **COST COMPARISON TABLE

YEAR	TTLCOST	YEREX	PV.YEX	PV.COST
1992	805.0	110.3	110.3	805.0
93	0.0	110.3	98.5	0.0
94	0.0	110.3	87.9	0.0
95	223.0	141.3	100.6	158.7
96	0.0	141.3	89.8	0.0
97	0.0	141.3	80.2	0.0
98	0.0	141.3	71.6	0.0
99	0.0	141.3	63.9	0.0
2000	699.0	240.0	96.9	282.3
1	0.0	240.0	86.5	0.0
2	0.0	240.0	77.2	0.0
3	223.0	271.1	77.9	64.1
4	0.0	271.1	69.5	0.0
5	0.0	271.1	62.1	0.0
6	0.0	271.1	55.4	0.0
TTL	1950.0	2842.6	1229.1	1310.1
T10	1727.0	1518.1	886.7	1246.0

PLAN: B **COST COMPARISON TABLE

YEAR	TTLCOST	YEREX	PV.YEX	PV.COST
1992	699.0	98.6	98.6	699.0
93	0.0	98.6	88.0	0.0
94	0.0	98.6	78.6	0.0
95	387.0	154.1	109.7	275.4
96	0.0	154.1	97.9	0.0
97	0.0	154.1	87.4	0.0
98	0.0	154.1	78.1	0.0
99	0.0	154.1	69.7	0.0
2000	805.0	264.5	106.8	325.1
1	0.0	264.5	95.3	0.0
2	0.0	264.5	85.1	0.0
3	223.0	295.5	84.9	64.1
4	0.0	295.5	75.8	0.0
5	0.0	295.5	67.7	0.0
6	0.0	295.5	60.4	0.0
TTL	2114.0	3042.8	1285.0	1363.7
T10	1891.0	1596.0	910.7	1299.6

PLAN: C **COST COMPARISON TABLE

YEAR	TTLCOST	YEREX	PV.YEX	PV.COST
1992	417.0	59.5	59.5	417.0
93	0.0	59.5	53.1	0.0
94	0.0	59.5	47.4	0.0
95	805.0	169.8	120.9	572.9
96	0.0	169.8	107.9	0.0
97	0.0	169.8	96.3	0.0
98	223.0	200.9	101.7	112.9
99	0.0	200.9	90.8	0.0
2000	0.0	200.9	81.1	0.0
1	0.0	200.9	72.4	0.0
2	0.0	200.9	64.6	0.0
3	699.0	299.5	86.1	200.9
4	0.0	299.5	76.8	0.0
5	0.0	299.5	68.6	0.0
6	0.0	299.5	61.3	0.0
TTL	2144.0	2891.1	1189.3	1303.9
T10	1445.0	1491.9	831.7	1103.0

6.4 Study on Coordination of Insulation

6.4.1 Basic Impulse Insulation Level (BIL)

In Central Sumatra Power System, the directly grounded neutral system is adopted for 150 kV system, and changeover from non-grounded neutral system to resistance grounded neutral system is under way for 20 kV systems, while the 150/20 kV secondary circuits of substations have already been changed over to resistance grounded neutral system.

According to the standards of PLN, the basic impulse insulation level (BIL) for 150 kV system and 20 kV system is designated respectively at 650 kV for transformer and 750 kV for the other equipments, and 125 kV, which comply with the IEC code. The same BIL is also adopted for substation equipment. Under this study, the same BIL is applied.

6.4.2 Isokeraunic Level (IKL)

According to the data obtained from PLN, the frequency of thunderstorm occurrence per year (isokeraunic level: IKL) in Central Sumatra is about 30 - 70, which is comparatively lower than the average level throughout Indonesia (Refer to Fig. 6.4-1).

In Japan, the IKL is about 30 along the coastal area of Japan Sea, roughly 20 in Northern Kanto District and about 10 around Tokyo. Therefore, more careful lightningproof design is adopted in Indonesia than Japan.

According to standard design in Japan, a lightning arrester for substation is installed near transformer, and no such arrester is installed for the transmission line within about 50 m from the substation arrester. Recently, however, lightning arresters tend to be installed also on the line side to protect circuit breakers, etc.

Under actual situations in Central Sumatra, lightning arresters are installed not only for all transformers but also for all transmission lines.

The fault ratio increases proportionally to the increase of IKL.

Since there is a difference in IKL in Japan and Indonesia, the standard system adopted in Indonesia has also been adopted under this study.

6.4.3 Salt-Contaminationproof Design

Any data and information pertaining to depositions of salt on insulators have not been collected under this study.

Although any typhoon scarcely occurs and there is no need to consider countermeasures against salt contamination generally in Indonesia, it is considered necessary to take such countermeasures in littoral area. According to the design documents for ongoing substation (Salak-Padang 150 kV Transmission Project Contract Document), the area up to 1,000 m from sea coast is specified to be a salty wind area.

Since it is considered essential to make sure the effect of salt contamination in the execution design stage, it is recommended to observe salt content at proposed sites near the sea.

Any salt content observation data, if obtained at and around the Simpangharu Substation locating about 2.5 km from the Indian Ocean, which is planned to be boosted to 150 kV, will be very useful for execution design.

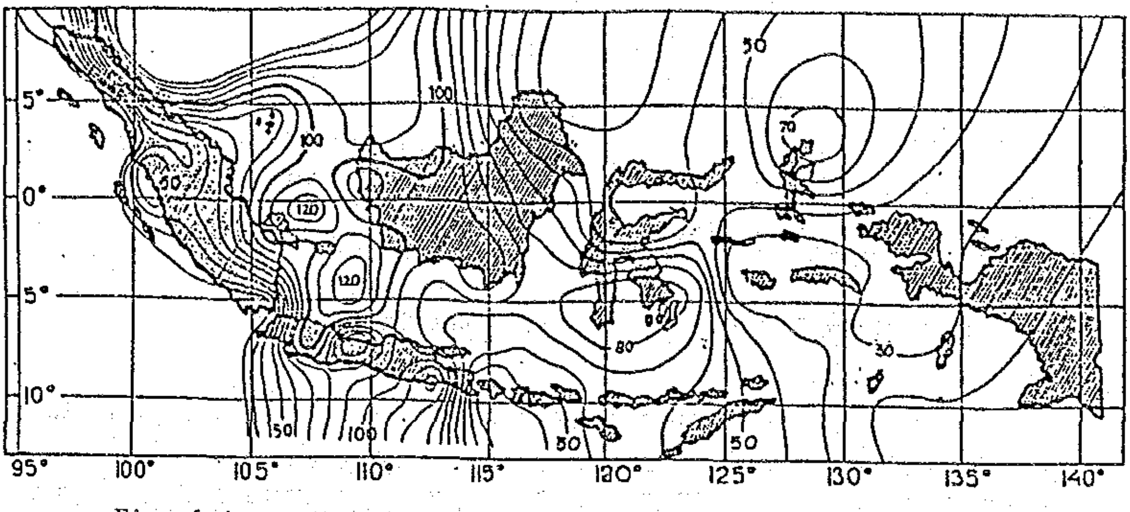
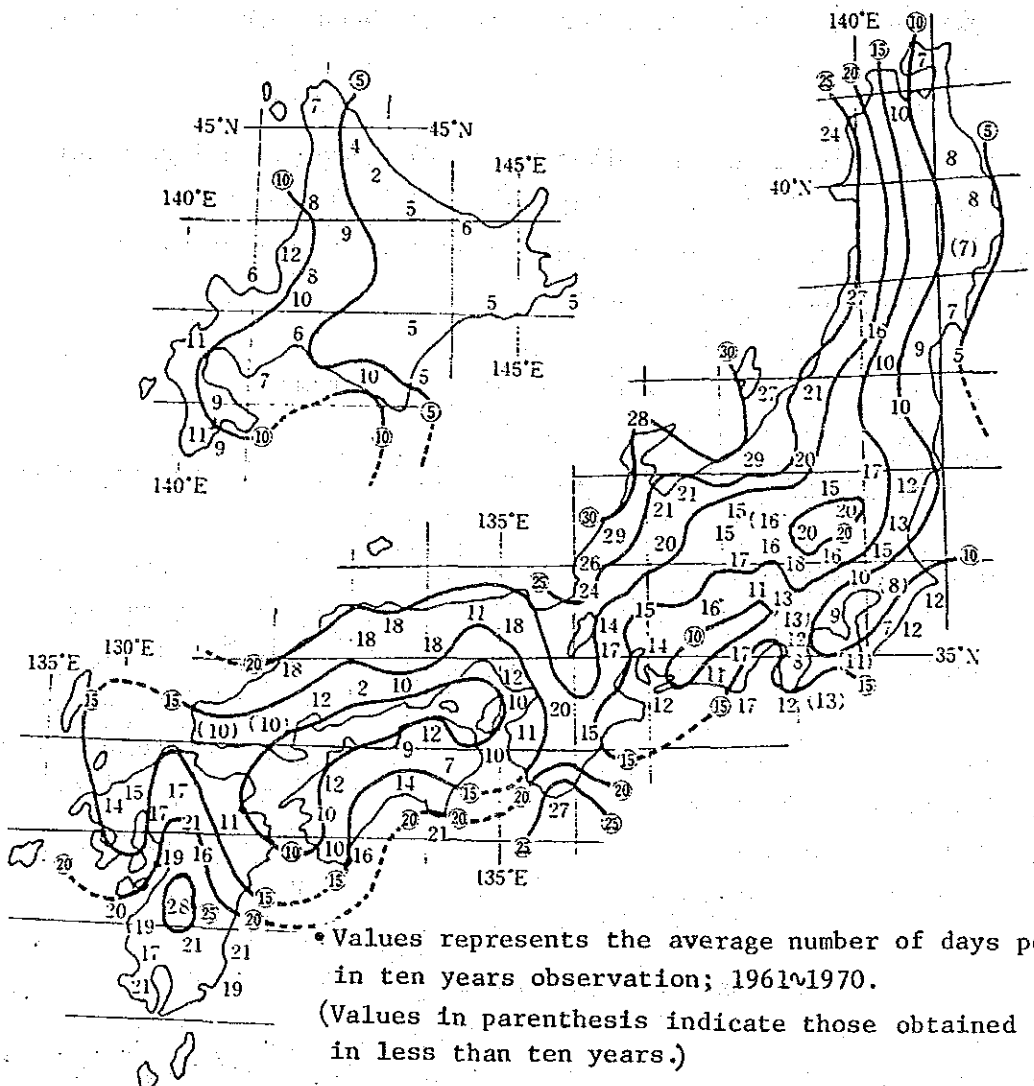


Fig. 6.4-1 Isokeraunic level (IKL) Map of Indonesia



- Values represents the average number of days per year in ten years observation; 1961~1970.
  (Values in parenthesis indicate those obtained in less than ten years.)
- The number of thunder of weak sound hearing is excluded.
- Lines show constant isokeraunic level which are plotted in a manner similar to the altitude contour lines on a topographic map.

Fig. 6.4-2 Isokeraunic level (IKL) Map of Japan

6.5 Protective Relaying System

6.5.1 Protective Relaying System for Transmission Line

For protecting long distance transmission lines such as in the 150 kV power system in Central Sumatra, the power line carrier (PLC) relay system which has been adopted in the existing transmission lines is economically more advantageous then other microwave and pilot wire (PW) systems. Therefore, PLC system has been adopted basically for protection of the transmission line.

However, since the pilot wire (PW) system is suitable for short distance transmission both economically and in view of simplification, application of these systems will be determined after study of individual power systems.

(a) Application of protective relaying systems

	Section	Distance (km)	System	Future plan
(1)	Ombilin - Payakumbuh	58	PLC	Divided at Batusangkar
(2)	Payakumbuh - Pekanbaru	143	PLC	Divided at Kotapanjang
(3)	Pekanbaru - Dumai	173	PLC	Divided at Duri
(4)	Padangluar - Payakumbuh	31	PLC	
(5)	Dumai - PERTAMINA	10	PW	
(6)	Pauh Limo - Simpangharu	7	PW	

These systems are shown in Annex 6-6, 6-7.

(b) Kinds of protection relays

(1) Power line carrier (PLC) relays

The main protective relaying system for both short-circuit and ground-fault protection should be of a distance and directional comparison type.

The back up protection system for both short-circuit and ground-fault protection should be of a distance and directional type.

The reclosing system should be of a high speed single phase reclosing or a three phase reclosing system.

(2) Pilot wire (PW) relay

The main protection system for short circuit and ground fault protection should be of an all-phase current circulating pilot wire relay system. The back up protection system for both short circuit and ground fault protection, and the reclosing system should be of the same system as that of the main protection system.

(c) As for the transmission line to PERTAMINA, it is required to determine whether to adopt a two circuit parallel receiving system or a one circuit receiving system with one circuit as standby depending upon the extent of reliability required by the consumer. Although details will be determined upon discussion with the consumer, a relaying system, which would also permit two circuit parallel operation, is adopted in this study.

6.5.2 Substation Protection System

(1) 150 kV bus protection system

For the Payakumbuh and Pekanbaru Substations which are expected to constitute specially important bases of the power system, a 150 kV bus protection system (voltage differential and current differential relaying systems) will be applied.

This system will also be applied for the Batusangkar Substation in the future when this substation is to be connected to the Singkarak Power Plant.

According to this system, input is obtained from current transformers for the respective feeders, and a faulty section is located and interrupted by means of circuit breakers for the respective feeders.

The 150 kV bus systems of the other substations will be protected by back up relays of transmission lines.

(2) Transformer protection system

Transformer windings will be protected by combinedly using high speed differential relays and overcurrent relays.

(3) 20 kV distribution line protection system

The neutral point of 20 kV system will be resistance-grounded. Therefore, the overcurrent and ground fault relays applicable to the above will be arranged.

These systems are shown in Annex 6-8.

6.5.3 Countermeasures against Major Power Failure in Power System

When a power generator unit has been stepped out from power system due to a trouble, the system frequency is lowered. The extent of frequency drop is proportional to the stepped out generator output, and the larger the stepped out output, the more extensively the system frequency is lowered. Thereby, it sometimes becomes difficult to continue operation of other remaining power generator units any more, and a major power failure would occur.

For instance, when a bus trouble has occurred in the Singkarak or Ombilin Power Plant, major power plants in the Central Sumatra Power System as shown in Fig. 6.5-1, two or more generator units will be isolated from the power system. In such a case, the system frequency will sometimes be lowered to 45 Hz or less depending upon the operating conditions of generator units. Thereby, it will become difficult to continue operation of thermal power units due to vibration of turbine blades and hydropower units due to reduction of the capacity of auxiliary equipment.

If these conditions have been left as they are, the thermal power plants will be shut down one after another, thereby resulting in a major power supply failure. Most of worldwidely famous major power supply troubles belong to this pattern.

(1) Frequency drop at the time of stepping out of major power generator units

Tables 6.5-1 and 6.5-2 indicate the conditions of frequency drop calculated in case the major power units have been tripped from the Central Sumatra power system. Table 6.5-1 shows the results of calculating the frequency drop at the time of power flow shown in Fig. 6.5-1, namely, at peak load. Table 6.5-2 indicates the results of calculating frequency drop at low load in the same system based upon the following assumptions. Namely, (1) because of light load, the thermal power units have been stopped; (2) although hydropower units are generally operated at partial output, these power units are assumed to be operated at the same output as that of Singkarak Power Plant at the time of peak load to assume a severe case; and (3) the total demand is assumed at 60% of peak hours.

(2) Effect of applying load shedding system

(a) In case the frequency in entire system is lowered

From Tables 6.5-1 and 6.5-2, the stepped out power is assumed to be 50% of the system capacity. Then, on the assumption that (1) the lowest frequency will not become 46 Hz or less even in the above case, and (2) the time when the frequency becomes 48 Hz or less should be kept within 10 seconds, a load shedding system plan has been worked out.

More concretely, it is intended to restore the system frequency under the conditions described in Table 6.5-3. According to the results of simulation shown in Annex 6.9 (a) - (f), it will be possible to attain an initial target of the effect.

(b) In case the system is separated

Should one transmission line route be interrupted, the power demand and supply will get out of balance. However, the effect when the two circuits of transmission line between Payakumbuh and Kotapanjang have been interrupted is severest according to the system in Fig. 6.5-1. When calculated based on the power flow at peak hours in Fig. 6.5-1, this trouble corresponds to stepout of 47% of power source as calculated below:

$$\frac{94.7}{94.7 + 105} \times 100\% = 47.4\%$$

Since this value is equivalent roughly to stepout of 50% of power source assumed due to frequency drop in all power system, it will be possible to continue stable operation not only in case of frequency drop in all power system but also in the above case, provided that the interrupting load capacity is equivalent to the value proportional to the system capacity on the left and right sides of Kotapanjang.

(3) Application of load shedding system

According to this system, the devices mainly designed for frequency relaying will be installed separately in individual substations. An outline of such a device is shown in Annex 6-10.

Further detailed design of this system will be determined after confirming the respective site conditions.

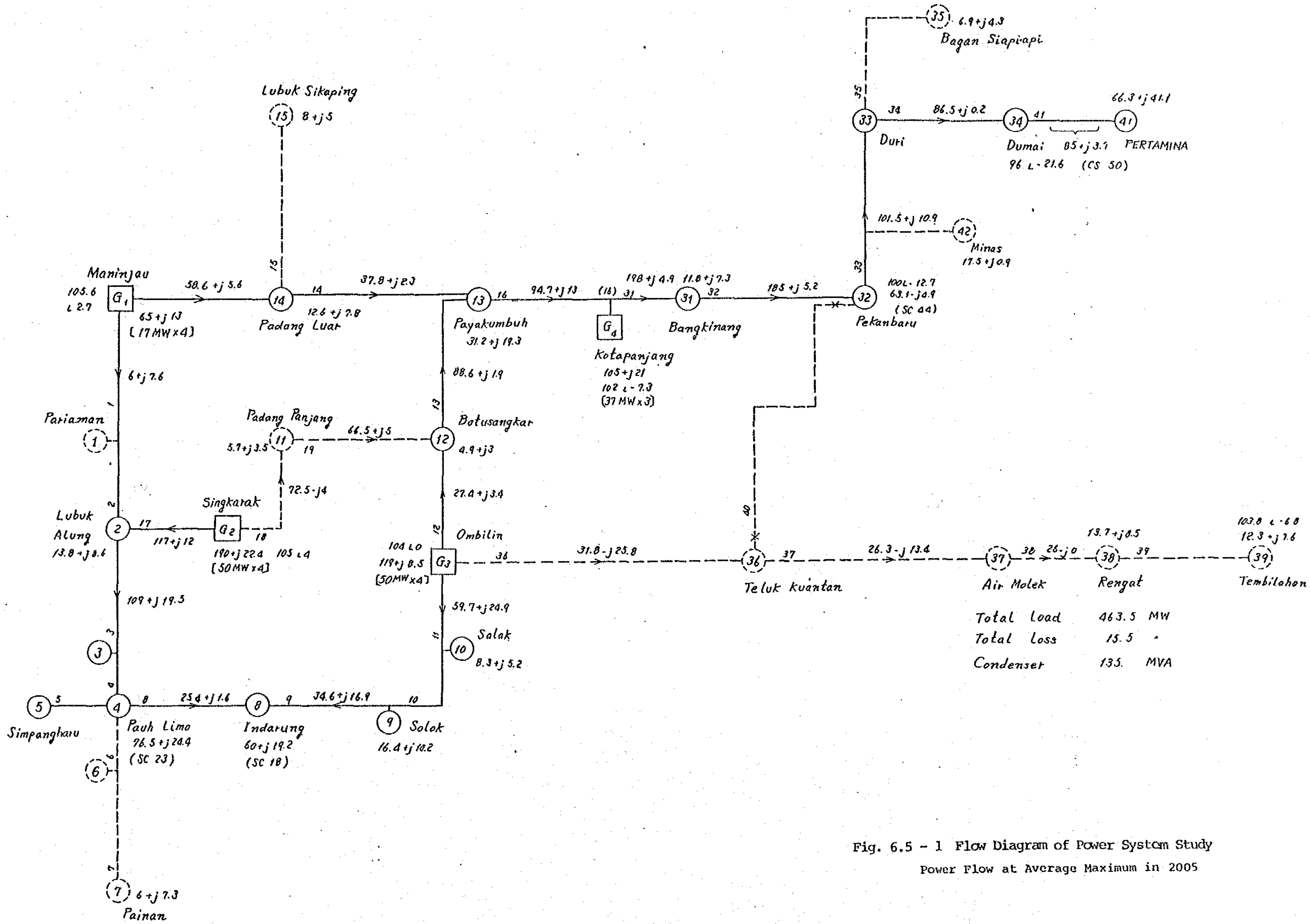


Fig. 6.5 - 1 Flow Diagram of Power System Study

Power Flow at Average Maximum in 2005

Table 6.5-1

Power Plants		Maninjau	Singkarak	Ombilin	Kotapanjang	Remarks
Capacity x No. of generator units		17 MW x 4	50 MW x 4	50 MW x 4	37 MW x 3	Total
Generated output (P)		65 MW + j13 MVR	190 MW + j22.4 MVR	119 MW + j8.5 MVR	105 MW + j21MVR	479 MW + j64.9 MVR
Stepout of one unit	Unit output P = P/No. of units	16.3 MW	47.5 MW	30 MW	35 MW	Calculated based on normal system frequency fluctuation of 8%/Hz.
	P /Total generated output x 100	3.4%	9.9%	6.3%	7.3%	
	Frequency at P stepout	49.6 Hz	48.8 Hz	49.2 Hz	49.1 Hz	
Stepout of two units	Output of two units (P = 2P)	32.6 MW	95 MW	60 MW	70 MW	
	P /Generated output x 100	6.8%	19.8%	12.6%	14.6%	
	Frequency at P stepout	49.2 Hz	47.5 Hz	48.5 Hz	48.2 Hz	
Stepout of all units	Total output	65 MW	190 MW	119 MW	105 MW	
	Total output/Total generated output x 100	13.6%	39.7%	24.8%	21.9%	
	Frequency at stepout of all units	48.3 Hz	45 Hz	46.9 Hz	47.3 Hz	

Table 6.5-2

Power Plants		Maninjau	Singkarak	Ombilin	Kotapanjang	Remarks
Capacity x No. of generator units		17 MW x 4	50 MW x 4	50 MW x 4	37 MW x 3	Total
Generated output (P)		27 MW + j7.6 MVR	190 MW + j22.4 MVR		70 MW + j10 MVR	287 MW + j40 MVR
Stepout of one unit	Unit output (P = P/No. of units	6.8 MW	47.5 MW		23.3 MW	Calculated based on normal system frequency fluctuation of 8%/Hz.
	P /Total generated output x 100	2.4%	16.6%		8.1%	
	Frequency at stepout of P	49.7 Hz	47.9 Hz		48.9 Hz	
Stepout of two units	Output of two units (P = 2P)	13.6 MW	95 MW		46.6 MW	
	P /Generated output x 100	4.8%	33%		16.2%	
	Frequency at stepout of P	49.4 Hz	45.9 Hz		48 Hz	
Stepout of all units	Total output	27 MW	190 MW		70 MW	
	Total output/Total generated output x 100	9.4%	66.2%		24.4%	
	Frequency at stepout of all units	48.8 Hz	41.7 Hz		47 Hz	

Table 6.5-3

Time Ry Contact Block		Interrupting load demand	Ry(1) Frequency drop time from 48.8 to 48 Hz	Ry(2) 48.5 Hz or less	Ry(3) 48 Hz or less
A	A 1	5%	2 sec. or less	0.5 sec.	
	A 2	5%		1.0 sec	0.2 sec.
B	B 1	5%	1 sec. or less	2.0 sec.	
	B 2	5%		3.0 sec.	0.5 sec.
C	C 1	5%	0.5 sec. or less	4.0 sec.	1.0 sec.
	C 2	5%		5.0 sec.	2.0 sec.
D	D 1	5%	0.3 sec. or less	6.0 sec.	3.0 sec.
	D 2	5%		7.0 sec.	4.0 sec.
E	E 1	5%	0.2 sec. or less	8.0 sec.	5.0 sec.
	E 2	5%		10.0 sec.	6.0 sec.
F	F 1	5%	0.15 sec. or less	12.0 sec.	7.0 sec.
	F 2	5%		14.0 sec.	8.0 sec.

Description of relay operation:

i. In case many power generator units are stepped out from power system due to major trouble.

In this case, the system frequency will be lowered rapidly. For example, in case one-third the power supply capacity has been stepped out at described in Annex 6-9 (d), the time when the frequency drops from 48.8 Hz to 48 Hz is about 0.4 sec. In this case, all of the contacts from A through to C will be closed by the relay Ry(1) to interrupt 30% of the load at one time. Then, the frequency will be restored.

ii. In case not many power generator units are stepped out due to comparatively minor trouble.

In this case, the system frequency will drop moderately. When roughly 17% of the power supply capacity has been stepped out as described in Annex 6-9 (a), for example, it will take about 1.2 sec. until the frequency drops from 48.8 Hz to 48 Hz. When the frequency still remains at 48.5 Hz or less for 0.5 sec. or more halfway during the above time interval, the relay Ry(2) will be actuated at first to close the contact A and interrupt 5% of the load.

In case the frequency has not been restored to a normal level and still remains at 48.0 Hz or less longer, the contact A will be closed by the relay Ry(1) to interrupt further 5% of the load.

When the frequency has not been restored and still remains at 48 Hz or less for 0.5 sec., the contact B will be closed by the relay Ry(3) to interrupt 10% of the load. Then, the frequency will gradually be restored.

As presented above, the total load interrupting capacity should be 20% of the rated load.

According to the conditions of troubles as assumed above, an optimum load interrupting capacity has been selected and an appropriate combination of protective relays has been adopted to ensure stable restoration of the power system frequency.

6.6 Effect of Shutting Down Transformers at Low Load upon Reduction of Power Loss

The effect of shutting down transformers at low load upon reduction of power loss was studied on the basis of the representative load curves in Central Sumatra.

Since shutdown of one bank at light load causes increase of copper loss of the bank in operation, it is widely known that the total loss increases except in case of low load. This relationship is shown in Table 6.6-2 in terms of values calculated from Fig. 6.6-1. Therefore, unless the availability in case one bank out of three banks is shut down and that in case one bank out of two banks is shut down have become approximately 35% and 30% of the rated values, respectively, it would be impossible to attain the effect of reducing power loss.

Judging from the representative load curves (Fig. 6.6-2) in Padang, it is considered possible to shut down the transformer bank for about eight hours a day under the present operating conditions of the substation. The effect of reducing power loss is estimated to become the amount as shown in Table 6.6-1.

Since there will be some problems regarding reduction of reliability at the time of fault due to shutdown of one bank in actual operation, operation policies should be worked out by studying the characteristics of load and transformers in individual substations in order to operate these substations under optimum conditions.

Table 6.6-1 Amount of loss reduced by shutting down transformers during low load

Day time average availability during operation of all banks	Shutdown of one bank among three banks		Shutdown of one bank among two banks	
	kW	kWh/year	kW	kWh/year
30%	13	37,960	6	17,520
25%	21	61,320	16	46,720
20%	27	78,840	24	70,080

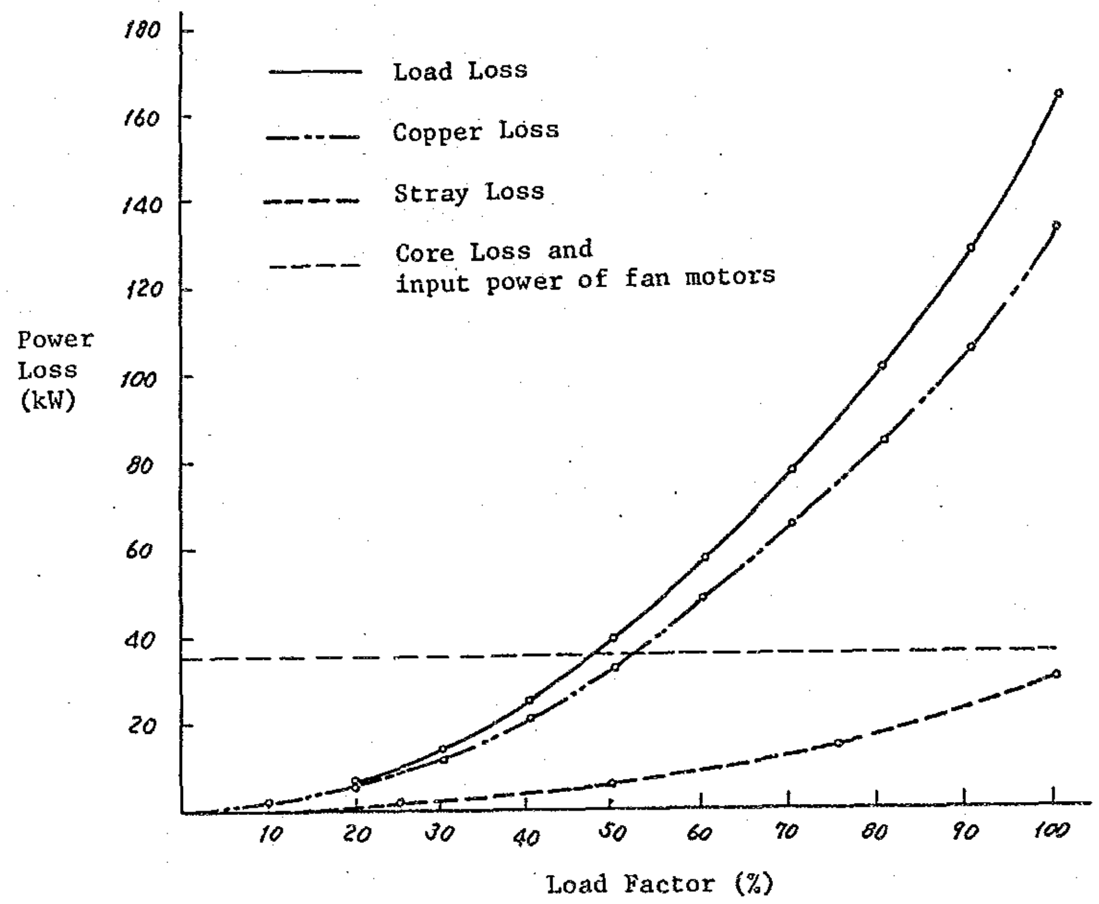


Fig. 6.6-1 Typical Loss Curve of 150/20 kV 30 MVA Transformer

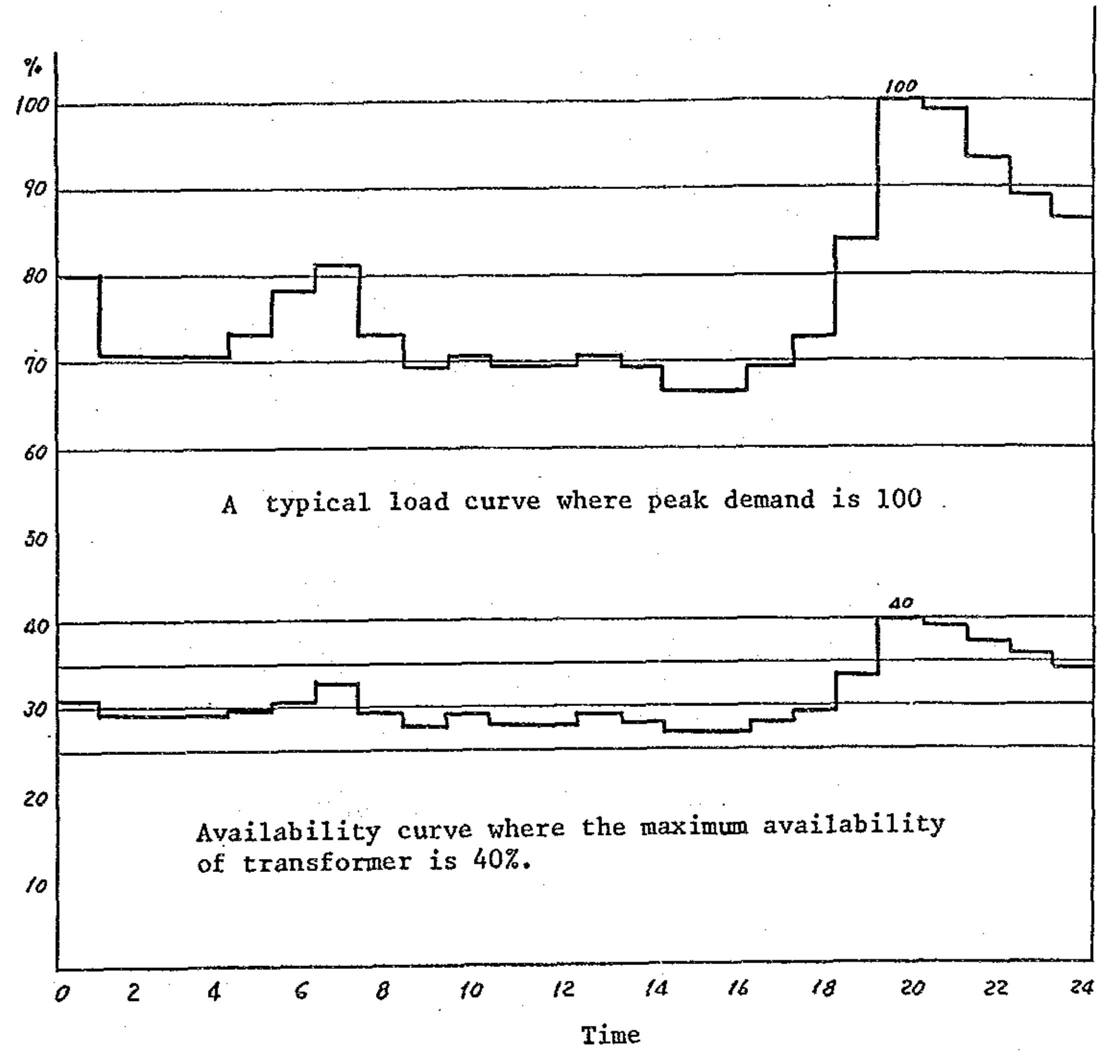


Fig. 6.6-2 Typical Load Curve in Padang

Table 6.6-2 Relation between the Availability of Transformers and Reduction of Loss

Unit : kW

Operating conditions	Availability		A. Loss during operation of all transformers			B. Loss during shut-down of one transformer			B - A
	All transformers are in operation	One transformer is shut down	Fixed loss	Load loss	Total	Fixed loss	Load loss	Total	
One of 3 transformers is shut down.	60% x 3	90% x 2	36x3=108	56x3=168	276	36x2=72	131x2=262	334	+58
	50% x 3	75% x 2		38x3=114	222		90x2=180	252	+30
	40% x 3	60% x 2		23x3=69	177		56x2=112	184	+ 7
	36% x 3	54% x 2		18.5x3=56	164		45x2=90	162	- 2
	35% x 3	52.5%x2		18x3=54	162		43x2=86	158	- 4
	33.3%x3	50% x 2		16x3=48	156		38x2=76	148	- 8
	30% x 3	45% x 2		13x3=39	147		31x2=62	134	-13
	25% x 3	37.5%x2		9x3=27	135		31x2=62	114	-21
	20% x 3	30% x 2		5.5x3=17	125		13x2=26	98	-27
One of two transformers is shut down.	50% x 2	100% x 1	36x2=72	76	148	36x1=36	163	199	+51
	40% x 2	80% x 1		46	118		103	139	+21
	35% x 2	70% x 1		36	108		78	114	+ 6
	30% x 2	60% x 1		26	98		56	92	- 6
	25% x 2	50% x 1		18	90		38	74	-16
	20% x 2	40% x 1		11	83		23	59	-24

6.7 Requirements for Civil and Architectural/Structural Facilities

The major requirements for substation site are:

(1) The ground should be in favorable conditions.
(2) The site should be safe against flood.
(3) The ground should be as flat as possible.
(4) Excellent drainage should be ensured.
(5) Easy construction of incoming and outgoing transmission lines should be ensured.
(6) Easy transportation of equipment and materials should be ensured.
(7) Easy maintenance and management of equipment and structures should be ensured.

Therefore, an optimum substation shall be so selected as to meet the above requirements. The conditions of major proposed substation sites are as outlined below.

(1) Simpangharu Substation

This substation site is located inside the diesel power plant in Padang adjacent to a tributary of Arau River. Since the space for substation construction is limited, new structures will be built after dismantling existing old power plant equipment.

(2) Tabing Substation

This substation site is located amid a flat paddy field zone. As a result of investigating the properties of soil excavated for drilling deep city water well adjacent to the site, the surface soil stratum is shallow, and there is a stratum consisting of sand or gravel under the surface soil stratum. Because of excellent ground conditions, this site will be suitable for constructing a substation.

(3) Pauh Limo Substation

This existing substation is located at the foot of a hill. Because of excellent ground conditions, there will be no particular problem regarding drainage, etc.

(4) Pekanbaru Substation

This proposed substation site is located about 12 km southwest from the central part of Pekanbaru, where the land is flat. Although the surface soil is black humus, the lower stratum consists of hard clayey soil.

Thus, this site is suitable for constructing a substation and there will be no particular problem regarding equipment transportation to the site.

Since the entire adjacent area is nearly in the same geological conditions, there will be no particular problem also in the case of the alternative plan.

(5) Dumai Substation

This site is located on a hill with a moderate slope in the outskirt of Dumai. The ground consisting of excellent sandy soil will ensure satisfactory drainage and do not cause any problem regarding transportation of equipment and materials to the site.

(6) Payakumbuh Substation

The ground in the paddy field zone around Payakumbuh consists of alluvium deposit of former river basin, where ground conditions are not favorable to ensure satisfactory drainage. Therefore, this substation site was selected on a high tableland of a terrace form instead of the above paddy field zone.

(7) Duri Substation

In consideration of branching of the transmission line to Bagan Siapiapi in the future, this substation site was selected in the outskirt of Duri. This site is surrounded by a hilly zone. The ground conditions are favorable and there will be no problem regarding drainage. Since this site is located adjacent to a main road, it will also be easy to construct an access road for equipment and material transportation.

(8) Batusangkar Substation

This site is comparatively flat with favorable ground conditions. Therefore, it is suitable for constructing a substation.

(9) Bangkinang Substation

Because of its location on the foot of a hill, there are some up and down portions. Therefore, it will be necessary to cut and fill the ground for site levelling. The ground conditions are favorable and satisfactory drainage will be ensured. Moreover, this site permits easy access from main road for transportation of equipment and materials to the site. Therefore, this site is suitable for substation construction.

SECTION 7

DISTRIBUTION FACILITIES

SECTION 7 DISTRIBUTION FACILITIES

7.1 Present Situations of Distribution Facilities

The power distribution system in Central Sumatra has been expanding successively along with the progress of electrification centering on diesel power plants installed in individual demand areas.

In Padang, Bukittinggi, Pekanbaru and other cities, interconnection of distribution lines and reinforcement of distribution systems has also been promoted together with expansion of 150 kV main power system.

The present situations of distribution facilities in Central Sumatra are as outlined below.

7.1.1 Medium Voltage Distribution System

(1) Voltage

Although 6 kV (composition ratio: 26%) and 20 kV (composition ratio: 74%) classes are adopted for the existing distribution lines as of June, 1985, PLN has standardized the distribution line voltage to 20 kV, and all new distribution lines are designed on the basis of 20 kV.

The 6 kV lines being extended are also designed on the basis of 20 kV and operated at 6 kV.

(2) Line capacity

Although any standard line capacity has not been designated, the size of conductor is standardized.

(3) Grounding system

Although the non-grounded neutral system has so far been adopted, the resistance-grounded neutral system has come to be applied for new 20 kV distribution systems to ensure adequate protection of distribution lines.

(4) Voltage regulation

While the upper limit voltage is designated to be regulated within +5% of rated voltage, the lower limit voltage has not been designated.

(5) Type of conductors

Out of about 1,000 km of distribution lines (June 1985), 85% of lines consist of overhead lines, for which bare aluminum conductors (AAAC and AAC conductors) are mainly used without using any insulated conductor.

(6) Transformers

Three-phase transformers with capacities ranging from 50 to 630 KVA are chiefly used, while small number of single-phase transformers are used.

7.1.2 Low Voltage Distribution System

(1) Voltage

Although 127/220 V and 220/380 classes are used, a standard voltage of 220/380 V is applied for power distribution to new demand areas.

(2) Voltage regulation

The upper and lower limit voltage is regulated within the ranges of +5% and -10%, respectively. According to the metering records in 1984 in Padang, the voltage was regulated roughly within the designated ranges.

(3) Type of conductor

The service lines to individual consumers are bare conductors for old facilities and insulated ones for new facilities. However, main overhead distribution lines consist of bare aluminum or bare copper conductors without any insulated conductor.

(4) Electric system

Three-phase-four-line system.

7.1.3 Distribution Line Power Loss

The distribution loss rate in Wilayh III is as given below:

1983 : 20% (22%)
1984 : 20% (22%)

Each value in parenthesis indicates the total transmission and distribution loss rate. This value is by about 10% higher than the average transmission and distribution loss in the entire power systems of PLN.

7.1.4 Situations of Troubles in Distribution Lines

The situations of troubles occurred in one year of 1984 in Wilayah III are as follows:

- o Service interruption time: 77 min./consumer
- o Frequency of service interruption:
  49 times/consumer

Major causes of such troubles are as broken down below:

- o Trip of medium voltage line due to contact with tree (17.9 min. and 3.2 times per consumer)
- o Fusing of secondary circuit of transformer (10.0 min. and 3.2 times per consumer)
- o Fusing of indoor lines of consumers (4.5 min. and 2.5 times per consumer)
- o Shutdown of power plants (4.5 min. and 5.8 times per consumer),

For further details, refer to Annex 7-1.

7.2 Countermeasures for Reducing Power Loss in Distribution Lines

Generally, the power loss in individual distribution facilities in Japan is broken down as listed in the table below:

	Composition (%)
Medium voltage line	43
Transformer	45
Low voltage line	5
Service lines	4
Instruments	3
Total	100

Judging from the conditions of distribution facilities in Indonesia, the composition ratio of power loss in medium and low voltage lines is considered to be high.

As a countermeasure for reducing power loss in distribution lines, it is fundamentally required to eliminate long distance distribution lines through extension or construction of substations and transmission lines and boost the distribution voltage. However, it would be very difficult to immediately step up the distribution voltage in view of cost and replacement of equipment and facilities. Therefore, the distribution voltage is required to be stepped up gradually under a long term plan by comprehensively taking into account the trend of the growth of power demand, service level and budgetary requirements.

Major workable countermeasures for reducing power loss in distribution lines are as presented below.

7.2.1 Enlargement of Conductor Size

The average size of conductors for medium voltage 6 kV distribution lines is 40 mm^2 with that of the majority of such medium voltage lines being as small as 25 mm^2. This size is comparatively smaller than that of 20 kV line (74 mm^2 on an average and 70 mm^2 for majority of 20 kV lines). Moreover, the capacity of transformers in 6 kV system which is 165 KVA per km of line length is considerably larger than that of 20 kV distribution lines which is 63 KVA/km. Consequently, the power loss in 6 kV distribution lines is considered to be substantially larger than that in 20 kV distribution lines.

Therefore, enlargement of conductor size is considered essential not only for the purpose of reducing the power loss in distribution lines but also in view of expansion of power supply capacity along with increase of load in the future.

It is, therefore, recommended to standardize the size of conductors for medium voltage distribution lines to 95 mm^2 when standardization of line capacity is taken into account.
(Refer to Annex 7-4)

Also, the size of conductors for low voltage distribution lines which is smaller than the standard size is recommended to be enlarged.

7.2.2 Boosting of Existing 6 kV Distribution Lines to 20 kV

(1) When the existing 6 kV distribution lines are stepped up to 20 kV, it will be possible to reduce the power loss to about 10% of the power loss in the existing 6 kV lines.

Many 6 kV distribution facilities are rather of an old type and the size of conductors is also small in many cases when considered the loading current. Therefore, stepping up of the existing 6 kV lines to 20 kV will be highly effective for promotion of system interconnection through standardization of distribution voltage, reinforcement of power supply capacity and improvement of reliability.

However, appropriation of budget required for large scale modification including reconstruction or replacement of transformers, supporting structures and insulators will cause a big problem.

It is considered to be an appropriate policy for PLN that the distribution facilities being extended have been designed on the basis of 20 kV and the existing 6 kV lines to be extended have also been designed on the basis of 20 kV in preparation for standardization of distribution line voltage to 20 kV in the future.

The time of stepping up the distribution voltage will be determined as a step next to enlargement of conductor size in view of the conditions of the existing facilities, increase of load, budget for distribution facilities, etc.

(2) Although step-up of low distribution line voltage is also desirable, it will be difficult to step up the voltage because of the necessity to modify the equipment of consumers. Therefore, it will be advantageous to adopt the present voltage for the time being.

7.2.3 Adoption of Parallel Condenser

The span length of distribution lines in Central Sumatra is very large because of low density of load, and therefore voltage drop and power loss are considered to be also large.

Therefore, it is proposed to install parallel condensers for distribution lines which are long in span length and large in reactive current with lagging power factor.

The optimum installation position of each parallel condenser should be at a point where average reactive current becomes half the reactive current from an adjacent parallel condenser. Economically-optimum installation position and capacity of parallel condensers will be determined according to the procedures given in Annex 7-2.

The parallel condenser is classified into a fixed type and a controlled type, each having inherent advantages and disadvantages. The control condenser is high in installation cost and requires much labor for maintenance though it is possible to attain sufficient effect during peak load. Therefore, the fixed condenser system is recommended to be adopted. Meanwhile, the capacity of parallel condenser should be determined so carefully as not to cause over-compensation of the system at the time of low load.

7.3 Countermeasures against Troubles in Distribution Lines

The present situations of troubles in distribution lines are as described in 7.1.4, and major countermeasures for preventing these troubles are as explained below.

7.3.1 Countermeasures for Preventing Tripping Faults of Medium Voltage System due to Contact with Trees

The troubles in distribution lines are caused most frequently by shutdown of medium voltage distribution systems resulting from contact with trees. These troubles would be resulted from the use of bare conductors when such bare conductors laid adjacent to trees have come into contact with trees due to wind. These troubles can be prevented by:

- o separating conductors sufficiently from trees;
- o and/or using insulated conductors or overhead cables.

The use of insulated conductors is recommended to ensure safety including prevention of electric shock to anybody who is in a house adjacent to trees which are likely to come into contact with bare conductors. However, use of insulated conductors makes it necessary to give the following design considerations:

- o Increase of wind load resulted from increase in the finished outside diameter of conductor necessitates to increase the strength of supporting structures.
- o The allowable current will be reduced due to changes of applicable thermal resistance of insulators and allowable temperature of conductor (OW conductor).

Moreover, the cost of insulated OW conductor (low voltage) becomes 1.5 or 2.0 times that of bare conductor, and the cost of insulated OC conductor (20 kV) ranges from 2.5 or 3.0 times that of bare conductor.

However, in view of safety and reduction of several faults, an application of insulated conductor to all low voltage lines shall be positively considered in some main cities like Padang and Pekanbaru.

7.3.2 Countermeasures for Preventing Fusing Troubles in Secondary Circuit of Transformer

Fusing troubles in the secondary circuit of transformer would be caused due chiefly to short circuit between low voltage lines and service lines. Such short circuit troubles are assumed to have been caused by contact of low voltage and service lines due to rolling of these lines by wind pressure and contact of lines with trees.

Therefore, the horizontal line-to-line distance of distribution line* was studied as described in Annex 7-3. As a result, line-to-line contact was concluded to be highly probable when the line-to-line distance is 300 mm as in the case of the existing low voltage distribution lines.

Therefore, it is proposed that the horizontal line-to-line distance of low voltage distribution lines be expanded to 500 mm from 300 mm in order to prevent occurrence of such line-to-line contact troubles. Thereby, it is considered possible to prevent contact of low voltage distribution lines with a span length of within 40 m which are strung at a sag rate of 2.0% or less. In case such distribution lines are not strung according to these requirements, adoption of vertical arrangement of conductors or use of insulated conductor is recommended.

*Note: In this study, the maximum wind velocity was assumed at 25 m/sec., and an equivalent wind velocity of the gustiness applied for calculation of rolling of conductors was calculated to be 8 m/sec. and adopted it for this study. In actual application, however, further detailed study is considered to be necessary.

7.3.3 Countermeasures for Preventing Fusing Troubles in Consumers' Buildings or Housing

Many fusing troubles in consumers' housing are also observed in Japan, and it would actually be impossible to totally eliminate these troubles. Although there would be no problem if such broken fuses are replaced, installation of breaker switches for individual indoor circuits instead of fuses is recommended in Japan to save labor force for visiting consumers on each occasion of fusing troubles and for restoration of power supply immediately after fusing troubles. Use of such indoor breaker switches is also recommended to prevent indoor fusing troubles in Indonesia.

7.4 Standardization of Design

7.4.1 Standardization of Low Voltage Distribution Lines

The average capacity per distribution transformer in Wilayah III is approximately 130 KVA, and the average span length of low voltage distribution lines connected thereto is about 1,800 m per transformer. Consequently, large voltage drop deemed to arise part of line terminals is considered to be one of the major causes of power loss.

Hence, study was carried out regarding standardization of the span length of low voltage distribution lines.

First, the span length of low voltage distribution lines was studied as the results are shown in Table 7.4-1. From this table, it is recognized that electric power can be supplied to considerably distant place without causing remarkable voltage drop in case the load is small.

Next, economically optimum length of low voltage distribution lines was studied by taking into account the cost and power loss within a certain limit of voltage drop. As the results are shown in Fig. 7.4-1, it was clarified to be economically-optimum in terms of the cost per one pole to extend the low voltage line fully up to the limit of voltage drop. Moreover, it was also made clear that small size conductors are economical in case the density of load is small while large size conductors are economical in case the density is high.

Based upon the results of above study, therefore, the design of low voltage distribution lines is recommended to be as described below.

o Size of conductor for low voltage distribution line

	Size of conductor
Load density = 20 A or less/one pole	35 mm^2
Load density = 20 A or more/one pole	70 mm^2

However, the density of load after five years was assumed in this case.

o Allowable span of low voltage distribution line

The distance from a transformer for distribution line should be within the values of allowable span in Table 7.4-1 according to the density of load (load forecast five years ahead) in each demand area.

However, in case the density of load is very low, the allowable span should be determined by individually calculating voltage drop in the respective areas regardless of the values indicated in the table.

7.4.2 Lightningproof Design of Distribution Lines

The number of thunderstorm days in Central Sumatra is 40 or

70 days per year, which is larger than that of Japan (30 or 40 days per year in frequent thunderstorm occurrence areas). According to the statistics of troubles, the frequency and duration of troubles caused by lightnings in distribution lines are 0.96 times and 0.91 minutes per consumer, which are smaller or shorter than those caused by other troubles. These data may vary depending upon the procedures for compiling the statistics of troubles, and it seems that a considerable number of disconnection faults and other troubles of high voltage distribution lines might have been caused by lightning. For reference, the number of troubles due to lightning occupies about 45% of the total number of troubles in medium voltage distribution lines in the case of some electric power company T in Japan.

As lightning-proof equipment, lightning arresters are installed on the poles on which transformer and underground cable terminal box are equiped in Central Sumatra. For lightningproof design of 20 kV distribution lines, it is necessary to take into account protection against both direct lightning attack and inductive lightning surge. However, it is impossible to prevent from the flashover direct lightning attack with arrester. As a lightning-proof facility against direct lightning attack, overhead grounding wire is used in Japan. The overhead grounding wire is effective not only for preventing flashover at the time of direct lightning attack but also for suppressing inductive lightning surge as well as for suppressing corona streamers arising from line conductors, supporting structures, etc. at the time of lightning attack in adjacent area. The data indicating the effects of overhead grounding wire are shown in Fig. 7.4-2 and Table 7.4-2.

Therefore, it is recommended to combinedly use overhead grounding wire and lightning arresters instead of using only lightning arresters as a countermeasures for protection of equipment against lightning. Meanwhile, the following items should be taken into account for lightning-proof design.

(Overhead grounding wire)

- o Overhead grounding wire shall be earthed for each pole.
- o The grounding resistance shall be 10 - 20 ohm.

(Lightning arrester)

- o A lightning arrester shall be installed on any equipment mounting pole.
- o The grounding of lightning arrester shall be used commonly as that of overhead grounding wire.

Meanwhile, when insulated conductors are used for medium voltage distribution lines instead of bare conductors as a countermeasure for preventing troubles as recommended previously, such insulated conductors become more susceptible to fusing due to dynamic current arc when insulation cover has been broken down due to lightning attack. Therefore, further thoroughgoing countermeasures are required for protecting insulated conductors against lightning attack.

In Japan, the construction cost of overhead grounding wire is about 220,000 yens per km.

7.4.3 Standardization of Distribution System Configuration

(1) In many cases of distribution systems in rural areas of Central Sumatra, electric power is supplied from one power source through one circuit line. Still more, individual distribution lines have not been interconnected to other distribution lines. Therefore, power supply is suspended until restoration of a fault point at the time of faults not only in power source but also in distribution lines. Although it would be desirable to interconnect adjacent power sources and distribution lines as much as practicable,

the present situations would be unavoidable until distribution lines have been expanded to some extent in proportion to the growth of power demand.

In the case of distribution systems in city areas, electric power is supplied from one or two power sources through several circuit lines. Where there are two power sources in the same city, these power sources are interconnected by means of no-load express feeders in preparation against faults in the power sources. Although adjacent distribution lines are interconnected, such interconnection has not been carried out based upon specially unified concept, and there are observed to be considerably large portions of distribution lines where restoration is impossible immediately after occurrence of faults.

In Bukittinggi, a 20 kV loop system connecting adjacent power sources and switching stations has been established in preparation against occurrence of troubles. Should further minute interconnection of mutual distribution lines from this loop system have been realized, the reliability would further be raised.

(2) In proportion to the growth of power demand in future, diesel power plants and distribution substations will be constructed, and distribution lines will also be expanded. In such a case, the following distribution system configuration is recommended:

- The configuration should be so determined as to make it possible to change over the load in a sound section to other distribution lines and continue power distribution at the time of fault in distribution lines.

- In view of faults in power sources, the configuration should be so provided as to enable changeover to the distribution lines from other power sources.

More concretely, the distribution system configuration should be established as described below.

a. Standard capacity of distribution lines

The maximum standard capacity of the portions of main distribution lines should, in principle, be 300 A.

b. Size of conductor

Judging from the standard capacity of distribution lines, the standard size of conductors for the portion of main distribution lines should, in principle, be AAAC 95 mm^2 and OC 120 mm^2 (ACSR OC 120 mm^2). In case voltage drop is substantially large, however, the conductor size should be determined individually on a case-by-case basis.

c. Split interconnection system of distribution lines

By adopting a radial form distribution line system, the load of one distribution line should be split into three sections, and a splitting-to-three-section three-interconnection system should, in principle, be adopted for the respective sections. In the areas where load is small and the number of distribution lines is small, however, adoption of splitting-to-two-section two-interconnection system, etc. should be taken into account.

d. Load in each section

In order that the load in a distribution line becomes within a standard capacity of 300 A when the load in one section is switched over to other distribution line at the time of faults, the load in the section should, in principle, be roughly 70 or 80 A in case the distribution line is split into three sections.

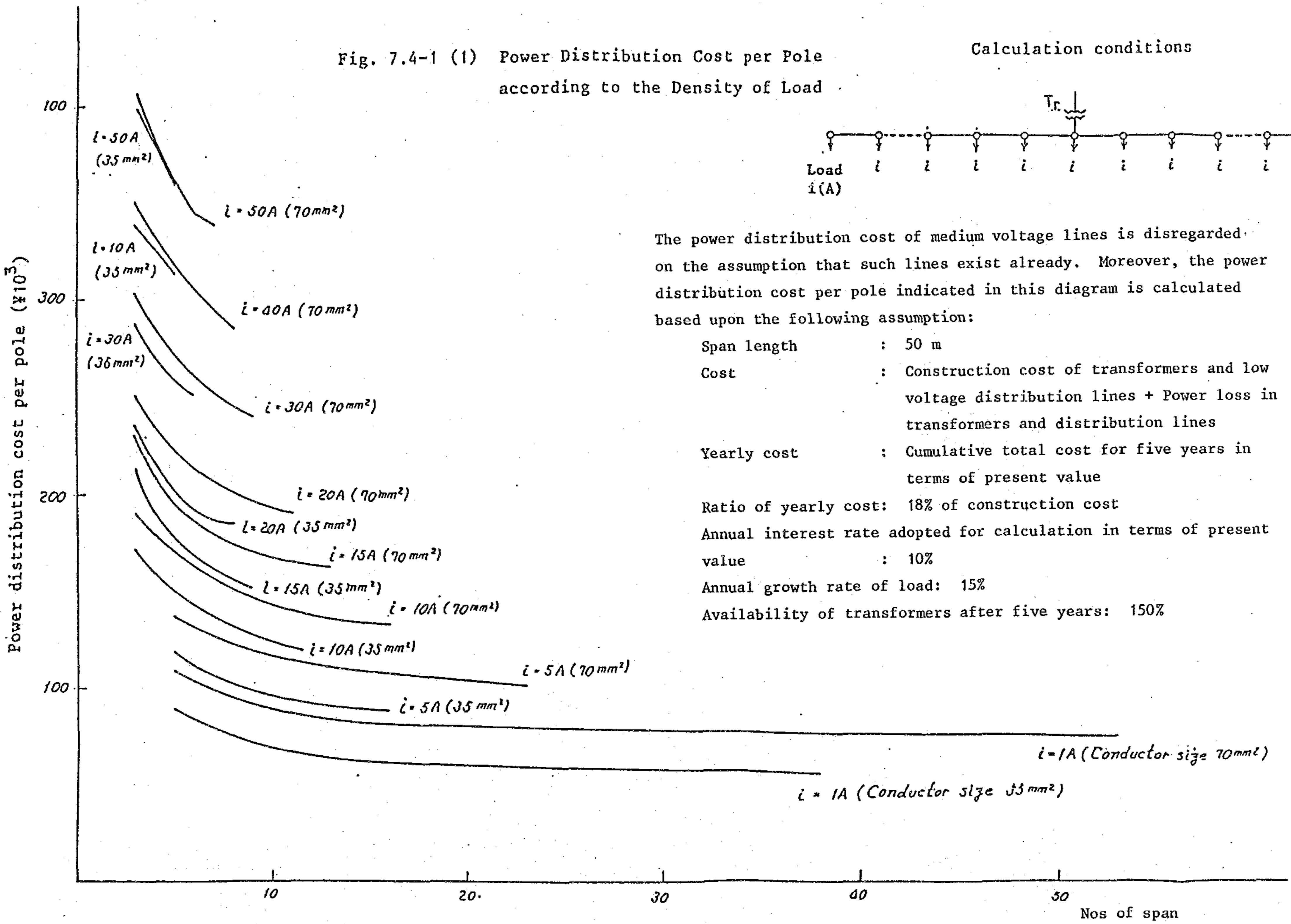
e. Switches for each section

Load switches should be installed at each split point and interconnecting point of distribution line.

f. Lower limit of voltage drop

A lower limit of voltage drop at line terminals should be determined (to 5 or 10% of sendout voltage) to keep voltage drop within the designated limit when load is changed over at the time of fault.

Fig. 7.4-1 (1) Power Distribution Cost per Pole according to the Density of Load



Calculation conditions

The power distribution cost of medium voltage lines is disregarded on the assumption that such lines exist already. Moreover, the power distribution cost per pole indicated in this diagram is calculated based upon the following assumption:

Span length	:	50 m
Cost	:	Construction cost of transformers and low voltage distribution lines + Power loss in transformers and distribution lines
Yearly cost	:	Cumulative total cost for five years in terms of present value

Ratio of yearly cost: 18% of construction cost

Annual interest rate adopted for calculation in terms of present value : 10%

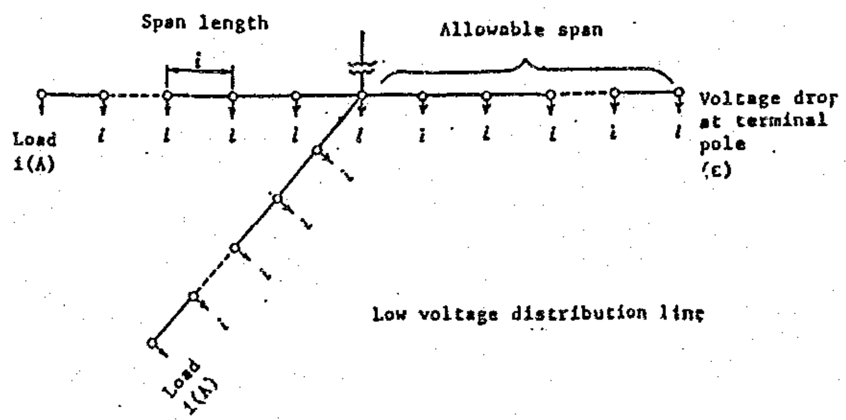
Annual growth rate of load: 15%

Availability of transformers after five years: 150%

Table 7.4-1 Criteria for Evaluating Voltage Drop in Low Voltage Distribution Line

Allowable number of span and optimum transformer capacity

Allowable voltage drop		20 V				10 V			
Average span length		40 m		50 m		40 m		50 m	
Conductor size / Allowable max. load density (A/pole)		35 mm^2	70 mm^2	35 mm^2	70 mm^2	35 mm^2	70 mm^2	35 mm^2	70 mm^2
1A	No. of span	43	60	38	53	30	42	27	37
	Tr. (KVA)	(25-100)	(25-100)	(25-50)	(25-100)	(16-50)	(25-100)	(16-50)	(16-50)
2A	No. of span	30	42	27	37	21	29	19	26
	Tr. (KVA)	(50-100)	(50-160)	(25-100)	(50-100)	(25-100)	(25-100)	(16-50)	(25-100)
5A	No. of span	19	26	16	23	13	18	11	16
	Tr. (KVA)	(50-160)	(100-200)	(50-160)	(50-160)	(50-100)	(50-160)	(25-100)	(50-160)
10A	No. of span	13	18	11	16	9	13	8	11
	Tr. (KVA)	(100-200)	(100-315)	(50-160)	(100-250)	(50-160)	(100-200)	(50-160)	(50-160)
15A	No. of span	10	15	9	13	7	10	6	9
	Tr. (KVA)	(100-200)	(100-315)	(100-200)	(100-315)	(50-160)	(100-200)	(50-160)	(100-200)
20A	No. of span	9	13	8	11	6	9	5	8
	Tr. (KVA)	(100-250)	(160-400)	(100-250)	(100-315)	(100-160)	(100-250)	(50-160)	(100-250)
30A	No. of span	7	10	6	9	5	7	4	6
	Tr. (KVA)	(100-315)	(160-400)	(100-250)	(160-400)	(100-200)	(100-315)	(100-160)	(100-250)
40A	No. of span	6	9	5	8	4	6	3	5
	Tr. (KVA)	(160-315)	(160-500)	(100-315)	(160-500)	(100-250)	(160-315)	(100-160)	(100-315)
50A	No. of span	5	8	5	7	3			
	Tr. (KVA)	(160-400)	(200-600)	(160-400)	(160-500)	(100-200)			



Optimum transformer capacity is figured out according to the following conditions:

(1) Availability of transformer when load density has reached max. load density is *150%.

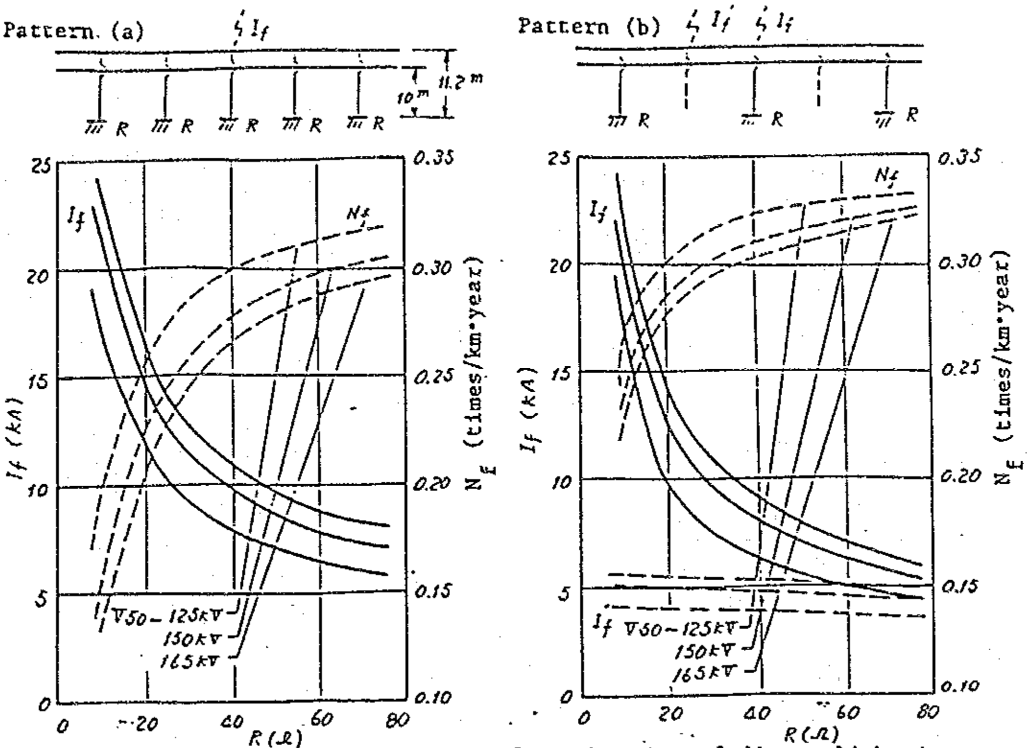
(2) Number of line direction varies from one (1) to three (3).

(3) Transformer is picked up among the PLN's standards as below.

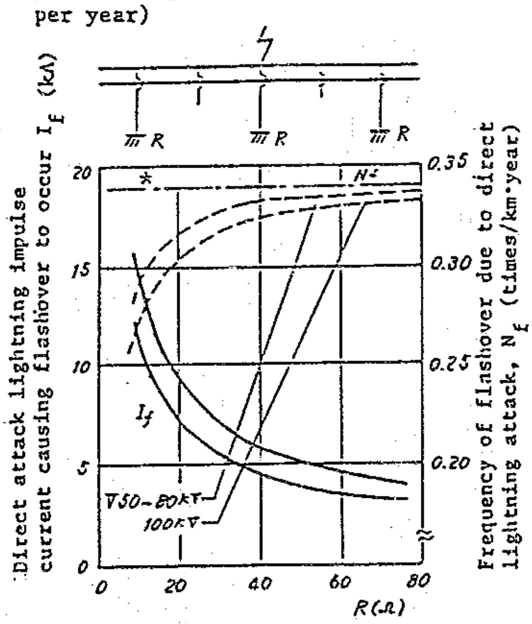
* PLN standard

KVA	KVA	KVA
5	25*	200*
6.3	31.5	250*
8	40	315*
10	50*	400*
12.5	63	500*
16*	80	630*
20	100*	800*
	125	1,000*
	160	1,250*
		1,600 dst.

* 150% or thereabout overload of distribution transformer at the max. load in actual line is generally assumed not to give much effect on the life of transformer.

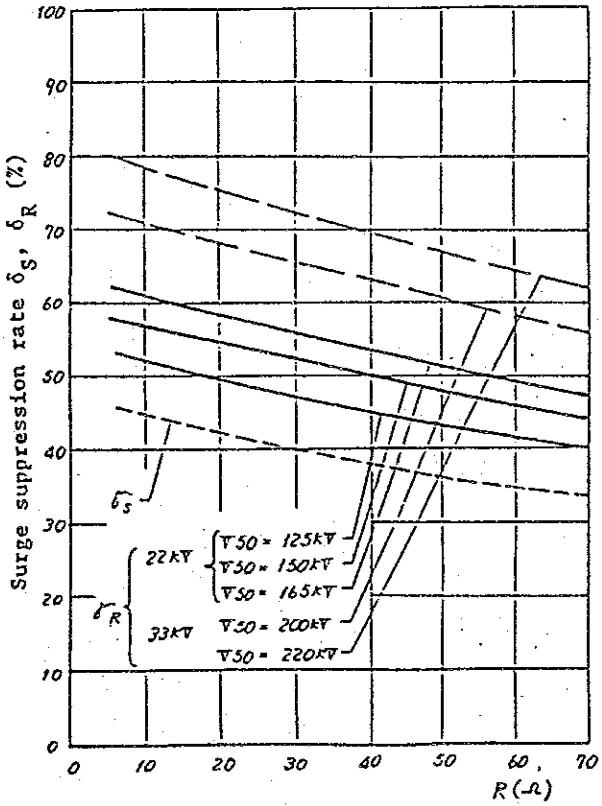


Reverse flashover current and frequency of at the time of direct lightning attack to overhead grounding wire for 22 kV distribution line (horizontally arranged on pole) (Height of line from ground level: 10 m; No. of thunderstorm days: 30 days per year)



Current and frequency of flashover causing flashover to occur due to direct lightning attack to overhead grounding wire pole for 6.6 kV distribution line (Height of line from ground level: 10 m; No. of yearly thunderstorm days: 30 days)

*: Without lightning-proof equipment



Suppression rate of inductive lightning surge in overhead grounding wire pole for 22 – 33 kV distribution line (horizontally arranged on pole)

Fig. 7.4-2 Effect of Overhead Grounding Wire

Table 7.4-2 Effect of Overhead Grounding Wire

Ratio of the frequency of flashover when there is no lightning-proof equipment to that when such equipment is provided for 22 - 33 kV distribution lines (Ratio in case there is no lightning-proof equipment: 1.0)

Lightningproof equipment \ Grounding resistance / Line insulation		To direct lightning attack 10 Ω		To inductive lightning 10 Ω	
		#20A	#30A	#20A	#30A
No lightning-proof equipment		1.00 (0.11 times/ km.year)	1.00 (0.11 times/ km.year)	1.00 (0.12 times/ km.year)	1.00 (0.06 times/ km.year)
Overhead grounding wire	Grounding interval: 50 m	0.41	0.26	0.40*	0.23*
Lightning arrester	Installation interval: 150 m	= 1.0	= 11.0	= 0	= 0
	Installation interval: 200 m	= 1.0	= 1.0	= 0	= 0
	Installation interval: 300 m	= 1.0	= 1.0	= 0	= 0
Combined use of overhead grounding wire and lightning arrester	Interval of grounding wire: 50 m Installation interval of lightning arrester: 200 m (Common grounding)	0.30	0.19	= 0	= 0
	Interval of grounding wire: 50 m Installation interval of lightning arrester: 200 m (Common grounding)	0.35	0.23	= 0	= 0
	Interval of grounding wire: 100 m Installation interval of lightning arrester: 200 m (Common grounding)	0.65	0.55	= 0	= 0

Notes: 1. Due to the effect of suppressing occurrence of corona streamer at the time of lightning attack in adjacent area in case overhead grounding wire is provided, the values in the above table is deemed to become roughly half the values in this table.

2. "= 0" indicates that the ratio is very small, and "= 1.0" indicates that it is almost impossible to prevent flashover.

3. The values in parenthesis in the column "No lightning-proof equipment" indicate the frequence of flashover in case the number of thunderstorm days when one distribution line is subjected to lightning attack in a frequent lightning occurrence area is ten days for reference.

SECTION 8

LOAD DISPATCHING SYSTEM

SECTION 8 LOAD DISPATCHING SYSTEM

8.1 Necesity of Modernizing Load Dispatching System

Subsequent to commissioning of Maninjau Hydro-Power Plant in West Sumatra in 1983 as a turning point, the power sources and system in Central Sumatra have been expanded successively, and along with development of large scale power sources including thermal and hydro-power plants, a trunk power transmission system with a total length of about 600 km extending to Dumai in Riau Province is expected to be operated by 1995.

At present, collection of information and load dispatching services are carried out through telephone communication at the existing 150 kV Pauh Limo Substation in West Sumatra. Incorrespondence with formation of a power system across the Province of West Sumatra and Riau Province, it will be a vital point to establish a load dispatching system with updated functions, to manage a total power system in a high effectiveness and reliability.

8.2 Basic Form of Load Dispatching System

In response to expansion of the power system, PLN has systematically been promoting modernization of its load dispatching system. In view of the compatibility, the load dispatching system in Central Sumatra should basically be in compliance being promoted by PLN.

On Java Island, integrated operation of load dispatching system is carried out by introducing computer system on an organization of Java Control Center (JCC) and four Areal Control Center (ACC) (one of the ACCs is scheduled for completion in 1987). JCC undertake the operation of power sources and main power systems as well as overall management of the ACCs, while the ACCs undertake the operation and control of the power systems in the corresponding areas.

Furthermore, on Java Island, construction of distribution control center (DCC) for control and management of distribution lines has been promoted.

Meanwhile, the power system on Sumatra Island is largely divided into the northern, central and southern parts, and has been expanded successively centering in Palembang, Padang and Medan, respectively. In Medan, a modernized load dispatching office has already been constructed and put into service, and construction of a load dispatching office of the same scale is also promoting in Palembang.

In the distant future, the entire power system will be interconnected through extra-high voltage systems, and, for integrated operation and management of power sources and trunk power system, a high ranking load dispatching office will become necessary on Sumatra Island as in the case of Java Island. Around that time, the load dispatching offices in the above-mentioned three districts will undertake control and management of the respective power system.

8.3 Location of Load Dispatching Office

For selecting location of load dispatching office, the following two points will be comparatively studied.

1) To ensure a convenient communication of load dispatching instruction, information and control of power system.

2) To ensure smooth communication with a high ranking management office, since a load dispatching office is essentially an organization directly executing the power

company policy.

As far as the requirement in 1) is concerned, the site is desired to be located geographically at the center of power system, which means the load dispatching office is situated in the center of communication system and this has been widely applied, by selecting the site in a large scale out-station. Along with recent development of communication system and improvement of reliability, however, it has become not necessarily essential to install load dispatching office at the geographical center of power system. Rather, an emphasis has come to be placed on the latter requirement in 2). Therefore, it is more reasonable and effective to locate the load dispatching office at the location of management center.

Considering that Padang will be a center of social and economic activities in Central Sumatra, and that Wilayah III, which is undertaking overall management of power system in this area, is located here, the load dispatching office should preferably be located in Padang.

8.4 Functions of Load Dispatching Center

The load dispatching center is required to perform an operation and management integratedly from the power sources to transmission and distribution lines.

Therefore, the load dispatching in Central Sumatra should have functions sufficient to fulfill load dispatching services which are borne by ACC and DCC, together with a part of JCC, in Java Island.

Judging from the above, the following functions should be provided.

8.4.1 Demand Forecast

Demand forecast constitutes the most fundamental requirement in load dispatching operation. Namely, it is essential to perform demand forecast in terms of yearly, seasonal, monthly, weekly, daily and hourly demand based upon the past records and other miscellaneous information and fulfill load dispatching services in accurate and quick response to any demand fluctuation factor.

8.4.2 Economically-Optimum Operation

An economically-optimum power plant operation plan must be worked out based upon demand forecast taking into account service level and stable system operation. For this purpose, the load dispatching facilities should respond accurately and quickly to fluctuation of demand, system troubles and other factors.

8.4.3 Frequency Control

To keep frequency within an allowable fluctuation level against change of power demond, adequate frequency control ability shall be provided to some designated power plants.

8.4.4 Voltage Regulation

By properly operating phase modifiers, transformer tap and reactive power of generator units, the system voltage should be regulated within an allowable fluctuation level at all times.

8.4.5 Supervision of Power System

To set accurate situation of power system, which is changing from time to time, the system conditions should be displayed automatically on a system diagram board (SDB) at all times, and further detailed information be displayed on a cathode ray tube (CRT) display unit as required.

8.4.6 Control

The major equipment in out-stations as well as the distribution lines in specially designated areas should be remote-controlled from the load dispatching center.

8.4.7 Collection and Filing of Data

Various data pertaining to operation of power system and out-stations should automatically be recorded, edited and filed in an appropriate format.

8.4.8 Technical Calculation

A function sufficient for technical calculation required for operation and management of power system should be provided.

8.5 Load Dispatching Equipment

The equipment and devices required to fulfill the above functions are as presented below.

8.5.1 Load Dispatching Center

(1) Central processing unit (CPU) and peripheral equipment

The CPU system should perfectly be duplicated to maintain the reliability at a high level.

(2) Interface of communication circuits

The communication circuits should be of a duplicated configuration.

(3) System diagram board (SDB)

The system diagram board should be so designed as to demonstrate normal functions even at the time of trouble in CPU circuit.

(4) CRT display unit for supervision

The conditions in power system should be displayed promptly and easily on the CRT display unit for operators, when required.

(5) Control desk

The control desk should be equipped with functions required for telephone, CPU operation, etc.

(6) Recording equipment

Printer, hard copy and other recording equipment necessary for filing and recording should be provided.

(7) Programmer console

The equipment capable of modifying simple software should be provided.

(8) Uninterrupting power source

Uninterruptly power source with high reliability should be installed to adequately maintain the functions of the load dispatching center.

(9) Load Dispatching Center Building

(a) A load dispatching center building should be built to accommodate various equipment and office rooms.

1st floor : Mainly accommodating power source and ventilation equipment

2nd floor : Operation control room, CPU room and office rooms

(b) Since load dispatching operation is carried out continuously on a twenty-four hour basis, the residence for operation and maintenance staff and as well as other facilities for improving their working and living environment will be required.

(10) Others

The equipment should be arranged by taking into account the following requirements in particular:

(a) Lighting, monitoring distance, angle of sight, etc. should be so provided as to permit easy monitoring and supervision by operators.

(b) Easy maintenance and extension of equipment should be ensured.

8.5.2 Power Plant and Substation

(1) Remote terminal unit (RTU)

For sending and receiving of various data and information to and from the load dispatching center, RTU with built-in microprocessor should be installed in each out-station.

The RTU is required to be sufficiently compatible for extension of system and equipment in the future.

(2) Remote control device

The devices required for remote control from load dispatching center, such as automatic synchronising facilities and remote-direct changeover switches, should be provided.

(3) Frequency controller

In the case of power plants designated for frequency regulation, the devices sufficient for frequency control should be equipped.