Chapter 7 Optimal Power Development Plan -Long Term Development Plan-

The optimal power development plan can be defined as a kind of the least cost development plan which contributes to continuous national development by providing stable power at affordable prices, taking environmental preservation and effective use of primary energy sources into account.

In the past, the PLN regarded the least cost development plan as the basis for investment decisions when they would invest in new equipment. In the future, however, the power supply system will be changed as the liberalization of the power market moves forward. Still, the fundamental policy of minimizing the necessary investment into the power market will not be changed. Thus, the least cost development plan described in this chapter will be appreciable as the optimal power development plan even in the liberalized energy market.

The role of the government is to study the ideal state of the electricity market and present this to the private sectors to encourage the grater investment to the power sector. The present of the optimal power development plan to the public should serve as a guide when private sectors decide to invest in the power market.

1st Step: Screening Curve Analysis

The screening curve analysis estimates approximately the optimal component ratio of power sources by using the levelized annual costs and the load duration curve. In order to understand the concept of the optimal component ratio and the results of the simulation analysis, it is greatly useful to analyze the screening curve before using the WASP-IV.

2nd Step: Preparing the Optimal Power Development Plan Simulated by WASP-IV

The least cost development plan is simulated using WASP-IV. The least cost plan is prepared as a base case and sensitive analysis is made from the viewpoints of the lead-time for construction, fuel supply constraints and environmental constraints. The issues to be solved for the stable power supply are studied and suggestions for realizing the power development plan are made.

3rd Step: Review of Optimal Power Mixture

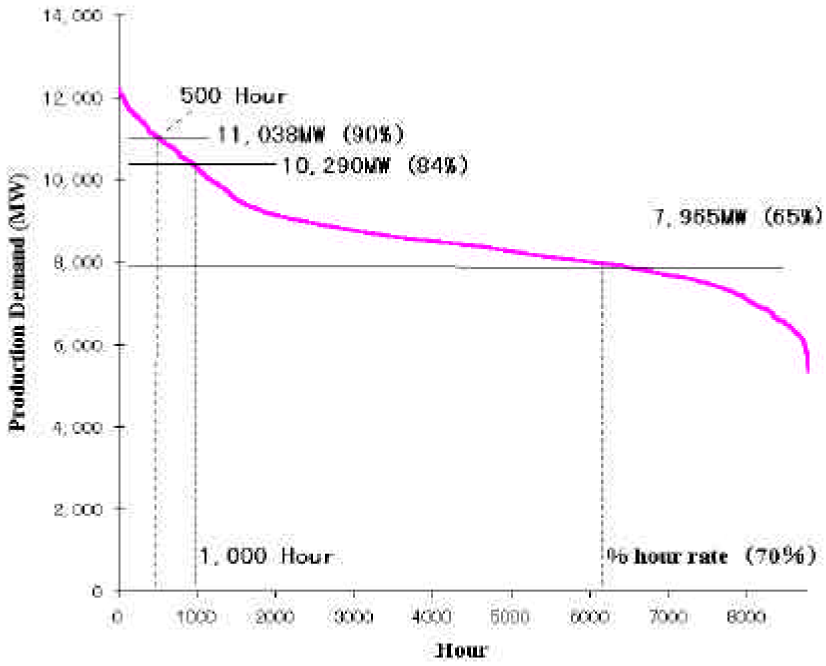
In order to establish an index for the long-term power development plan, the component ratio of power sources to realize the least expensive development is examined, assuming that limitations are relieved. Moreover, the trial calculation is done on the component ratio of power sources taking the environmental issues and effective energy use into account.

7.1 Screening Curve Analysis

7.1.1 Load Duration Curve

Figure 7.1.1 shows the duration curve for the year 2000. The maximum peak load was 12,231 MW, and the load factor was 69.9% in 2000.

Figure 7.1.1 Load Duration Curve in 2000



Source: P3B

(1) Peak load analysis

As is shown in Table 7.1.1, and the demand at 500th hour is 11,038MW (90.2% of maximum peak load demand), the demand at 1,000 hour is 10,290MW (84.1%).

Table 7.1.1 shows the result of classification of peak demand during 1,000 hours into the quota of the year, the time of days and the day of weeks.

Although peak load demands occurs in the every quota, the ratio of third and fourth quotas is rather big. It is considered that the load does not depend on the constant temperature of the tropical zone, but the high growth of power in a year. On the other hand, it can be easily known that the peak load demands emerge only in a time band between 18:00-21:00, demand of Saturdays is rather high as well. The DSM menu should be studied taking this data into account.

Table 7.1.1 Classification of Peak Demand

Periods of a year		Time of a day		Day of a week	
Quarter	Hour	Time	Hour	Day of week	Hour
1st Q	155	17:00	0	Sun.	47
2nd Q	244	18:00	154	Mon.	137
3rd Q	316	19:00	333	Tue.	181
4th Q	285	20:00	313	Wed.	181
		21:00	200	Thurs.	171
		22:00	0	Fri.	149
				Sat.	134
Total	1,000	Total	1,000	Total	1,000

Source: P3B / PLN

(2) Base load demand analysis

Generally speaking, the capacity factor of base load power source should be around 70%. Calculating the demand at 70% of 8,760 hours, the demand is 7,965MW, which is about 65% of maximum peak load. Also the load factor is about 70% as mentioned in the next section.

Incorporating this into the concept for the best mix of power sources in Indonesia, the proportion of base load power sources, such as hydro, geothermal and coal power in installed capacity should be rather high.

7.1.2 Load Factor

Table 7.1.2 shows the load factors in the South-East Asian countries. The load factors of tropical countries are generally high, likewise, in the Java-Bali area the demand is around 70%. However, the load factor in Thailand is greater than that in Indonesia.

Table 7.1.2 Load Factors in the South - East Asian Countries (Unit: %)

Country \ year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Indonesia (Java-Bali)	62.1	67.5	65.1	72.8	74.9	68.0	66.8	68.6	70.1	68.9	67.6
Thailand	68.8	70.4	71.7	73.6	74.4	74.5	75.1	73.1	71.3	71.9	74.4
Philippine	70.3	71.2	71.2	56.6	65.0	72.6	71.3	70.3	69.6	70.8	68.6

Source: Overseas Electric Power Industry Statistics/ Japan Electric Power Information Center, Inc.
PLN STATISTICS

Figure 7.1.2 shows the daily load curve of the last 10 years in Thailand. The peak demand occurred in the evening 10 years ago. In contrast, the current peak load occurs in the daytime. The load curve in Indonesia is expected to change in the same manner because of increasing power demand in the industrial sector.

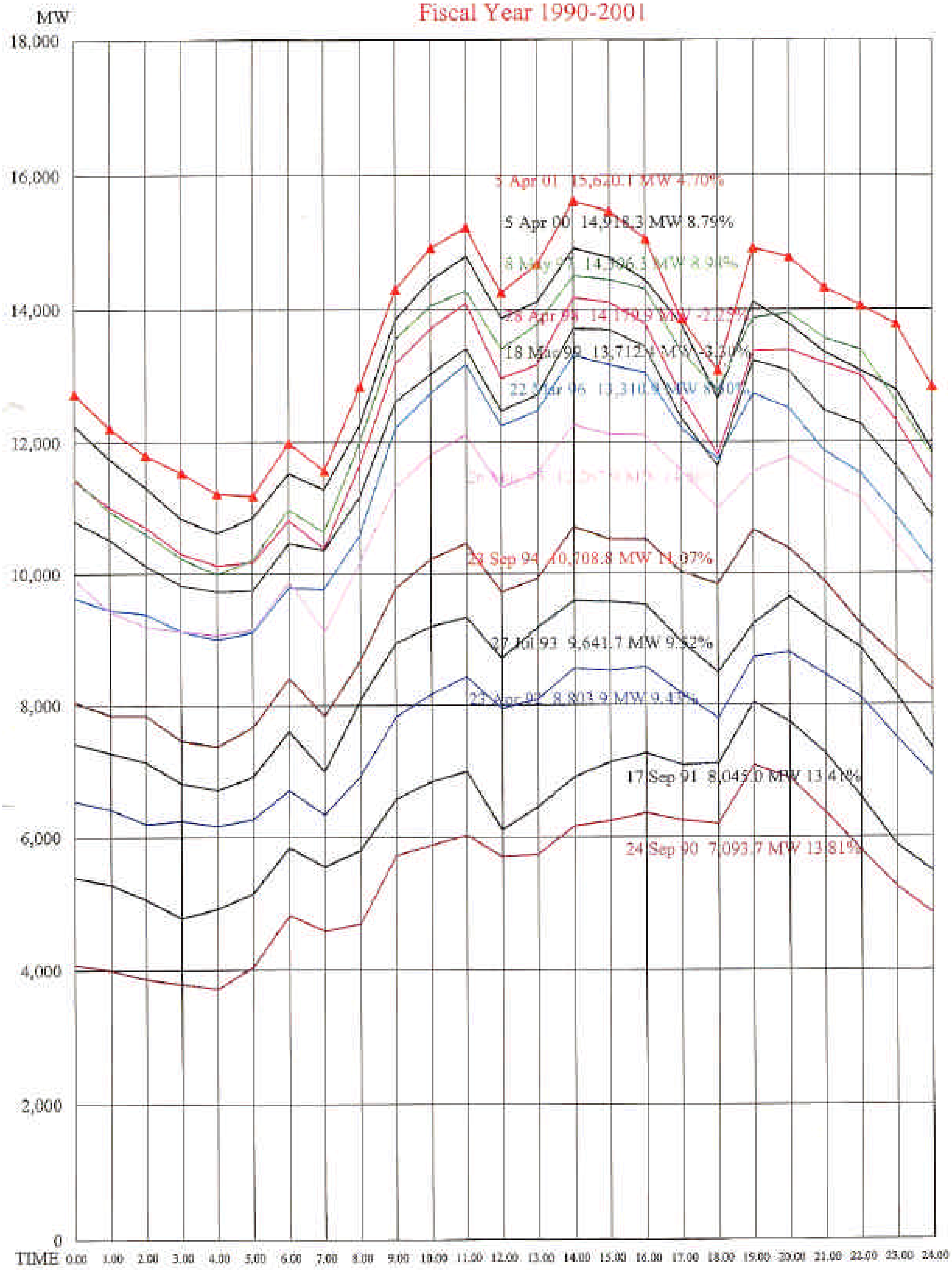
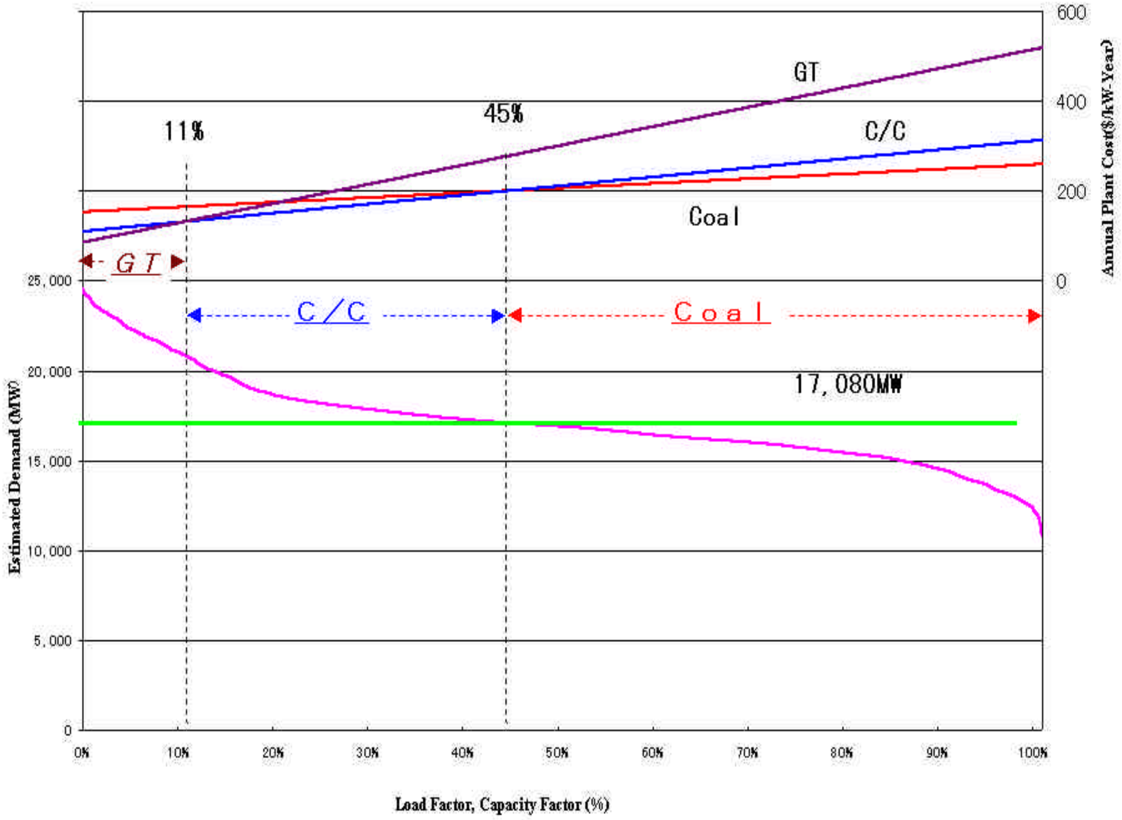


Figure 7.1.2 Load Shapes in Thailand

7.1.3 Screening Curve Analysis

Before simulation using WASP-IV, the screening curve analysis should be performed. Figure 7.1.3 shows the screening curve of the power sources and the estimated duration curve in 2010.

Figure 7.1.3 Screening Curve Analysis



Source: PLN, P3B

Based on the result of screening curve analysis, the criteria between coal fired steam power plant and combined cycle power plant is around 45%, it would be 17,080MW of load demand in 2010.

In the meantime, the present base load capacity is 9,950MW (Hydro: 2,536MW, Geothermal: 765MW, Coal: 6,650MW). The additional capacity of coal power units would be about 7,000 MW (= 17,080MW - 9,950MW), assuming the necessary base load is developed only by coal.

Reference 1

The base conditions, such as the construction cost of the power sources, are determined to be the same conditions used in PLN (referred in 7.3.3). The formula to calculate the annual production cost is shown below:

<u>Annual Production Cost = APC ($/kW-year)</u>

$$(APC)_f = [r]_i^T \text{ x } I + \frac{i \text{ x } (FIC)}{100} + 12 \text{ x } (O\&M_{fixed}) +$$

$$8.76 \text{ x } [(FC)_f + (O\&M_{variable})_f] \text{ x } \frac{f}{100}$$

$$[r]_i^T = \frac{i \text{ x } (1+i)^T}{(1+i)^T - 1}$$

where:

APC	=	Annual Plant Cost
I	=	Investment Cost
FIC	=	Fuel Inventory Cost
FC	=	Fuel Cost
O&M	=	Operation & Maintenance
T	=	Life Time
i	=	annual interest rate
f	=	average annual capacity factor of the plant (in %)
$[r]^T_i$	=	annual capital recovery factor: (Levelized annual fixed charge rate)

Source: The manual of WASP-IV

The economical criteria of power sources are shown below:

Capacity Factor	Economical Order
11% >	Gas Turbine (Oil) is the most economical power source.
>45%, >11%	Combined Cycle System (Gas) is the most economical power source.
>45%	Steam Turbine System (Coal) is the most economical power source.

7.2 Optimal Power Development Plan

By using Wasp-IV, the optimal power development plan is examined. The study procedure is shown below:

Step	Description
a. Preparing the least Cost Power Development Plan (Base Case)	The least-cost power development plan is simulated by WASP-IV as the base case.
⇩	
b. Sensitive Study	Effects of limitations such as fuel price, environment issues etc. are examined from the viewpoint of effective use of primary energy.
⇩	
c. Examining problems to be solved for stable power supply	The results of sensitive study are used to clarify problems that need to be solved for ensuring a stable power supply. The methods for realizing the power development plan are then examined.

7.2.1 Base Case Study

(1) Conditions

The Base Case is defined as the least-cost power development plan with no limitations both in and after 2006.

<u>a. Power projects to be considered as the fixed project</u>

Projects are determined based on the "Base Case" mentioned in Chapter 5. Model power sources are added to this scenario.

[Base Case]

- Pemaron: Operations will start in 2003 (100MW) / GT only
  in 2004 (150MW) / complete
- Tanjung-Jati B: Operations will start in 2005 (1,320MW = 660MW x 2)
- Muara-Karang re-powering: Operations will start in 2006 (500MW) / GT only
  in 2007 (720MW) / complete

<u>b. Electricity demand</u>

Demand "JICA/LPE_CASE1 and JICA/LPE_CASE2", mentioned in Chapter 4

c. Study period

15 years

d. System reliability

The system reliability criteria is set at 1 day / year in LOLP from 2006.

e. Discount rate

12%

f. Fuel supply limitation

* Combined Cycle (Gas): Take-or-Pay contracts are considered only for the existing units. Fuel conversion from HSD to Gas at Grati, Tamba-Lorok, Muara-Tower power stations are not considered.

g. Model power sources

Four kinds of model power sources are considered in the simulation. Table 7.2.1 shows the characteristics of each model power source.

Table 7.2.1 Characteristics of the Model Power Sources

Unit Type	Steam Turbine Unit	Combined Cycle Unit	Gas Turbine Unit	Pump-Storage Unit
Abbreviation	ST	C/C	GT	PS
Fuel	Coal	Gas	HSD	-
Capacity (MW)	600	600	120	250
Construction Cost ($ / kW)	900	650	500	600
Life Time (Years)	25	20	15	50
Construction Period (Years)	4	3	2	5
Fuel cost (US$ / Gcal)	4.2	*8.7-10.1	14.5	-
Cycle efficiency for Pump Storage unit	-	-	-	70%
Heat Rate (kcal / kWh)	2,380	2100	3,100	-

* Depending on units / power plants

** Using straight depreciation method

h. Commissioning year

*Steam Turbine P/S (Coal): from 2006, except for Tanjung-Jati B.

*Combined Cycle P/S (Gas): from 2006, except for Muara-Karang.

*Gas Turbine P/S (HSD): from 2006

(2) Power development plan

Table 7.2.2 shows WASP-IV outputs in case of JICA/LPE_CASE2 demand and JICA/LPE Case_1 demand.

Table 7.2.2 Simulation Output of WASP-IV (Base Case)

Year	Demand-JICA/LPE CASE 2					Demand-JICA/LPE CASE 1				
	Demand	ST	C/C	GT	P-S	Demand	ST	C/C	GT	P-S
	(MW)	Number of Units				(MW)	Number of Units			
2001	13,041					13,041				
2002	14,089					13,821				
2003	15,073					14,497				
2004	16,071			3) 1		15,266			3) 1	
2005	17,170	1) 2				16,185	1) 2			
2006	18,374	4	2) 2			17,220	3	2) 1		
2007	19,659		2			18,348		2		
2008	21,075		2	3		19,612	1	1		
2009	22,621	3		1		21,000	1	1	3	
2010	24,297	3		2		22,539	2	1		
2011	26,099	3		2	1	24,225	4			
2012	28,040	3	1			26,058	3			1
2013	30,131	3			2	28,048	2	1	2	1
2014	32,380	3			3	30,208	2		1	4
2015	34,800	5				32,549	5			
Total Number		29	7	9	6	-	25	7	7	6
Total Capacity (MW)		17,520	4,320	1,110	1,500		15,120	4,320	870	1,500

1) The figure shows Tanjung-Jati B, 2) The figure includes the Muara-Karang Repowering

3) The figure shows the Pemaron C/C

a. Steam Turbine Power Unit (Coal-fired)

The power development would rely on many coal-fired steam turbine units. This is coincident with the result of the screening curve analysis in section 7.1.3. The necessary capacity in 2015 is nearly 17,520MW in JICA/LPE_CASE2 and 15,120MW in JICA/LPE_CASE1. Coal-fired power plants are influenced by demand more than other power sources.

The simulation result says that three steam turbines are necessary in 2006. However, construction of coal-fired power station requires at least 6 years. Since specific projects are not identified at present, it is very difficult to develop them.

b. Combined Cycle Power Unit (Gas-fired)

The necessary capacity of combined cycle power units is not as easily affected as coal-fired units which are used as base load units, because it is believed that a certain capacity to meet middle / peak demand is necessary to operate the power system in a stable manner.

c. Gas Turbine Power Unit (HSD-fired)

The necessary capacity of about 870MW - 1,110MW is not so large in both the JICA/LPE_CASE1 and JICA/LPE_CASE2. To meet peak load demand, the number of gas turbine units is greatly affected by the number of pumped storage power units.

d. Pumped Storage Power Unit

The number of required pumped storage power units depends on the component ratio of coal fired units that provide the surplus power to be pumped up and also on the gas turbines available to meet peak load demand. The 1,500MW of development should be introduced by 2015 for both JICA/LPE CASE 1 and CASE2. This result implies the necessity of pump storage unit in the optimal power development plan.

(3) Installed capacity

Table 7.2.3 shows the installed capacity and its component ratio. The component ratio of coal-fired power units is increased to about 55% in 2015. The total base load capacity including hydro and geothermal power units roughly exceeds 60%. Figure 7.2.1 shows the installed capacity from 2001 to 2015 in JICA/LPE_CASE2.

Table 7.2.3 Installed Capacity (Base Case)

Demand:JICA/LPE CASE 2 (UNIT:MW,%)

	2001		2005		2010		2015	
Hydro	2,536	13.6%	2,536	12.7%	2,536	8.4%	2,536	6.0%
P.S.	0	0.0%	0	0.0%	0	0.0%	1,500	3.5%
Coal	6,650	35.7%	7,970	39.9%	13,970	46.4%	24,170	57.1%
Gas	4,749	25.5%	4,649	23.3%	8,369	27.8%	8,969	21.2%
HSD	3,108	16.7%	3,258	16.3%	3,978	13.2%	4,218	10.0%
MFO	800	4.3%	800	4.0%	500	1.7%	200	0.5%
GEO	765	4.1%	765	3.8%	765	2.5%	765	1.8%
Total	18,608	100.0%	19,978	100.0%	30,118	100.0%	42,358	100.0%

Demand:JICA/LPE CASE 1 (UNIT:MW,%)

	2001		2005		2010		2015	
Hydro	2,536	13.6%	2,536	12.7%	2,536	8.4%	2,536	6.4%
P.S.	0	0.0%	0	0.0%	0	0.0%	1,500	3.8%
Coal	6,650	35.7%	7,970	39.9%	12,170	40.4%	21,770	54.8%
Gas	4,749	25.5%	4,649	23.3%	8,369	27.8%	8,969	22.6%
HSD	3,108	16.7%	3,258	16.3%	3,618	12.0%	3,978	10.0%
MFO	800	4.3%	800	4.0%	500	1.7%	200	0.5%
GEO	765	4.1%	765	3.8%	765	2.5%	765	1.9%
Total	18,608	100.0%	19,978	100.0%	27,958	92.8%	39,718	100.0%

Abbreviation:

Hydro: Hydro power plant, P.S.: Pumped Storage Power Plant,

Coal: Coal Fired Power Plant, Gas: Gas fired Power Plant,

HSD: HSD oil fired Power Plant, MFO: MFO fired power plant,

GEO: Geothermal Power Plant

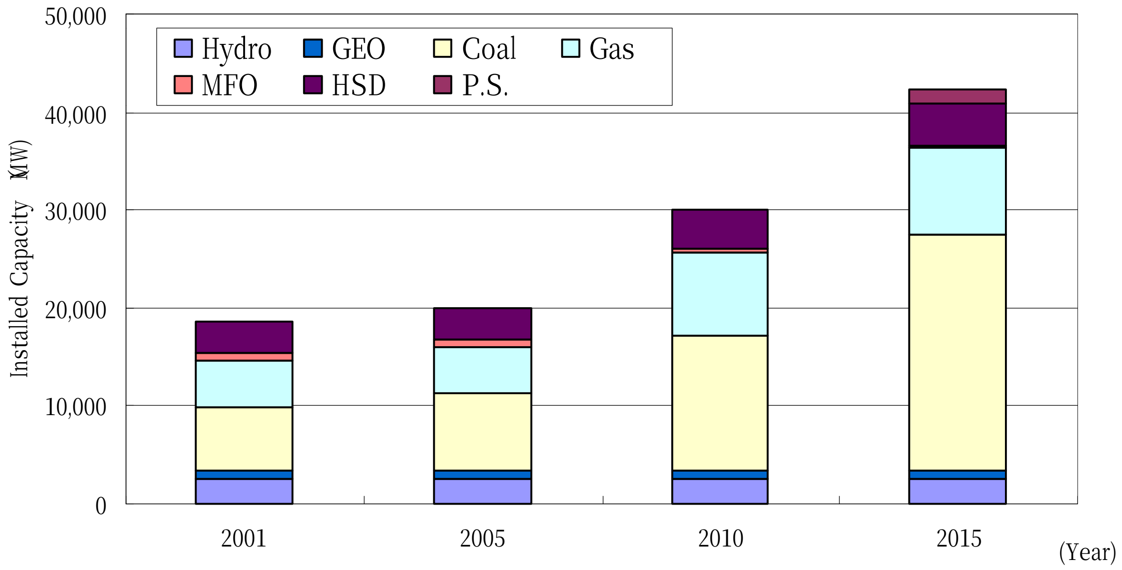


Figure 7.2.1 Trend of Installed Capacity (Demand:JICA_CASE2)

(4) Power production

Table 7.2.4 shows the generation and its component ratio. Coal-fired power units generate over 70% of the electricity in both cases in 2015. The ratio of base load power sources including hydro and geothermal power exceeds about 80%.

Table 7.2.4 Power Generation (Base Case)

Demand:JICA/LPE CASE 2 (UNIT:GWh,%)

	2001		2005		2010		2015	
Hydro	7,719	9.5%	7,719	7.2%	7,719	5.1%	7,719	3.5%
P.S.	0	0.0%	0	0.0%	0	0.0%	1,500	0.7%
Coal	37,577	46.2%	53,776	50.5%	92,893	61.6%	159,187	72.9%
Gas	21,965	27.0%	24,805	23.3%	38,332	25.4%	39,694	18.2%
HSD	6,880	8.5%	11881	11.2%	5,230	3.5%	4,054	1.9%
MFO	1,717	2.1%	2510	2.4%	833	0.6%	377	0.2%
GEO	5,402	6.6%	5,864	5.5%	5,864	3.9%	5,864	2.7%
Total	81,260	100.0%	106,555	100.0%	150,871	100.0%	218,395	100.0%

Demand:JICA/LPE CASE 1 (UNIT:GWh,%)

	2001		2005		2010		2015	
Hydro	7,719	9.5%	7,719	7.7%	7,719	5.5%	7,719	3.8%
P.S.	0	0.0%	0	0.0%	0	0.0%	1,209	0.6%
Coal	37,577	46.2%	52,169	51.8%	81,560	58.3%	143,922	70.5%
Gas	21,965	27.0%	23,141	23.0%	38,488	27.5%	40,294	19.8%
HSD	6,880	8.5%	9,629	9.6%	5,504	3.9%	4,608	2.3%
MFO	1,717	2.1%	2,243	2.2%	879	0.6%	385	0.2%
GEO	5,402	6.6%	5,864	5.8%	5,864	4.2%	5,864	2.9%
Total	81,260	100.0%	100,765	100.0%	140,014	100.0%	204,001	100.0%

Figure 7.2.2 shows the power production trend and Figure 7.2.3 shows the duration of power generation in 2015.

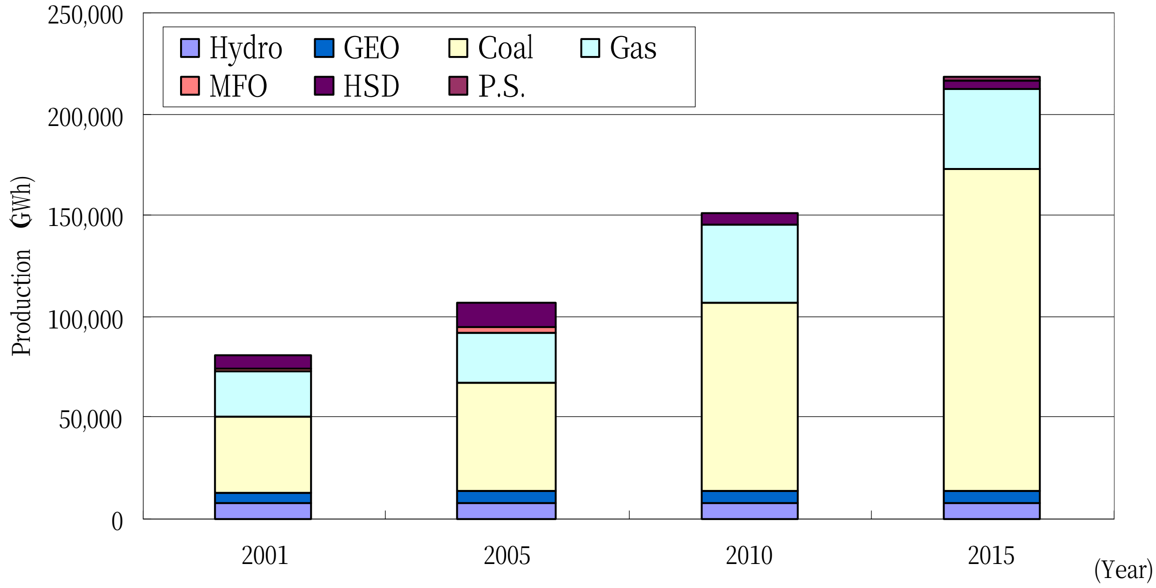


Figure 7.2.2 Trend of Power Production (Demand:JICA/LPE_CASE2)

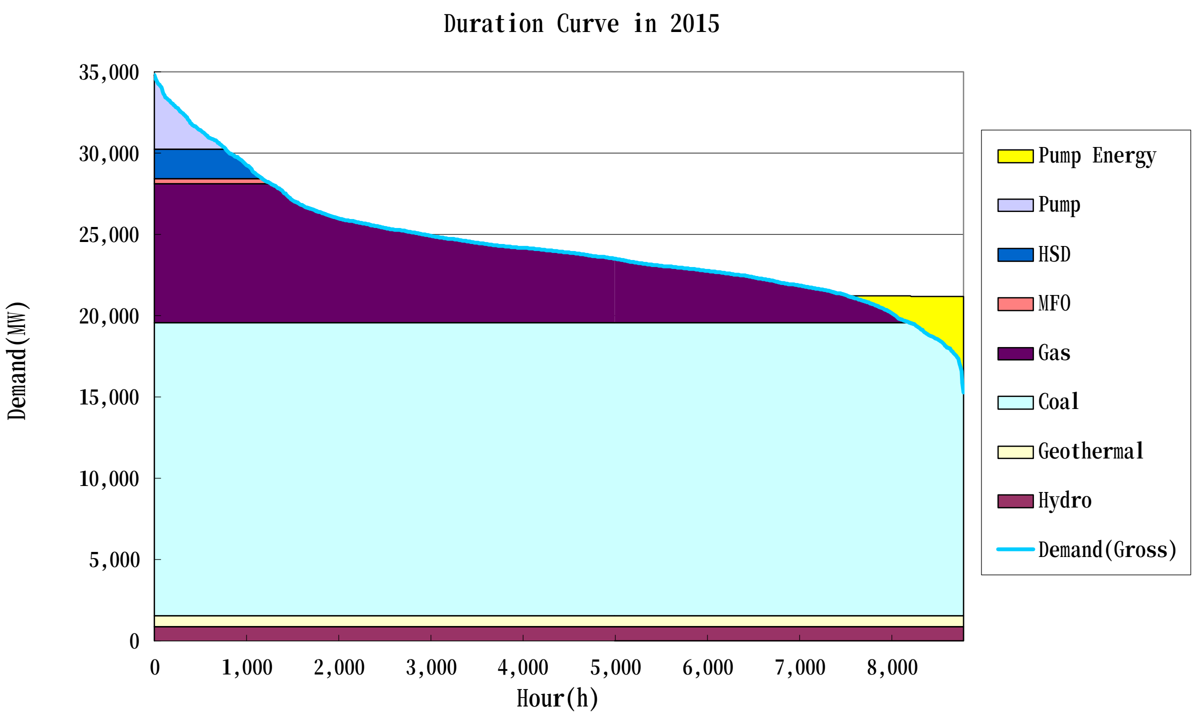


Figure 7.2.3 Duration of Power Generation (in 2015)

(5) Capacity factor

Table 7.2.5 shows the capacity factor. Capacity factors are increased to over 75% for coal fired units, 50% for gas fired, 20% for MFO fired, and 10% for HSD fired in 2015. This is almost coincident with the result of screening curve analysis.

Table 7.2.5 Capacity Factor (Base Case)

Demand:JICA-CASE2 (UNIT:%)

	2001	2005	2010	2015
Hydro	35%	35%	35%	35%
P.S.	-	-	-	11%
Coal	65%	77%	76%	75%
Gas	53%	61%	52%	51%
HSD	25%	42%	15%	11%
MFO	25%	36%	19%	22%
GEO	81%	88%	88%	88%
Total	50%	61%	57%	59%

Demand:JICA-CASE1 (UNIT:%)

	2001	2005	2010	2015
Hydro	35%	35%	35%	35%
P.S.	-	-	-	9%
Coal	65%	75%	77%	75%
Gas	53%	57%	52%	51%
HSD	25%	34%	17%	13%
MFO	25%	32%	20%	22%
GEO	81%	88%	88%	88%
Total	50%	58%	57%	59%

(6) Fuel consumption

Table 7.2.6 shows the fuel consumption. As power generation increases, coal consumption increases until 2015 and reaches about 72,000kT in JICA/LPE_CASE2. It is nearly four times as much as the current consumption level. Gas consumption increases to about 340 BSCF in both cases, and it is nearly two times as much as the current consumption level.

Table 7.2.6 Fuel Consumption (Base Case)

Demand:JICA-CASE2 (UNIT:KT,BSCF,kl)

	2001	2005	2010	2015
Coal	17,016	24,352	42,065	72,085
Gas	192	216	327	337
HSD	1,682	3,013	1,316	1,035
MFO	478	699	233	100

Demand:JICA-CASE1 (UNIT:KT,BSCF,kl)

	2001	2005	2010	2015
Coal	17,016	23,624	36,933	65,172
Gas	192	202	328	343
HSD	1,682	2,412	1,374	1,160
MFO	478	625	246	102

(7) Environmental impact

Table 7.2.7 shows the CO_2 emission in base case. As fuel consumption increases, CO_2 emission increases to 180 million ton (JICA/LPE-Case2), and to 170 million ton (JICA/LPE-Case1. CO_2 emission factor increases from 0.66kg-CO_2/kWh to 0.82kg-CO_2/kWh in JICA/LPE-Case2.

In Japan, CO_2 emission factor is about 0.403 kg-CO_2/kWh (in 2000). The reasons why CO_2 emission factor in Indonesia is higher than the one in Japan are as follows:

a. There is no nuclear power station in Indonesia.

b. The efficiency of thermal power plant is lower than that in Japan.

Table 7.2.7 CO_2 Emission (Base Case)

Demand:JICA-CASE2 (UNIT:kT)

	2001	2005	2010	2015
Coal	36,925	52,843	91,280	156,423
Gas	11,271	12,725	19,232	19,828
HSD	4,113	7,369	3,218	2,532
MFO	1,432	2,091	698	298
Total	53,742	75,028	114,428	179,082
GWh	81,260	106,555	150,871	218,395
kg-CO2/kWl	0.661	0.704	0.758	0.820

Demand:JICA-CASE1 (UNIT:KT)

	2001	2005	2010	2015
Coal	36,925	51,263	80,144	141,423
Gas	11,271	11,875	19,302	20,152
HSD	4,113	5,899	3,361	2,838
MFO	1,432	1,870	736	304
Total	53,742	70,907	103,542	164,717
GWh	81,260	100,765	140,014	204,001
kg-CO2/kWl	0.661	0.704	0.740	0.807

(8) Investment

Table 7.2.8 shows the necessary investment cost. The necessary investment cost to implement the development plan until 2010 is about US$9.4 billion in JICA/LPE CASE2 and about US$7.6 billion in JICA/LPE-CASE1.

Table 7.2.8 Necessary Investment (Base Case)

Demand:JICA/LPE CASE 2 (UNIT:Million US$)

	2001-2005	2006-2010	2001-2010	2011-2015	Total
Coal	1,188	5,400	6,588	9,180	15,768
Gas C/C	0	2,355	2,355	390	2,745
HSD	98	360	458	120	578
P-S	0	0	0	900	900
Total	1,286	8,115	9,401	10,590	19,991

Demand:JICA/LPE CASE 1 (UNIT:Million US$)

	2001-2005	2006-2010	2001-2010	2011-2015	Total
Coal	1,188	3,780	4,968	8,640	13,608
Gas C/C	0	2,355	2,355	390	2,745
HSD	98	180	278	180	458
P-S	0	0	0	900	900
Total	1,286	6,315	7,601	10,110	17,711

(9) System cost

Table 7.2.9 shows the total system cost in the Base Case. These figures are the same as the objective function to be minimized in WASP-VI. The necessary system cost is about US$ 20,555million in present value for JICA/LPE_CASE2, and US$ 18,731million for JICA/LPE_CASE2. It means the additional about US$1,800 million should be required in case of high demand case.

Table 7.2.9 Necessary System Cost for Base Case (2001-2015)

(UNIT: Million US$)

	JICA/LPE CASE 2	JICA/LPE CASE 1
Construction Cost	7,716	6,536
Salvage Value	3,267	2,911
Operation Cost	15,886	15,060
E.N.S. Cost	220	46
Total (Difference)	20,555 -	18,731 △1,824
%	100.0%	91.1%

*The present price in the beginning of 2001

**Because of the specification of WASP-IV, the investment for planed projects such as Tanjung Jati B, Muara-Karang Repowering and Pemaron is NOT included in this figure.

***Please refer to the supplementary discussion 1 of Chapter 7

7.2.2 Sensitive Studies

(1) Sensitive study on fuel price - Fuel price increase scenario -

In this section, the impact of a fuel price increase on the power development plan was examined. The scenarios studied are shown in Table 7.2.10.

Table 7.2.10 Fuel Price Increase Scenario

Item \ Case	Base Case	Gas Price Increase		Coal Price Increase	
		Case1	Case2	Case1	Case2
Coal ($/ton)	20	20		25	30
Gas ($/MMBTU)	2.5	3.0	3.5	2.5	
HSD oil ($/Gcal)	14.5				

1) Power development plan

Table 7.2.11 shows the output of WASP-IV in each case. In the Gas Price Increase Case, the capacity of the combined cycle power plants to be developed will decrease in accordance with the gas price increase, while the capacity of coal power plants will increase. This trend will emerge prominently in 2008.

In the Coal Price Increase Case, the capacity of the coal power plants will decrease in accordance with the coal price increase, while the capacity of the combined cycle power plants will increase.

Table 7.2.11 Power Development Plan by WASP-IV (Fuel Price Increase Scenario)

Case		Base Case				Gas Price Increase Case 1				Gas Price Increase Case 2				Coal Price Increase Case 1				Coal Price Increase Case 2			
Gas Price		2.5$/MMBTU				3.0$/MMBTU				3.5$/MMBTU				2.5$/MMBTU							
Fuel Price		20$/ton				20$/ton								25$/ton				30$/ton			
Year	Demand	ST	C/C	GT	PS	ST	C/C	GT	PS	ST	C/C	GT	PS	ST	C/C	GT	PS	ST	C/C	GT	PS
	(MW)	Number of Units				Number of Units				Number of Units				Number of Units				Number of Units			
2001	13,041																				
2002	14,089																				
2003	15,073																				
2004	16,071			[3] 1				[3] 1				[3] 1				[3] 1				[3] 1	
2005	17,170	[1] 2				[1] 2				[1] 2				[1] 2				[1] 2			
2006	18,374	4	[2] 2			5	[2] 1			5	[2] 1			2	[2] 4			1	[2] 4	3	
2007	19,659		2			1	1	1		2		1		1	1			1	1	1	
2008	21,075		2	3			2	3		2		4		1	1	3		1	2		
2009	22,621	3		1		2	1			1	2			3		1		3			
2010	24,297	3		2		3			1	2	1		1	2	1	2		2	1	1	
2011	26,099	3		2	1	2	1	4		2	1	3		3		2	1	3		2	1
2012	28,040	3	1			4				3	1			4				4			
2013	30,131	3			2	2	1		2	2			4	3			2	2	2	3	
2014	32,380	3			3	4			1	4			1	3	1		1	2			4
2015	34,800	5				4		2	1	5				3	1	1	1	3	1	3	
Total Number		29	7	9	6	29	7	11	5	30	6	9	6	27	9	10	5	24	11	14	5
Total Capacity (MW)		17,520	4,320	1,110	1,500	17,520	4,320	1,350	1,250	18,120	3,720	1,110	1,500	16,320	5,520	1,230	1,250	15,120	6,720	1,710	1,250

1) The figure shows Tanjung-Jati B,

2) The figure includes the Muara-Karang Repowering

3) The figure shows the Pemaron C/C

2) Gas consumption

Figure 7.2.4 shows the gas consumption trends in each case. If gas prices increase, the amount of necessary gas consumption will decrease. This trend will emerge clearly in 2008. The amount in 2008 is about 330BSCF/year in the Base Case, while 290BSCF/year at a price of 3.0US$/MMBTU, and 220BSCF at 3.5US$/MMBTU. On the other hand, if coal prices increase, the amount of gas consumption will increase. The amount of gas in 2015 will reach 390BSCF/year at a price of 25US$/ton, and 450BSCF/year at 30US$/ton, while 340BSCF/year in the Base Case. Thus, the gas consumption will go above the present supply plan.

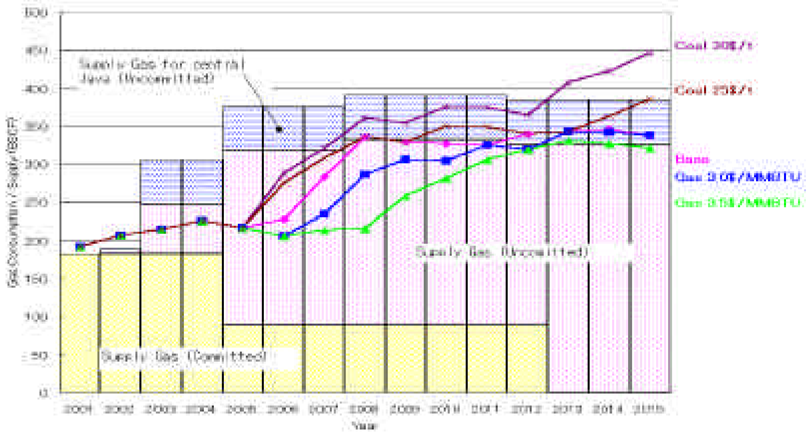


Figure 7.2.4 Trend of Gas Consumption (Fuel Price Increase Scenario)

3) Coal consumption

Figure 7.2.5 shows the coal consumption trends in each case. If a coal price increases, the amount of coal consumption will decrease. The amount in 2007 will fall down to 30,000kton/year at a price of 25US$/ton, and 28,000kton/year at 30US$/ton, while 31,000kton/year in the Base Case. On the other hand, if gas prices increase, the amount of coal consumption will increase. The amount in 2008 will reach about 34,000kton/year at a price of 3.0US$/MMBTU, and 38,000kton at 3.5US$/MMBTU, while 32,000kton/year in the Base Case.

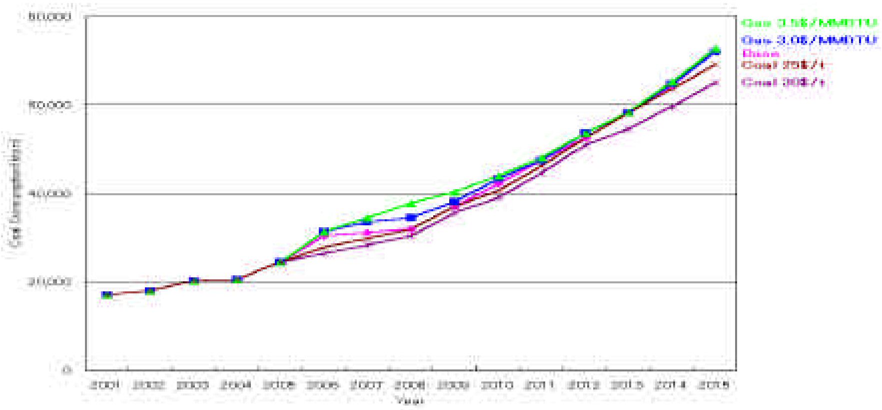


Figure 7.2.5 Trend of Coal Consumption (Fuel Price Increase Scenario)

4) System cost

Table 7.2.12 shows the total system cost of each case. The operation cost will increase in accordance with the increasing of fuel cost. The construction costs of coal price increasing case are below the cost of the Base Case. It is considered that the conversion from coal fired power plants to more cheaper gas combined cycle power plant will be made. However the system cost of the Base Case is the cheapest in all cases. The incremental system cost will reach about US$ 951million at the gas price of US$3.0/MMBTU and US$2,474 million at the coal price of US$30/ton.

Table 7.2.12 Necessary System Cost (Fuel Price Increase Scenario)

(UNIT: Million US$)

	Base Case	Gas Price 3.0$/MMBT	Gas Price 3.5$/MMBTU	Coal Price 25$/ton	Coal Price 30$/ton
Construction Cost	7,716	7,782	7,937	7,538	7,251
Salvage Value	3,267	3,234	3,291	3,158	3,023
Operation Cost	15,886	16,736	17,539	17,182	18,581
E.N.S. Cost	220	221	221	219	219
Total (Difference)	20,555 -	21,506 951	22,407 1,852	21,782 1,227	23,029 2,474
%	100.0%	104.6%	109.0%	106.0%	112.0%

*The present price in the beginning of 2001

**Because of the specification of WASP-IV, the investment for planed projects such as Tanjung Jati B, Muara-Karang Repowering and Pemaron is NOT included in this figure.

***Please refer to the supplementary discussion 1 of Chapter 7

(2) Sensitive study on power development limitation - Limited development Scenario-

In this section, the impact of the limitations on the lead-time of construction and on the capacity itself was studied. The concept of the studied case is as follows.

・No Coal Power Plant Case

Since the Base Case is the least-cost power development plan in the calculated period, the output consists mainly of coal power plants because of the low fuel price. Since the necessary investment for a coal power plant is quite expensive, investors in power captives and IPPs are likely to construct combined cycle or gas turbine power plants that are cheaper in investment and can be constructed in a shorter period, in place of coal power plant. This has been the case in other countries introducing market mechanisms. The No Coal Power Plant Case is the case in which no coal power plants will be developed until 2010 except for Tanjung-Jati B.

- Coal Power Plant Limited Case

  Taking the lead-time into account, the Coal Power Plant Limited Case is the case for which the commissioning years of the coal power plant should be from 2008. Moreover, the number of coal power plants to be developed until 2010 are limited to only two units per year.

- Combined Cycle Limited Case

  Regarding the effective use of natural gas, power plants should be developed in cooperation with the gas infrastructure. The Combined Cycle Limited Case is the case for which the number of combined cycle power plants to be developed is limited to only three until 2010, except for Muara-Karang re-powering.

- Pumped Storage Limited Case

  Currently the only candidate for a pump storage power unit is the Upper Cisokan Pumped Storage Power Plant (Total 1,000MW). Thus, the Pumped Storage Limited Case is the case for which the capacity of the pumped storage power plant is limited at 1,000MW.

In these cases, limitations would be relieved from 2011 assuming an environment supporting large investment by the private sectors is prepared. Table 7.2.13 shows the conditions of each case.

Table 7.2.13 Power Development Limited Scenario

<table>
<tr><th>Case</th><th>Base Case</th><th>No Coal Power Plant Case</th><th>Coal Power Plant Limited Case</th><th>C/C Power Plant Limited Case</th><th>P.S. Power Plant Limited Case</th></tr>
<tr><td>1) Demand</td><td colspan="5">JICA/LPE CASE 2</td></tr>
<tr><td>2) Fixed Project</td><td colspan="5">・Pemaron C/C: 2003 (100MW) - GT Commissioning
2004 (50MW) - Complete
・Tanjung-Jati B: 2005 (660MW x 2)
・Muara-Karang Repowering: 2006 (500MW) - GT Commissioning
2007 (720MW) - Complete</td></tr>
<tr><td>3) Model Power Sources
・Coal Power Plant</td><td>In and after 2006</td><td>In and after 2011</td><td>In and after 2008
2 units / year
(2008-2010)</td><td colspan="2">In and after 2006</td></tr>
<tr><td>・Combined Cycle Plant</td><td colspan="3">In and after 2006</td><td>In and after 2006 (Maximum 3 units until 2010)</td><td>In and after 2006</td></tr>
<tr><td>・Gas Turbine</td><td colspan="5">In and after 2006</td></tr>
<tr><td>・Pumped Storage Plant</td><td colspan="4">In and after 2008</td><td>In and after 2008 (Maximum 4 units)</td></tr>
<tr><td>4) LOLP</td><td colspan="5">・Not to take into account until 2005
・1day / Year in and after 2006</td></tr>
</table>

1) Power Development Plan

Table 7.2.14 shows the power development plan for the Power Development Limited Scenario. In the No Coal Power Plant Case and the Coal Power Plant Limited Case, combined cycle power plants are developed in place of coal power plants. However, since coal power development will increase after relieving the limitations, the total number of coal power plants until 2015 in the Coal Power Plant Limited Case will decrease only by 3 units as compared to the Base Case. In the No Coal Power Plant Case, the number of coal power plants will decrease by 7 units because of the limited development until 2010.

Similarly, in the Combined Cycle Power Plant Limited Case, coal power plants are developed as alternative power sources. However, more combined cycle power plants are developed after 2010, so that the total capacity to be developed until 2015 is the same as that of the Base Case.

Taking this into account, the component ratio needed to realize the least-cost power development will be at the same level, even though the development year is different.

Table 7.2.14 Power Development Plan by WASP-IV (Power Development Limited Scenario)

Case		Base Case				No Coal Power Plant Case				Coal Power Plant Limited Case				Combined Cycle Power Plant Limited Case				Pumped Storage Power Plant Limited Scenario			
Year	Demand	ST	C/C	GT	P-S	ST	C/C	GT	P-S	ST	C/C	GT	P-S	ST	C/C	GT	P-S	ST	C/C	GT	P-S
	(MW)	Number of Units				Number of Units				Number of Units				Number of Units				Number of Units			
2001	13,041																				
2002	14,089																				
2003	15,073																				
2004	16,071			[3] 1				[3] 1				[3] 1				[3] 1				[3] 1	
2005	17,170	[1] 2				[1] 2				[1] 2				[1] 2				[1] 2			
2006	18,374	4	[2] 2				[2] 5	3			[2] 5	3		4	[2] 2			4	[2] 2		
2007	19,659		2				2				2				2				2		
2008	21,075		2	3			2	4		2	1			2		4			2	3	
2009	22,621	3		1			3			2	1			3		1		3		1	
2010	24,297	3		2			3			2	1	1		3		2	1	3		2	
2011	26,099	3		2	1	4				3		3	1	1	2	1		3		2	1
2012	28,040	3	1			4				4				3	1			3	1		
2013	30,131	3			2	4			1	3			2	3			2	3			2
2014	32,380	3			3	4		1		3		2	2	3			3	4			1
2015	34,800	5				4		2	1	5				5				5			
Total Number		29	7	9	6	22	15	11	2	26	10	10	5	29	7	9	6	30	7	9	4
Total Capacity (MW)		17,520	4,320	1,110	1,500	13,320	9,120	1,350	500	15,720	6,120	1,230	1,250	17,520	4,320	1,110	1,500	18,120	4,320	1,110	1,000

1) The figure shows Tanjung-Jati B,

2) The figure includes the Muara-Karang Repowering

3) The figure shows the Pemaron C/C

2) Gas consumption

Figure 7.2.6 shows the gas consumption trends for each case. In the Base Case, the Combined Cycle Power Plant Limited Case and the Pumped Storage Power Plant Limited Case, gas consumption will move within the gas supply plan. However, in the No Coal Power Plant Case and the Coal Power Plant Limited Case, the gas consumption will be bigger than that which is stipulated in the gas supply plan. Especially, in the No Coal Power Plant Case, gas consumption will reach 600BSCF / year.

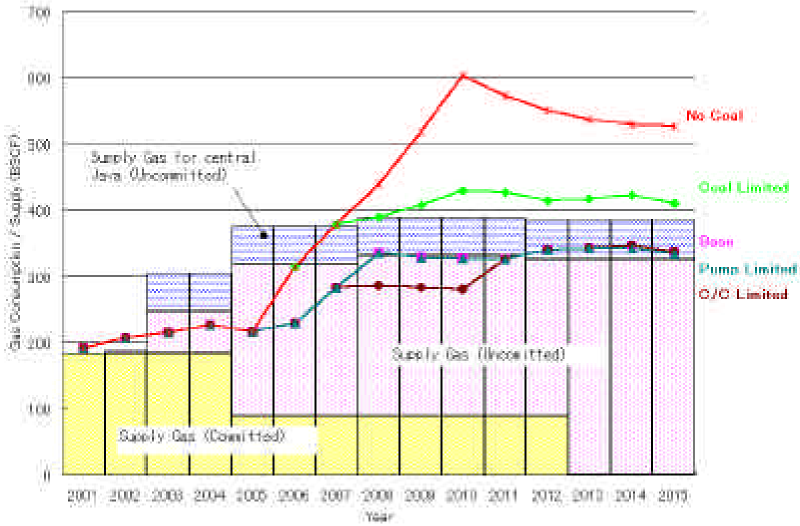


Figure7.2.6 Trend of Gas Consumption (Power Development Limited Scenario)

3) Coal consumption

Figure 7.2.7 shows the coal consumption trends in each case. Coal consumption is about 20,000kton / year in 2001, and will become 60,000 – 70,000kton / year in 2015 in all cases.

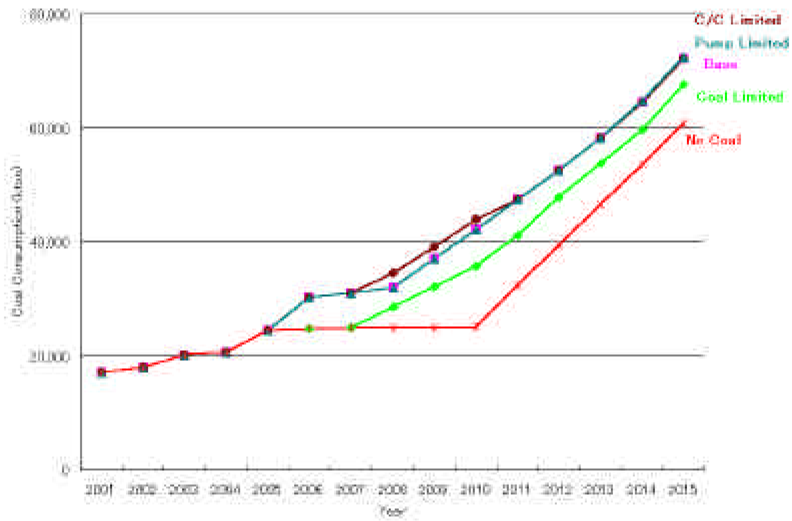


Figure 7.2.7 Trend of Coal Consumption (Power Development Limited Scenario)

4) System cost

Table 7.2.15 shows the total system cost of each case. The system cost will increase in the case coal fired power plant decrease. The incremental system cost will reach US$390million in the No Coal Power Plant Case and US$183 million in the Coal Power Plant Limited Case. The system cost will increase in the Combined Cycle limited Case and Pumped Storage Power Plant Limited case as well, however the incremental system cost is smaller than other cases because the limitation is rather loose.

Table 7.2.15 Necessary System Cost (Power Development Limited Scenario)

(UNIT: Million US$)

	Base Case	No Coal Case	Coal Limited Case	C/C Limited Case	Pump Limited Case
Construction Cost	7,716	6,766	7,245	7,787	7,749
Salvage Value	3,267	2,970	3,149	3,259	3,287
Operation Cost	15,886	16,931	16,423	15,913	15,879
E.N.S. Cost	220	218	219	220	220
Total (Difference)	20,555 -	20,945 390	20,738 183	20,660 105	20,561 6
%	100.0%	101.9%	100.9%	100.5%	100.0%

* The present price in the beginning of 2001

**Because of the specification of WASP-IV, the investment for planed projects such as Tanjung Jati B, Muara-Karang Repowering and Pemaron is NOT included in this figure.

***Please refer to the supplementary discussion 1 of Chapter 7

(3) Sensitive study on environmental issues -Environmental scenario-

As mentioned before, the power development plan of the Base Case consists mainly of coal power plants. On the other hand, since the global warming issue has become an important topic around the world, such environmental concerns must be taken into account in this report. In this section a case for which renewable energy is effectively used and a case that keeps CO_2 emission / kWh at present levels is examined. Table 7.2.16 shows conditions for each case.

Table 7.2.16 Environmental Scenario

Item	Renewable Energy Effective Use Scenario	CO_2 Emission Limited Case
Renewable Energy Power Plant	Refer to Table 7.2.17	
Combined Cycle Power Plant	Calculated by WASP-IV (Least Cost planning)	Adjusted to keep CO_2 emission at the present level
Coal Power Plant		
Gas Turbine		Calculated by WASP-IV (Least Cost planning)
Pumped Storage Power Plant		

Although renewable energy is developed by national policy, the investment should be met a certain economic level. Thus, candidates are chosen based on construction cost/kW, specifically US$ 2,000 / kW. Table 7.2.17 shows the amount of renewable energy treated in this scenario. These power plants are assumed to start operating from 2011.

Table 7.2.17 Amount of Renewable Energy

Unit Type	Number of Plant	Number of Unit	Total Capacity
Hydro Power Plant	8	-	1,697MW
Geothermal Power Plant	8	17	990MW

1) Power development plan

Table 7.2.18 shows the power development plan for the Environmental Scenario. In the Renewable Energy Case, the number of coal power plants will decrease, since the base power plants, such as run off river type hydro and geothermal power plants, are developed. The number of reduced units is about 4.

To keep CO_2 emission / kWh at the present level, the number of coal power plants should be decreased, while the number of combined cycle power plants should be increased. The number of units to be developed until 2015 is 12 for coal power plants and 20 for combined cycle power plants. Thus, it is necessary to develop twice as many combined cycle power plant as coal power plants.

Table 7.2.18 Power Development Plan By WASP-IV (Environmental Scenario)

		Base Case				Renewable Energy Case						CO_2 Emission Limited Case					
Year	Demand (MW)	ST	C/C	GT	P-S	ST	C/C	GT	P-S	Hyd	Geo	ST	C/C	GT	P-S	Hyd	Geo
		Number of Units				Number of Units						Number of Units					
2001	13,041																
2002	14,089																
2003	15,073																
2004	16,071			[3] 1				[3] 1						[3] 1			
2005	17,170	[1] 2				[1] 2						[1] 2					
2006	18,374	4	[2] 2			4	[2] 2						[2] 5	3			
2007	19,659		2				2						2				
2008	21,075		2	3			2	3				1	2				
2009	22,621	3		1		3		1				1	2				
2010	24,297	3		2		3		2					3				
2011	26,099	3		2	1	1		1	1	2	2			3	2	2	2
2012	28,040	3	1			2		1		2	2	1	1			2	2
2013	30,131	3			2	3			1	2	2	2	1		1	2	2
2014	32,380	3			3	2		1	3	2	2	2	2			2	2
2015	34,800	5				5		1				3	2				
Total Number		29	7	9	6	25	6	11	5	8	8	12	20	7	3	8	8
Total Capacity (MW)		17,520	4,320	1,110	1,500	15,120	3,120	1,350	1,250	1,697	990	7,320	12,120	870	750	1,697	990

Hyd: Hydro Power Plant, Geo: Geothermal Power Plant

1) The figure shows Tanjung-Jati B,

2) The figure includes the Muara-Karang Repowering

3) The figure shows the Pemaron C/C

2) Gas consumption

Figure 7.2.8 shows the gas consumption trends in each case. In the Renewable Case, gas consumption is not so different from the Base Case because the amount of renewable energy is not so much. However, in the CO_2 Emission Limited Case, the gas consumption will exceed 700BSCF/year.

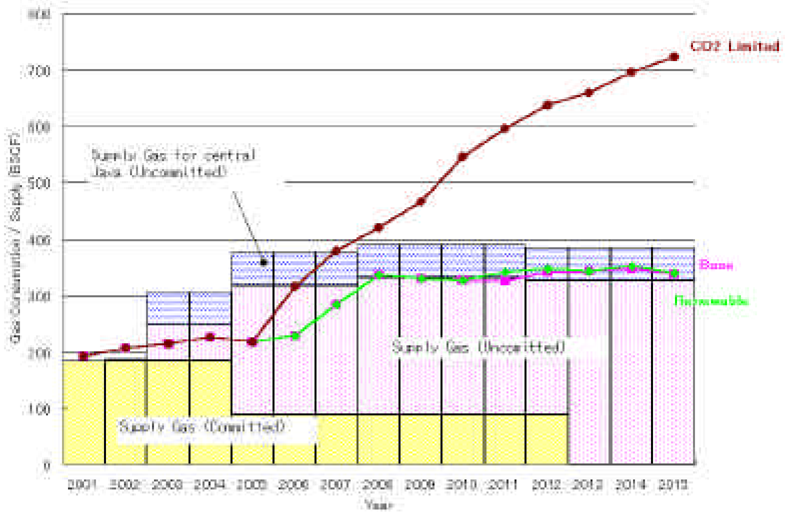


Figure 7.2.8 Trend of Gas Consumption (Environmental Scenario)

3) Coal consumption

Figure 7.2.9 shows the coal consumption trends in each case. In the Renewable Case, coal consumption is not so different from the Base Case because the amount of renewable energy is not so much. However, in the CO_2 Emission Limited Case, coal consumption will not exceed 40,000kton / year.

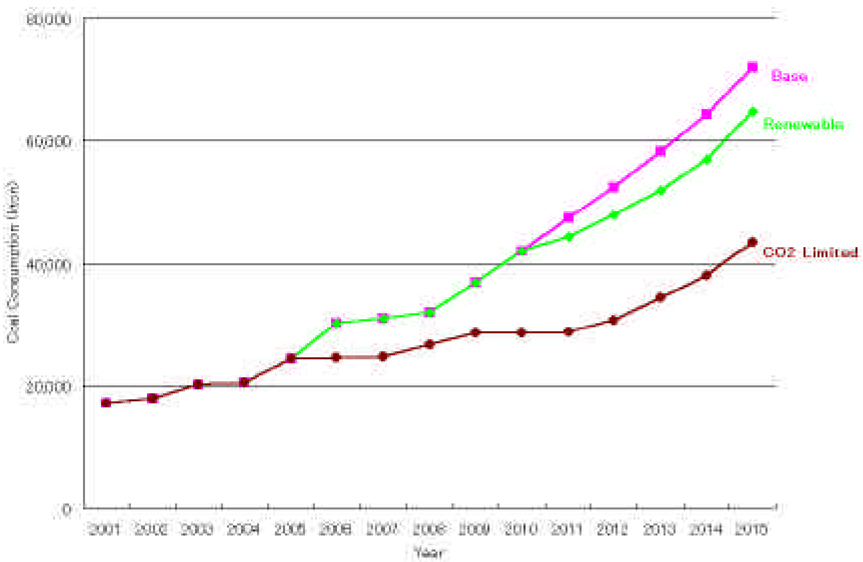


Figure 7.2.9 Trend of Coal Consumption (Environmental Scenario)

Table 7.2.19 shows fuel consumption and CO_2 emissions for each case in 2015. By using the renewable energy effectively, CO_2 emission will decrease from 0.820kton-CO_2/kWh to 0.764kton-CO_2/kWh in 2015, however, the CO_2 emission cannot be maintained at the present level (0.661kton-CO_2/kWh). In the CO_2 Emission Limited Case, CO_2 emission can keep within the 0.660kT-CO_2, while the gas consumption will jump up.

Table 7.2.19 Fuel Consumption and CO_2 Emission (Environmental Scenario)

Fuel Consumption (UNIT:KT,BSCF,kl)

Year	2001	2015		
	Base	Base	Renewable	CO2 Limited
Coal	17,016	72,085	64,795	43,433
Gas	192	337	339	722
HSD	1,682	1,035	2,288	2,473
MFO	478	100	129	130

CO2 Emission (UNIT:kT)

Year	2001	2015		
	Base	Base	Renewable	CO2 Limited
Coal	36,925	156,423	140,604	94,251
Gas	11,271	19,828	19,930	42,474
HSD	4,113	2,532	5,595	6,047
MFO	1,432	298	387	390
Total	53,742	179,082	166,517	143,161
GWh	81,260	218,395	218,039	217,020
kg-CO2/kWh	0.661	0.820	0.764	0.660

4) System cost

Table 7.2.20 shows the total system cost of each case. The system cost of the Renewable Case will be almost same as the Base Case. It is considered that total amount of the renewable energy is not so large that the development plan can not be affected. In the CO_2 Limited Case, the system cost will increase by US$402million. Because combined cycle power plant should be developed in place of the coal fired power plant.

Table 7.2.20 Necessary System Cost (Environmental Scenario)

(UNIT: Million US$)

	Base Case	Renewable	CO2 Limited
Construction Cost	7,716	7,812	6,633
Salvage Value	3,267	3,393	2,914
Operation Cost	15,886	15,959	17,020
E.N.S. Cost	220	220	218
Total (Difference)	20,555 -	20,598 43	20,957 402
%	100.0%	100.2%	102.0%

* The present price in the beginning of 2001

**Because of the specification of WASP-IV, the investment for planed projects such as Tanjung Jati B, Muara-Karang Repowering and Pemaron is NOT included in this figure.

***Please refer to the supplementary discussion 1 of Chapter 7

7.2.3 Issues to be addressed for the Power Development Plan

Sensitive studies on fuel price, limitation of power development and environmental policy are made and the impact of these conditions on power development plan is examined. In this section, issues to be solved and subjects to be realized the power development plan are proposed.

(1) Issues to be solved for realizing the power development plan

1) Investment

- For providing power stably, necessary capacity to be developed will reach 24,500MW and required investment will reach US$ 20 billion until 2015.
- Since it is difficult to procure this investment by government, investment by private sector can not but be expected.
- Taking the suspense of development and re-negotiation of purchase price with IPPs, it is not in the situation for foreign investors to invest the IPP project in Indonesia.
- Therefore, to make clear the organization that has the responsibility to provide power to the system under the new electricity law, and to introduce the private capitol to power sector, are very important.

2) Type of power sources

- The output of WASP-IV is the least cost plan to minimize the operation cost and levelized investment cost. Since Indonesia has the high load factor at about 70%, the simulation result becomes the development plan consisting of coal power plants mainly.
- Private investors are likely not to invest on the coal power plant because of its high investment caused by high construction cost per kW and great capacity per unit. Consequently, the gas turbine or combined cycle power plant using fuel gas is likely to be the objective of investment because of lower investment and shorter construction period.
- Therefore, to introduce the private capitol, it should be the urgent matters to construct the gas infrastructure and to provide fuel gas stably at low cost. Thus, gas infrastructure for the private sector should be constructed under the responsibility of the government for the time being.
- For the long-term development, energy policy regulating the amount of available gas for power sector and taking the effective use of coal should be required from the viewpoint of primary energy resources. Therefore, the government should study the optimal ratio of power sources, taking the effective use of primary energy and environmental issues into account.

3) Gas supply

- The amount of gas consumption is greatly influenced by fuel price and the development of coal power plant. Thus, In order to provide the necessary gas at necessary time, fuel supply plan should be prepared periodically with taking the situation of demand and power development into account.
- Amount of mineable resource of gas in west Java is limited and no gas project is expected to be developed except for the gas pipeline between Java and South Sumatra. Therefore, gas consumption for power sector it is likely to be limited.
- Gas consumption in middle term is considered to move at about 380BSCF
- In long term, new gas projects, such as Tanguh project in Irianjaya, are expected to be developed. The project scale of Tanguh would be about 300BSCF / year. Considering the gas for other sectors, gas supply for power sector can not but be a part of this project.
- In order to reduce the impact on environment, power sources should be developed by fuel gas. In this case, since the gas consumption jumps up, the capacity to be developed should be set deliberately, with considering the environmental policy and energy policy.

4) Coal supply

- In the least cost plan at JICA/LPE case 2, the coal consumption will reach 70million ton / year in 2015. On the other hand, mineable reserve of coal in Indonesia is about 4,928million ton. The amount ratio of the bituminous coal and sub bituminous coal for electric power is estimated to be 40%. Moreover, amount of confirmed resources is about 11,569million ton, thus leaving the export, consumption in other sector and use in outer island, the fuel coal for power sector in Java-Bali is enough to supply. Therefore, coal should be used from the point of primary energy in Indonesia.

Table 7.2.21 Mineable Resources on Coal (UNIT : million T)

Mineable Reserve	Amount of Resources		
	Confirmed	Expected	Total
4,928	11,569	27,306	38,875

Source: Directorate of Coal, "Indonesian Coal Yearly Statistics, Special Edition 2000"

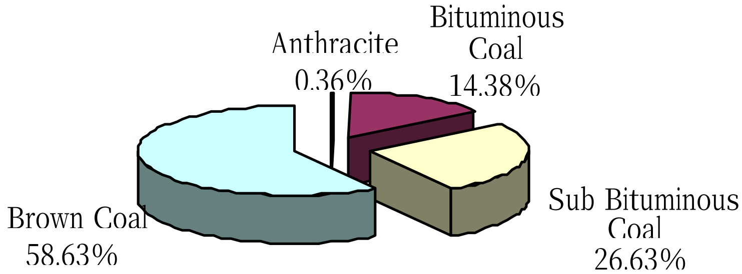


Figure 7.2.10 Composition of Coal Reserve by Type

- In case of coal power plant can not be developed sufficiently, gas power plant would be developed instead of coal power. Thus the gas consumption will jump up beyond the capacity of infrastructure. In order to control the gas consumption, a certain capacity of coal power plant should be developed.
- Despite the enough resources, fuel coal circulating in the market is rather short. This means the shortage of infrastructure from mining to the market. Thus the infrastructure of coal should be developed in accordance with the development of power sources with forecasting the coal consumption periodically.

5) Lead time for construction.

- In the case of a coal fired power unit, it requires four years for the actual construction period, and six to seven years including the environmental impact assessment. Considering the above, it seems very difficult to commitment in 2008. Therefore, the coal power plant should be developed by government policy or encourage of investor should be done by the favorable treatment.

(2) Suggestion to realize the power development plan

- In order to develop power sources by using private capital, the environment for investment should be prepared for developing gas turbines or combined cycle power plant requiring the small investment. Actually it is necessary to provide the fuel gas stably at low cost by constructing the infrastructure. In case that the necessary infrastructure is not prepared, the fuel gas for power sources can not be supplied, thus the infrastructure of fuel gas should be developed under the responsibility of the government.

- Taking the mineable reserve of coal and the amount of available gas for power sector, coal power plant should be developed in a certain extent from the viewpoint of primary energy. Since coal power plants require the big investment, the private capital is not likely to introduce to coal power plant. Therefore, the coal power plant should be developed by government policy or encourage of investor should be done by the favorable treatment.

- In order to meet power development plan, fuel infrastructure and environmental policy, national energy-environmental policy is required. In order to make full use of private capital, it is important to provide the information to the private investors for making clear the direction of the national development and the information for judging to the investment.

7.3 Study on Optimal Power Component Ratio

The concept of power mix in Japan includes energy security and environmental impact, since Japan does not have enough primary energy resources. Considering the power mix in Indonesia, the concept of effective use of the country's own primary energy and environmental factors should be considered. Considering the issues shown in section 7.2, the concept of optimal power mix is mentioned, trial calculation is done along the following procedure.

1) Study on Power Mix to realize the least cost development

In the condition that limitation will be relieved after 2010, the output of WASP-IV will converge to the same component ratio.

2) Trial Calculation of Ideal Power Mix for Long Term Development study on Power Mix to realize the least cost development

Trial calculation of long term power mix taking the way to use private sector, effective use of renewable energy and natural gas for environment, the upper bound of the amount of natural gas and effective use of coal etc. into account.

7.3.1 Component Ratio to realize the Least Cost Development

Table 7.3.1 shows the installed capacity of Base Case and Power Development Limited Case (Coal Limited & Combined Cycle Limited Case) in 2015. The component ratios of all cases are almost the same level, in other words, it has not affected very much by demand and development plan.

Table 7.3.1 Installed Capacity (in 2015)

(UNIT:MW,%)

	Demand:JICA/LPE_Case2						Demand: JICA/LPE_Case1	
	Base Case		Coal Limited		Combined Cycle Limited		Base Case	
Hydro	2,536	6.0%	2,536	6.0%	2,536	6.0%	2,536	6.4%
P.S.	1,500	3.5%	1,250	3.0%	1,500	3.5%	1,500	3.8%
Coal	24,170	57.1%	22,370	53.0%	24,170	57.1%	21,770	54.8%
Gas	8,969	21.2%	10,769	25.5%	8,969	21.2%	8,969	22.6%
HSD	4,218	10.0%	4,338	10.3%	4,218	10.0%	3,978	10.0%
MFO	200	0.5%	200	0.5%	200	0.5%	200	0.5%
GEO	765	1.8%	765	1.8%	765	1.8%	765	1.9%
Total	42,358	100.0%	42,228	100.0%	42,358	100.0%	39,718	100.0%

Table 7.3.2 shows the power generation ratio in 2015. The component ratios of all cases are almost the same as ones for installed capacity.

Table 7.3.2 Power Generation (in 2015)

(UNIT:GWh,%)

	Demand:JICA/LPE_Case2						Demand: JICA/LPE_Case1	
	Base Case		Coal Limited		Combined Cycle Limited		Base Case	
Hydro	7,719	3.5%	7,719	3.5%	7,719	3.5%	7,719	3.8%
P.S.	1,500	0.7%	1,250	0.7%	1,500	0.7%	1,209	0.6%
Coal	159,187	72.9%	149,375	73.2%	159,187	69.5%	143,922	70.5%
Gas	39,694	18.2%	48,401	18.0%	39,694	21.1%	40,294	19.8%
HSD	4,054	1.9%	5,024	1.6%	4,054	2.1%	4,608	2.3%
MFO	377	0.2%	405	0.3%	377	0.3%	385	0.2%
GEO	5,864	2.7%	5,864	2.7%	5,864	2.7%	5,864	2.9%
Total	218,395	100.0%	218,038	100.0%	218,395	100.0%	204,001	100.0%

The following is considered from Table 7.3.1 and Table 7.3.2

a. In case the limitation is relived, component ratios of installed capacity and power generation realizing the least cost development will converge to the ratios shown in Figure 7.3.1.
b. Load factor in Japan is about 60% (average of 10 power companies) and the component ratio of base load power plant, such as hydro, geothermal, nuclear and coal fired power plant, is 40% in installed capacity and 60% in power generation.
c. The component ratio of base load power sources, such as hydro, geothermal and coal-fired power plant, exceeds 60% in installed capacity and 75% in power generation. The high load factor (=70%) in Indonesia is likely to contribute it.

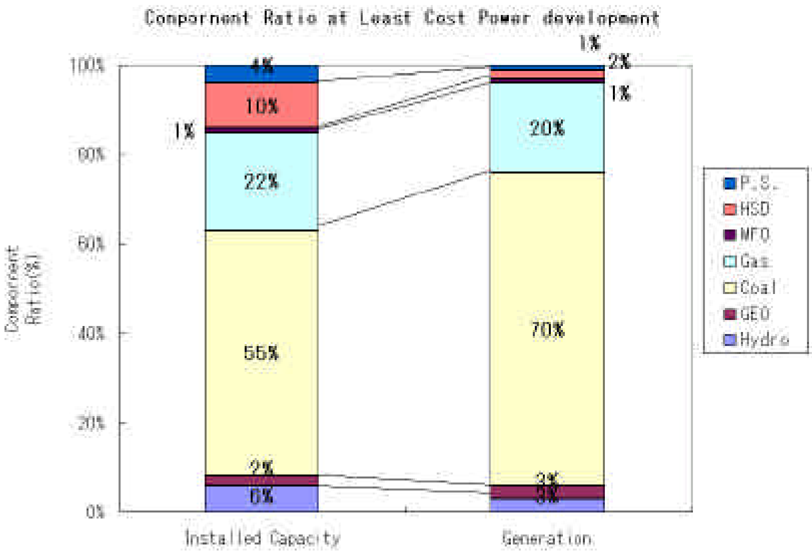


Figure 7.3.1 Component Ratio to Realize the Least Cost Development

7.3.2 Trial Calculation of Target Power Mixture in Long Term

Trial calculation of target power mixture in long-term is prepared, taking the way to use private sector, effective use of natural gas for environment, the upper bound of the amount of natural gas and effective use of coal etc. into account.

(1) Conditions

Picking up the CO_2 Emission Limited Case as original case, the amount of gas consumption is adjusted about 500–550 BSCF / year in the future, based on the following concept.

The amount of natural gas to be supplied

= The amount of present plan + 1/2 of gas supply by * new project

= 380 BSCF/year + 150 BSCF/year (300BSCF x 1/2)

= 500 – 550 BSCF / year

* Expectable amount of Tanguh project in Irian Jaya.

Table 7.3.3 Scenario of Trial Calculation on Optimal Power Mixture

Type of Power Source	Effective Use of Primary Energy	CO_2 Emission Limited Case (Listed Again)
Renewable Energy Power Plant	Refer to Table 7.2.17	
Combined Cycle Power Plant	Adjust the Upper Bound of Gas Consumption at about 550BSCF/ year	Adjust the CO_2 emission at about present level
Coal Power Plant		
Gas Turbine	Calculated by WASP-IV (Least Cost Planning)	

(2) Power development plan by WASP-IV (Primary energy effective use Case)

Table 7.3.4 shows the power development plan of the Primary Energy Effective Use Case. In this case, the number of coal power plant will decrease, and the Number of combined cycle power plant will decrease. The number of both power sources is between the Base Case and the CO_2 emission Limited Case.

Table 7.3.4 Power Development Plan By WASP-IV (Primary Energy Case)

Year	Demand (MW)	Base Case				CO_2 Emission Limited Case (listed again)						Primary Energy Effective Use Case					
		ST	C/C	GT	P-S	ST	C/C	GT	P-S	Hyd	Geo	ST	C/C	GT	P-S	Hyd	Geo
		Number of Units				Number of Units						Number of Units					
2001	13,041																
2002	14,089																
2003	15,073																
2004	16,071			[3] 1				[3] 1						[3] 1			
2005	17,170	[1] 2				[1] 2						[1] 2					
2006	18,374	4	[2] 2				[2] 5	3					[2] 5	3			
2007	19,659		2				2						2				
2008	21,075		2	3		1	2					1	2				
2009	22,621	3		1		1	2					1	2				
2010	24,297	3		2			3						3				
2011	26,099	3		2	1			3	2	2	2	2		1		2	2
2012	28,040	3	1			1	1			2	2	2		1		2	2
2013	30,131	3			2	2	1		1	2	2	3			1	2	2
2014	32,380	3			3	2	2			2	2	3			2	2	2
2015	34,800	5				3	2					4		1			
Total Number		29	7	9	6	12	20	8	3	8	8	18	14	7	3	8	8
Total Capacity (MW)		17,520	4,320	1,110	1,500	7,320	12,720	990	750	1,697	990	10,920	8,520	870	750	1,697	990

Hyd: Hydro Power Plant, Geo: Geothermal Power Plant

1) The figure shows Tanjung-Jati B,

2) The figure includes the Muara-Karang Repowering

3) The figure shows the Pemaron C/C

(3) Gas consumption

Figure 7.3.2 shows the trend of gas consumption in each case. In the CO_2 Emission Limited Case, the gas consumption will move over 700BSCF/year. However, in the Primary Energy Effective Use Case, the gas consumption will move about 550BSCF / year.

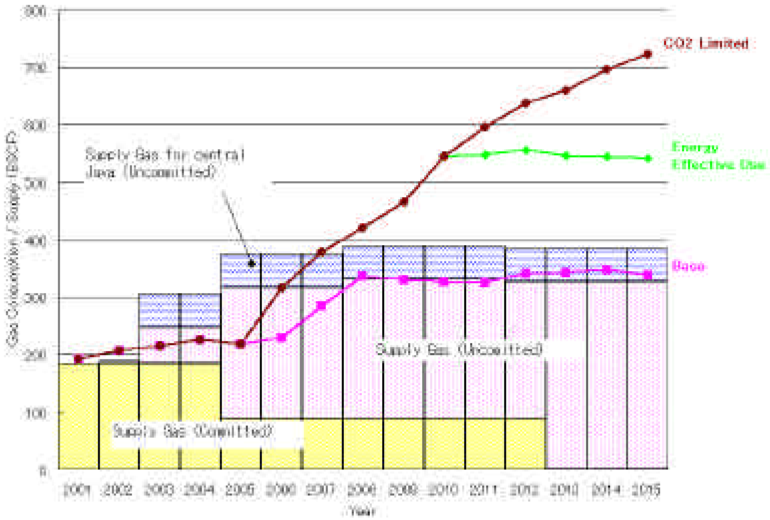


Figure 7.3.2 Trend of Gas Consumption (Primary Energy Case)

(4) Coal consumption

Figure 7.3.3 shows the trend of coal consumption in each case. In the CO2 Emission Limited Case, coal consumption will move not more than 40,000kton / year. In the Primary Energy Effective Use Case, the coal consumption will reach about 60.000kton / year.

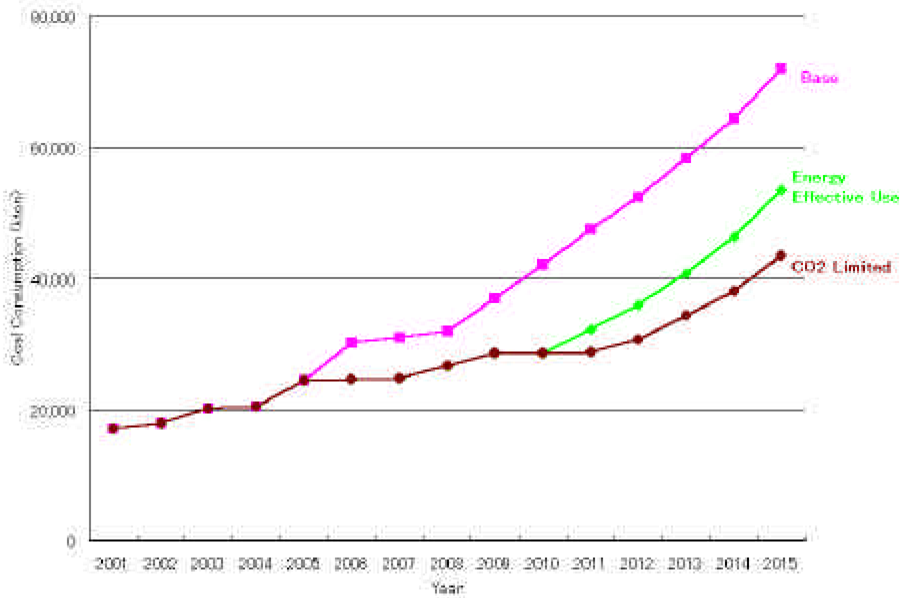


Figure 7.3.3 Trend of Coal Consumption (Primary Energy Case)

(5) Fuel consumption, CO_2 Emission

Table 7.3.5 shows fuel consumption and CO_2 emission in each case in 2015. In Primary Energy Case, CO_2 emission /kWh will decrease from Base Case. However, it will increase from the present CO_2 /kWh.

Table 7.3.5 Fuel Consumption and CO_2 Emission (Primary Energy Case)

Fuel Consumption (UNIT:KT,BSCF,kl)

Year	2001	2015		
	Base	Base	CO2 Limited	Energy Effective Use
Coal	17,016	72,085	43,433	53,450
Gas	192	337	722	541
HSD	1,682	1,035	2,473	2,365
MFO	478	100	130	131

CO2 Emission (UNIT:kT)

Year	2001	2015		
	Base	Base	CO2 Limited	Energy Effective Use
Coal	36,925	156,423	94,251	115,986
Gas	11,271	19,828	42,474	31,833
HSD	4,113	2,532	6,047	5,783
MFO	1,432	298	390	392
Total	53,742	179,082	143,161	153,995
GWh	81,260	218,395	217,020	217,027
kg-CO2/kWh	0.661	0.820	0.660	0.710

(6) Installed capacity and power production

Table 7.3.6 shows the install capacity of each case in 2015. The installed capacity of the Primary Energy Effective Use Case will be between the Base Case and the CO_2 Emission Limited Case

Table 7.3.6 Installed Capacity of Each Case (Primary Energy Case)

(UNIT:MW,%)

	Demand:JICA/LPE_Case2					
	Base Case		CO2 Limited		Energy Effective Use	
Hydro	2,536	6.0%	4,233	10.1%	4,233	10.2%
P.S.	1,500	3.5%	750	1.8%	750	1.8%
Coal	24,170	57.1%	13,970	33.4%	17,570	42.2%
Gas	8,969	21.2%	16,769	40.1%	13,169	31.6%
HSD	4,218	10.0%	4,098	9.8%	3,978	9.5%
MFO	200	0.5%	200	0.5%	200	0.5%
GEO	765	1.8%	1,755	4.2%	1,755	4.2%
Total	42,358	100.0%	41,775	100.0%	41,655	100.0%

Table 7.3.7 shows the power production of each case in 2015. The power production of the Primary Energy Effective Use Case will be between the Base Case and the CO_2 Emission Limited Case.

Table 7.3.7 Power Production of Each Case (Primary Energy Case)

(UNIT:GWh,%)

	Demand:JICA/LPE_Case2					
	Base Case		CO2 Limited		Energy Effective Use	
Hydro	7,719	3.5%	10,963	5.1%	10,963	5.1%
P.S.	1,500	0.7%	535	0.2%	542	0.2%
Coal	159,187	72.9%	95,916	44.2%	118,035	54.4%
Gas	39,694	18.2%	85,761	39.5%	64,037	29.5%
HSD	4,054	1.9%	9,884	4.6%	9,486	4.4%
MFO	377	0.2%	493	0.2%	496	0.2%
GEO	5,864	2.7%	13,468	6.2%	13,468	6.2%
Total	218,395	100.0%	217,020	100.0%	217,027	100.0%

Figure 7.3.4 shows the result of trial calculation of target power mixture in long-term. It is important to show the figure to the private investors, in order to use the private capitol actually.

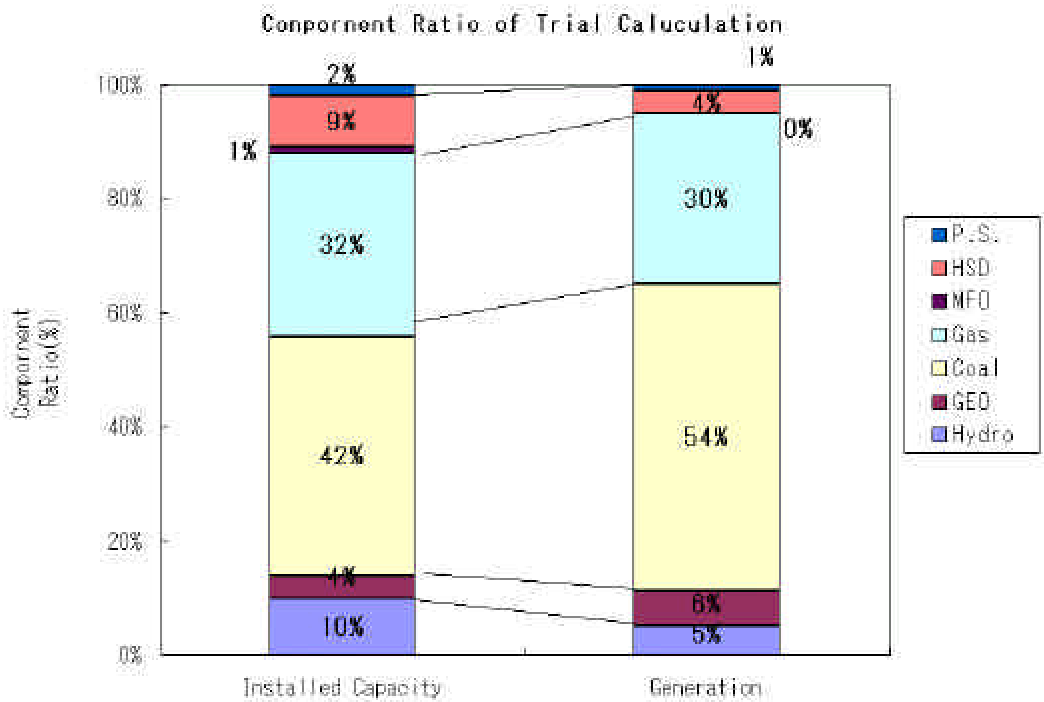


Figure 7.3.4 Component Ratio of Power Sources in Long-Term (2015)

4) System cost

Table 7.3.8 shows the total system cost of each cases. As is mentioned before, the system cost will increase by US$402million in the CO_2 Limited Case, because combined cycle power plant should be developed in place of the coal fired power plant. In the Energy Effective Use Case, The system cost will be increased by US$392million as well as the CO_2 Limited Case. On the other hand, the decrease of construction cost will contribute to relieve the barrier of investment to power sectors for private capitals. Thus the power development by using natural gas effectively is likely to be realized in this case.

Table 7.3.8 Necessary System Cost (Primary Energy Case)

(UNIT: Million US$)

	Base Case	CO2 Limited	Energy Effective Use
Construction Cost	7,716	6,633	7,012
Salvage Value	3,267	2,914	3,109
Operation Cost	15,886	17,020	16,827
E.N.S. Cost	220	218	216
Total (Difference)	20,555 -	20,957 402	20,947 392
%	100.0%	102.0%	101.9%

* The present price in the beginning of 2001

**Because of the specification of WASP-IV, the investment for planed projects such as Tanjung Jati B, Muara-Karang Repowering and Pemaron is NOT included in figures.

***Please refer to the supplementary discussion 1 of Chapter 7

Supplementary Discussion 1: Outline of WASP-IV

1.1 Reason to Choose the WASP-IV

The simulation program chosen for making the optimal power development plan requires the following characteristics:

(1) The result should be enough reliable for the other organization.
(2) The program should be revised in the future.
(3) The program should be easily handled, so that data can be easily arranged.

For the above reasons, the WASP-IV was chosen as the simulation program to be transferred.

As WASP-IV is used in many countries, the simulation result is sufficiently reliable. Since the new version will be released at any moment, the user could use the latest version after completing this study and also in the future. Moreover, the interface has improved from the former version, and at the same time, the user can learn the program from its manual. Considering the above conditions, WASP-IV is regarded as the best choice for the Optimal Power Development Simulation Program. In addition, the MEMR has itself already prepared WASP-IV. Therefore, the study team for the most part only to provide the necessary data and the instruction lecture.

The basic capacity of Sihombing model used in PLN is almost same to WASP-IV. Table 7.S.1 shows the difference between WASP-IV and Sihombing model.

Table 7.S.1 Differences between WASP-IV and Sihombing model

Items	WASP-IV	Sihombing model
Pump-Storage Power Unit	Available	N.A.
Impact against the Environmental Issues	Available	N.A.

1.2 Concept to Minimize the System Cost

WASP-IV is the simulation program to be minimize the system cost in calculation period as is shown the following equation:

$$B_j = \sum_{t=1}^{T} [\, \overline{I_{j,t}} - \overline{S_{j,t}} + \overline{F_{j,t}} + \overline{L_{j,t}} + \overline{M_{j,t}} + \overline{O_{j,t}} \,] \qquad \text{(Eq.7.S.1)}$$

Here:

Bj : Objective Function

T : Calculation Period, t : Year to be calculated, j : Development Plan No.j

I : Construction Cost

S : Salvage Value

F : Fuel Cost } Operation Cost

M : Non-fuel operation and maintenance costs } Operation Cost

L : Fuel Inventory Cost

O : Cost of the energy not served

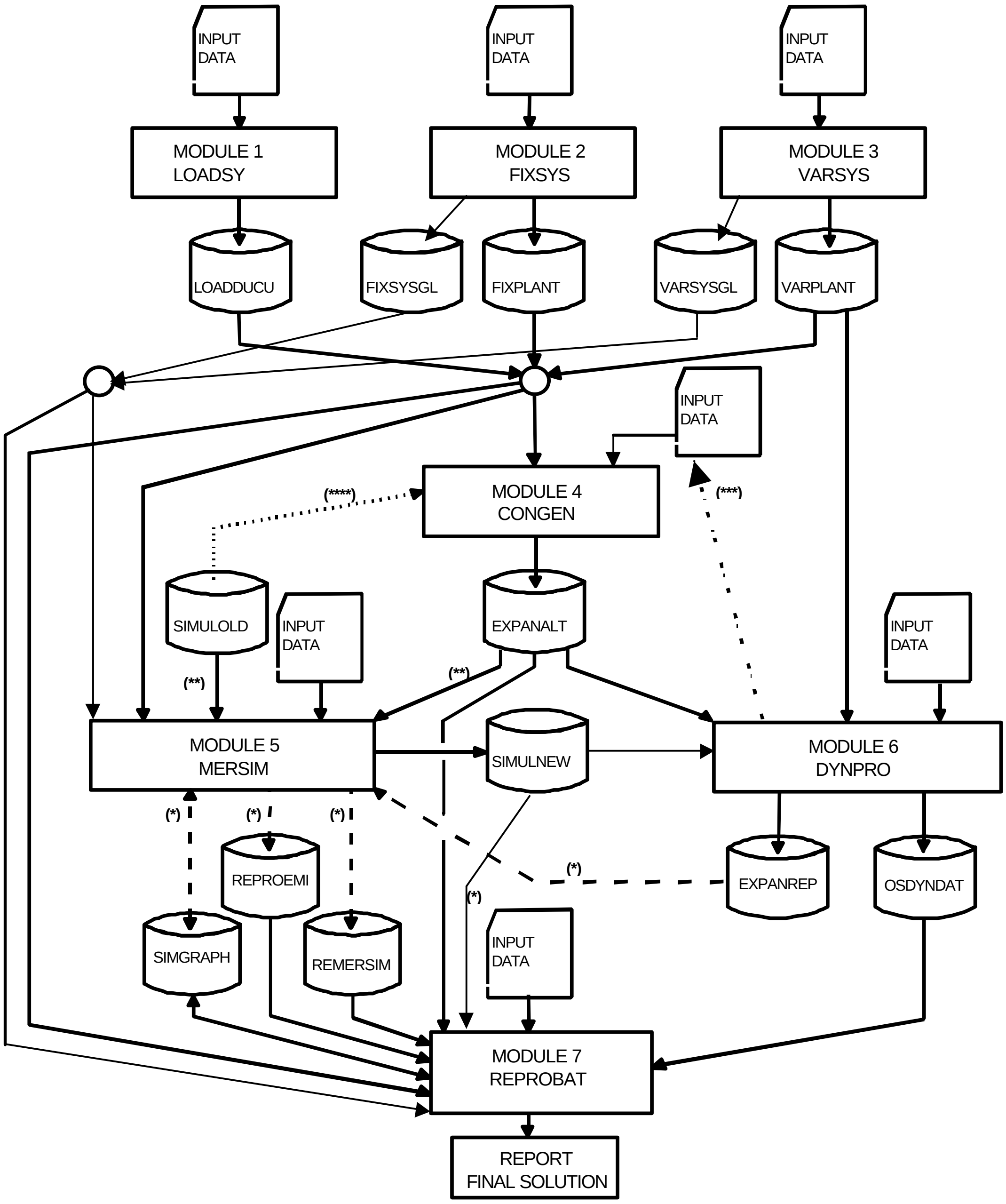
The least cost development plan is defined by the following equation using the dynamic planning method.

$$\text{Minimum} \quad B_j \quad (\text{among all } j) \qquad \text{(Eq.7.S.2)}$$

7.3.2 Structure and Capacity of WASP-IV

Figure 7.S.1 shows the calculation flow of WASP-IV. The program consists of the following seven modules:

- Module 1, LOADSY (Load System Description)
  The module which forecasts the future load curve by using the actual load curve
- Module 2, FIXSYS (Fixed System Description)
  The module which describes the data of the existing facilities and the fixed development project
- Module 3, VARSYS (Variable System Description)
  The module which describes the data of the candidate power sources
- Module 4, CONGEN (Configuration Generator)
  The module which defines the basic development plan and its variations
- Module 5, MERSIM (Merge and Simulate)
  The module which calculates the operation cost, fuel consumption etc.
- Module 6, DYNPRO (Dynamic Programming Optimization)
  The module which determines the optimal development plan by using the operation cost and the construction cost
- Module 7, REPROBAT (Report Writer of WASP in a Batched Environment)
  The Module which reports the result of simulation



(*)	*FOR RESIMULATION OF BEST SOLUTION ONLY*
(**)	*OMMIT FOR RESIMULATION OF BEST SOLUTION*
(***)	*ITERATION PATTERN IF BEST SOLUTION STILL CONSTRAINED*
(****)	*FOR CHECK OF CONFIGURATIONS ALREADY SIMULATED*

Source: Manual of WASP-IV

Figure 7.S.1 The calculation Flow of WASP-IV

Table 7.S.2 shows the principal capabilities of WASP-IV. Since WASP-IV has the enough capabilities to calculate the power system in Java-Bali, it will be possible to use WASP-IV in the future.

Table 7.S.2 Principal Capabilities of WASP-IV

Parameters	Maximum allowable
Years of study period	30
Periods per year.	12
Load duration curves (one for each period and for each year).	360
Cosine terms in the Fourier representation of the inverted load duration curve of each period.	100
Types of plants grouped by "fuel" types of which: 10 types of thermal plants; and 2 composite hydroelectric plants and one pumped storage plants.	12
Thermal plants of multiple units. This limit corresponds to the total number of plants in the Fixed System plus those thermal plants considered for system expansion which are described in the Variable System (87 if P-S is used).	88
Types of plants candidates for system expansion, of which: 12 types of thermal plants (11 if P-S is used); 2 hydroelectric plant types, each one composed of up to 30 projects; and1 pumped storage plant type with up to 30 composed projects.	15
Environmental pollutants (materials)	2
Group limitations	5
Hydrological conditions (hydrological years).	5
System configurations in all the study period (in one single iteration involving sequential runs of modules 4 to 6).	5000

Source: Manual of WASP-IV

Supplementary Discussion 2:

Study on Adequate Proportion of Pumped Storage Power in Optimal Power Development

Various power development plans were shown in the planning of the optimum power development. It is one of the noteworthy results that development of pumped storage power was required as a new kind of power source in the future Java-Bali electric power system. On the other hand, in Indonesia, new introduction of pumped storage power to the system has been studied independently up to now and the detailed design of the pumped storage power plant has been carried out recently. Taking account of these situations, we summarized here the need of pumped storage power in the optimum power development plan by adding a new study to this discussion.

2.1 Features of Pumped Storage Power

(1) Features as power resource

Pumped storage power is a type of hydropower for peak demand. It has two reservoirs, an upper and lower one. During peak demand, a pumped storage power plant generates power. During the off-peak demand period it stores the water in the upper reservoir by pumping it up using power from thermal or nuclear power.

Features of pumped storage power are as follows.

1) Power supply for peak demand

Pumped storage power can achieve full power output in only a few minutes from startup. It also has a swift follow-up ability against load fluctuation. Therefore, it is suitable to supply power for peak demand.

2) Power for pumping

It needs power to pump water up.

3) Constraints on operation

It alternates between generating and pumping up water, controlling the water between two reservoirs. Therefore, the storage capacity of reservoirs constrains generation time and pumping time.

4) Economic construction cost

Its unit construction cost beyond a certain capacity scale is cheaper than the cost of other power types of power.

(2) Features of system operation

Features of system operation are as follows.

1) Generation to meet supply and demand balance

Pumped storage power can respond to load fluctuation. It is used effectively for peak supply and to balance demand and supply.

2) Economic operation of pumped storage power plants

It can reduce the total fuel cost by pumping water up during the off-peak period, using power from low cost base-load plants; and generating during the peak period, instead of other cost thermal plants.

3) Control of power system frequency and voltage

It can maintain stable power system frequency through automatic frequency control, and control the system voltage as a source of reactive power.

4) Operating reserve

It can be used as operating reserve providing for failures of power sources or unexpected increases in power demand, because it is easy to start and stop generation.

2.2 Actual Development of Pumped Storage Power

(1) Background of actual development

Considering the above-mentioned characteristics of pumped storage power, its construction is planned in the following situations.

1) Increase of peak demand

Maximum demand is increasing with peak demand increase.

2) Availability of power for pumping

The proportion of base power sources such as thermal and nuclear power is increasing, and these power sources can provide the power for pumped storage.

3) Economically efficient power system operation

Efficient power system operation in terms of capacity factor and fuel consumption is possible by combining pumped storage and large thermal or nuclear power sources.

4) Location requirements

Suitable sites for pumped storage power plants are available.

(2) Actual development in Japan

Table 7.S.3 shows development of pumped storage in Japan, where day-time peak demand has rapidly increased since the 1970s, especially due to demand from air-conditioners. At first multiple-used pumped storage power plants were planned and constructed to cope with the

maximum demand caused by the increase in peak demand. Later, technologies for recirculating pumped storage power plants with large capacity and high head were developed and numerous of these plants have been constructed.

Table 7.S.4 shows the development of pumped storage power by Chubu Electric Power Company, Incorporated (CEPCO), which has been carried out in the same manner mentioned above. In 1980, large-scale plants were introduced in CEPCO when the company began operation of the Okuyahagi power plant (1,095MW). Later in 1995, it commenced operation of the Okumino power plant (1,500MW) and is planning new development, including the Kaore power plant (1,350MW).

Using the below mentioned simulation model, CEPCO studied on the optimal-share of pumped storage power in total power capacity and identified it as 10% up to 15%. CEPCO developed a power source plan according to this data.

Table 7.S.5 displays the operation record of the pumped storage of CEPCO, showing a relatively high capacity factor and high efficiency of pumped storage.

Table 7.S.3 Development of Pumped Storage in Japan

Year	1970	1975	1980	1985	1990	1995	1999
Maximum Demand (MW)	49,220	72,480	88,810	110,250	143,720	171,130	168,660
Installed Capacity (MW) A	59,050	99,740	129,350	154,250	175,070	204,210	226,960
Pumped Storage (MW) B	3,360	10,780	14,350	17,000	17,000	22,280	24,310
B/A (%)	5.7	10.8	11.1	11.0	9.7	10.9	10.7

Source: Outline of Power Development in Japan, Ministry of Economy Trade and Industry

Table 7.S.4 Development of Pumped Storage by CEPCO

Year	1970	1975	1980	1985	1990	1995	2000
Maximum Demand (MW)	7,450	10,930	13,500	16,650	22,280	26,010	26,360
Installed Capacity (MW) A	7,460	13,500	17,220	19,780	23,040	28,470	32,730
Pumped Storage (MW) B	760	1,440	2,090	2,820	2,820	4,320	4,320
B/A (%)	10.2	10.7	12.1	14.3	12.2	15.2	13.1
Load Factor (%)	67.0	60.4	60.1	58.2	56.2	53.8	58.0

Source: CEPCO

Table 7.S.5 Operation Record of Pumped Storage by CEPCO

Pumped Storage Power Plant	Annual Generation Generating Duration	Annual Pumped Generation Pumping Duration	Equivalent Peak Duration	Pumped Storage Efficiency
Okumino P/S (1,500MW)	840 GWh 2,134 h	1145 GWh 1,752 h	560 h	73.3%
Okuyahagi P/S (1,095MW)	303 GWh 835 h	413 GWh 826 h	277 h	73.5%

Source: CEPCO

2.3 Simulation Using WASP-Ⅳ

According to the study of planning of the optimum power development in the generation mix by simulation model WASP-IV, development plan of pumped storage power plant is summarized as follows:

1) It is necessary to develop pumped storage power plants in the long term optimum power development plan to realize the generation mix.
2) Installation of pumped storage power would be required after around 2010.
3) Pumped storage power which total capacity is around 1,500MW would be required in the last year 2015 of the plan.

2.4 Simulation Using Optimization Model for Pumped Storage Power Development

(1) Outline of the optimization model

Utilizing a linear programming method, the optimization model simulates power source development and identifies the most economical development plan in terms of yearly cost, based on input data of demand growth estimation, existing power source capacities, construction cost, fuel price, fuel procurement etc. One of the features of this model is that pumped storage operation is minutely considered. Central Research Institute of Power Industry (CEPCO) developed it, and CEPCO has been using it for pumped storage development planning.

The objective function is shown by the following formulation.

(Objective Function)=(Annual Equipment Expenses of Development Powers)
+(Fuel Costs of Existing and Development Powers)

Constraints on the model are as follows.

1) On-peak kW balance
Aggregate capacity requirements are derived with reserve margin for each season.
2) Off-peak kW balance
Assuming that surplus generation during the off peak period is absorbed by energy storage equipment, minimum storage capacity is determined
3) Annual maintenance capacity
The total duration for maintenance outage in a year is determined.

4) kW balance by daily load hours

The allotment of power generation is divided among power sources according to the daily load curve of each power source.

5) Upper and lower limits on generation output

The upper limit of generation output for each power source is determined.

6) Storage capacity of reservoirs

The storage capacity of reservoirs constrains the generation time and the pumping time.

7) Upper and lower limits of fuel consumption

Upper and lower limits of fuel consumption are determined.

8) Upper and lower limits of MW capacity development

Upper and lower limits of MW capacity development are determined.

(2) The conditions of simulation

The conditions of simulation were studied to determine a long term plan at the year 2015. Table 7.S.6 shows principle input data necessary for the study.

Table 7.S.6 Input Data

Maximum Demand (Gross)	34,800 MW
Yearly Generation (Gross)	216,442 GWh
Annual Load Factor	71.0 %
Initial Installed Capacity	Installed Capacity in 2001
Construction Cost	The same as WASP
Fuel Cost	The same as WASP
Annual Charge Rate	The same as WASP
Reserve Margin	The same as WASP
Operation Margin	The same as WASP
Yearly Maintenance Days	The same as WASP
Pumped Storage Efficiency	70%
Capacity of Reservoir	6.5 h (Maximum Output Duration)

(3) Simulation results

Figure 7.S.2 shows the results of the study. Since the coal fired base power development is sufficient enough, it is the most economical to keep 5% up to 8% the proportion of pumped storage power in the total power capacity. In this case, the total power development necessary from 2001 up to 2015 is 24,400MW,and the total power installed capacity in 2015 is 43,000MW.

Figure 7.S.3 shows a relation between the proportion of pumped storage power in the optimum generation mix and unit construction cost of pumped storage power plant. The proportion of pumped storage power greatly depends on the unit construction cost.

The higher unit construction cost is, the lower proportion of pumped storage power is. The pumped storage power which costs more than 1,000US$/kW is not necessary. To the contrary, the lower unit construction cost is, the higher proportion of pumped storage power is. Proportion of pumped storage power less than 600US$/kW is almost constant in the optimum generation mix.

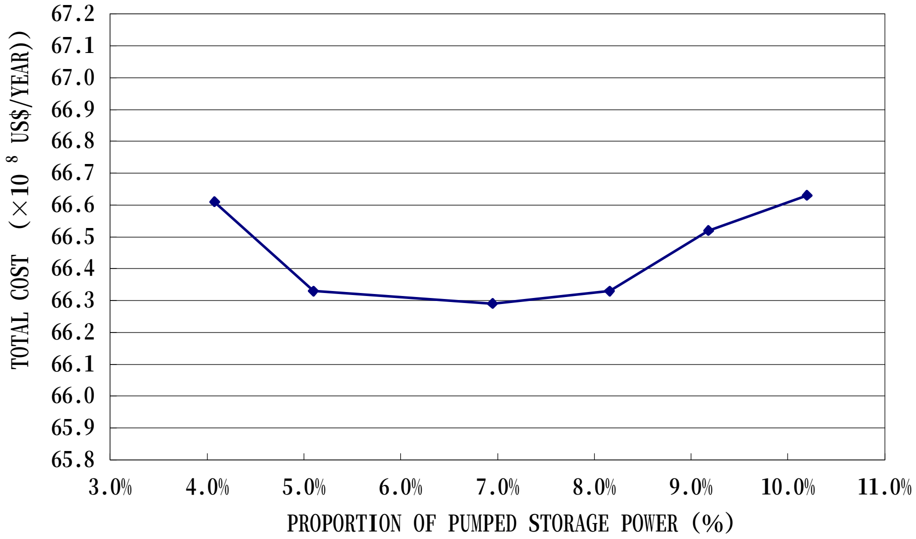


Figure 7.S.2 Proportion of Pumped Storage Power

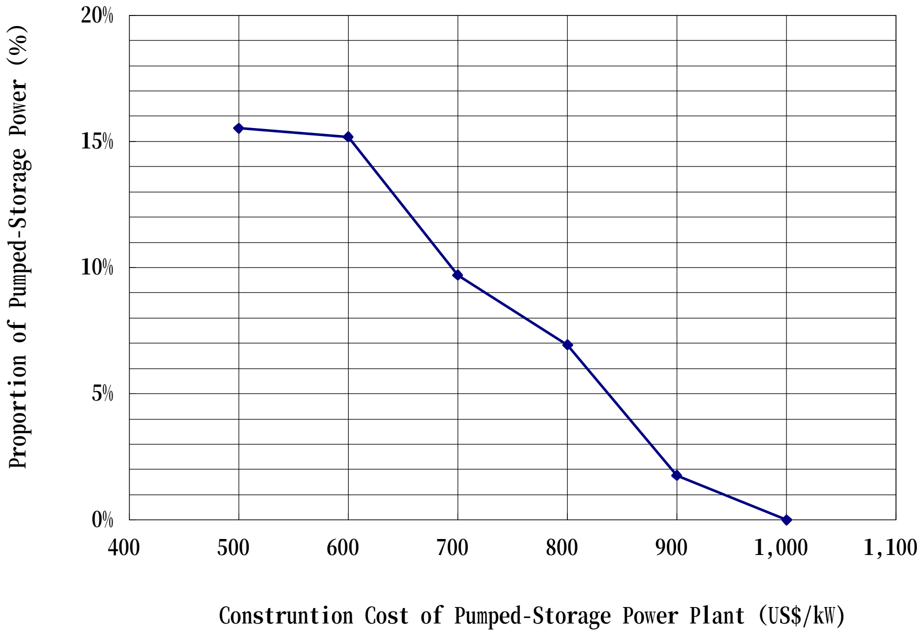


Figure 7.S.3 Proportion and Unit Construction Cost of Pumped Storage Power

5. Key Points for Planning of Pumped Storage Power Development

(1) Requirements for location

The location requirements for planning a pumped storage power plant are as follows. It is important to select economical candidates in terms of requirement for location.

1) Geographical

Two sets of dam-sites, where sufficient heads are secured, should be available at planned location.

2) Geological

The planned location should have good geological characteristics, suitable for the construction of dams, powerhouse and water tunnels.

3) Project scale

Planning for large-scale capacity should be possible in order to take advantage of the benefits of scale.

4) Transmission planning

The planned location should be near existing transmission lines in order to reduce transmission costs.

5) Vicinity to large demand area

The planned location should be near a large demand area, taking into account the transmission loss and the current stability.

(2) Recommendations for planning of pumped storage power as a peak power source

Pumped storage power has various merits besides features of typical peak supply power sources. The above study clarifies needs of pumped storage power development in planning of long term power source development. Recommendations for planning of pumped storage power as a peak power source are summarized as follows:

1) Development of economical site

It is recommended to accord a priority to development of the most economical site in terms of total cost through studying candidate sites in detail.

2) Step by step or extension development

In some cases, flexible development such as a step by step or an extension development according to future power demand is more economical.

3) Utilization of existing reservoirs and natural lakes

Some existing reservoirs and natural lakes have sufficient reservoir capacities. If those are available for upper reservoirs or lower ones, there is a possibility to develop an economical pumped storage power plant.

4) Development of multiple-used pumped storage power plants

Multiple-used pumped storage power plant, which combines conventional hydropower and pumped storage power, has a possibility to be more economical.

5) Regulating operation system of small and medium scale hydropower

If many small and medium scale hydropower plants with reservoirs can regulate operation for peak demand at the same time, they could be efficient power sources for peak demand even if each of them has a relatively small capacity of reservoir.

6) Repowering of existing hydropower plants with reservoir

There is a possibility to construct additional units for existing hydropower plants with huge reservoirs if they have enough reservoir capacities and are possible to repower.

Chapter 8 Transmission Planning and System Analysis

In this chapter, the current state and problems of the Java Bali system are analyzed. Various types of system analysis (power flow analysis, stability analysis, short circuit analysis, frequency analysis), are used and optimal transmission plans are developed to achieve the development of power stations.

Short-term transmission planning (approximately until 2007) is studied to verify the PLN transmission plan and to evaluate generation constraints caused by the transmission limit of the 500kV trunk lines for stability.

Mid- and long-term transmission plans for 2010 (approximately 25,000MW) and for 2015 (approximately 35,000MW) are studied in order to cope with the power development until approximately 2015. The study accounts for the various distribution patterns for the new power stations (balanced development, development mainly in West Java, development mainly in East Java, development heavily in East Java).

8.1 Current State and Problems of the Java Bali System

8.1.1 Introduction

Indonesia is a country consisting of many islands, and so the power system of each island has been developed independently. The Java Bali system consists of the Java system and the Bali system, and two-circuit 150kV submarine cables are connecting the two systems.

Java is a long and narrow island, and the length from east to west is almost 1,000km, so power must be transmitted over a long distance. To cope with this problem, a 500kV transmission system was introduced in 1984 and has since been expanded. In 1999, northern 500kV transmission lines, which consist of two circuits, were completed from the Suralaya Power Station in West Java to the Paiton Power Station in East Java.

As shown in Table 8.1.1, demand in West Java is high because of the high demand at Jakarta, which is located in this region. However, some of the large power stations, such as Paiton and Gresik, are located in East Java. Thus a lot of power flows from east to west through 500kV transmission lines, and power transmission is being restricted by stability considerations.

To remove this restriction, southern 500kV transmission lines are being constructed. The section from the Paiton Power Station to the existing Klaten substation in central Java will be completed in 2003, and the section from the Klaten substation to the new DepokIII substation in south Jakarta will be completed in 2004.

The one circuit of the transmission lines from Paiton to Klaten has already been in operation since April 2002, by bypassing the delayed Kediri substation.

Figure 5.1.1 shows the Java Bali 500kV system in 2001.

Table 8.1.1 Demand and supply balance of each area in the Java Bali system (2001)

	West Java (Area1,2)	Central Java (Area3)	East Java (Area4)	Total
Demand (MW)	7,811 (60%)	2,057 (16%)	3,173 (24%)	13,041 (100%)
Supply (MW)	9,848 (53%)	1,755 (9%)	7,005 (38%)	18,608 (100%)

The voltages utilized in the Java Bali system are 500kV, 150kV, 70kV and 20kV. 500kV is utilized for the bulk system. 150kV was used for the bulk system before 500kV was introduced. Now 150kV is used to support the 500kV system and to transmit power of middle-scale power stations. It is also used for distribution to 150/70kV and 150/20kV substations. The 500kV system and 150kV system are operated as loop systems with some exceptions, and the 150kV system is divided into 12 subsystems called islands.

70kV is used for distribution to 70/20kV substations in local areas, but PLN will not actively expand the 70kV system. The 20kV is also used for distribution.

Table 8.1.2 and Table 8.1.3 show the outline of transmission lines and substations in the Java Bali system.

Table 8.1.2 Transmission lines (Unit: km-cct)

	Overhead lines			Underground lines		Submarine cables
	500kV	150kV	70kV	150kV	70kV	150kV
1996	1,873	9,085	3,854	244	29	17
1997	2,241	9,478	3,974	277	29	21
1998	2,546	9,771	3,946	282	29	26
1999	2,699	9,871	3,979	293	23	26
2000	2,774	10,040	3,961	340	24	30

Source: STATISTIK 2000 UBS P3B

Table 8.1.3 Substations(Transformers)   (Unit: MVA)

	500/150kV	150/70kV	150/20kV etc	70/20kV etc
1998	11,500	3,798	18,011	4,049
1999	12,000	4,018	20,814	4,165
1998	13,000	4,248	21,055	3,811
1999	14,000	4,028	22,708	4,177
2000	14,500	3,966	23,924	4,268

Source: STATISTIK 2000 UBS P3B

8.1.2 Reliability in the Java Bali System

Table 8.1.4 shows the SAIFI (System Average Interruption Frequency Index) and SAIDA (System Average Interruption Duration Index) in Java Island in 2000.

Table 8.1.4 Reliability in Java Island (In 2000)

	SAIFI (times/customer)	SAIDA (hours/customer)
Java island	9.46	7.07
Japan (1999) (10 Electric Power Companies)	0.22	0.62

Source: PLN STATISTICS 2000

The level of reliability in Java Island is not satisfactory, so many customers have back-up generators against blackouts. Reliability should be improved by constructing transmission lines and distribution lines.

In terms of large-scale blackouts, a blackout that extended throughout the entire Java Bali system occurred in 1997. Additionally a blackout of 2000MW occurred in the Jakarta area in August 2001 because of the failure of a 500kV transmission line.

8.1.3 Transmission and Distribution Losses

Table 8.1.5 shows the transmission losses and distribution losses in the Java Bali system.

Table 8.1.5 Transmission Losses and Distribution Losses (In 2000)

	Transmission losses	Distribution losses
Java Bali system	2.5%	8.5%
Japan (10 Electric Power Companies)	2.4%	4.1%

Source: PLN STATISTICS 2000

The transmission losses are at a low level because the system has been expanded.

Distribution losses should be reduced by expanding distribution lines to a level comparable to transmission lines. Non-technical losses, such as power theft, should also be reduced.

8.1.4 State of System Operation in the Java Bali System

(1) Supervision and control of the Java Bali System

In the Java Bali system, the 500kV system is supervised and controlled by the Java Control Center (JCC) located at Gandul substation. The 150kV and 70kV systems are supervised and controlled by four Area Control Centers (ACC) that are located at Cawang, Cigereleng, Ungaran and Waru substations.

(2) System stability

The amount of power flow of a transmission line is regulated by stability or the thermal capacity. In the case of a trunk line, it is often regulated by stability. In the Java Bali system, power that is generated by stations in east Java, such as Paiton, is transmitted to the Jakarta area across the entire island, so there is a stability problem. If the power flows beyond the limit and there is a transmission line fault, the generators at Paiton will step out. In the worst case, the power supply to the entire Java Bali area will be interrupted.

(3) Availability

Table 8.1.6 shows the availability factor of transformers in the Java Bali system.

Table 8.1.6 Availability Factors (AF) of transformers (In 2000) (unit: Unit)

	500/150kV		150/70kV		150/20kV, etc		70/20kV, etc	
AF＜20%	2	(7%)	6	(10%)	51	(11%)	44	(24%)
20%≦AF＜40%	0	(0%)	8	(13%)	71	(15%)	13	(7%)
40%≦AF＜60%	10	(33%)	14	(23%)	104	(21%)	34	(19%)
60%≦AF＜80%	5	(17%)	18	(29%)	140	(29%)	53	(29%)
80%≦AF	13	(43%)	15	(25%)	117	(24%)	38	(21%)
Total	30	(100%)	61	(100%)	483	(100%)	182	(100%)

Source: EVALUASI OPERASI SISTEM TENAGA LISTRIK JAWA BALI 2000

According to this table, the availability factors of some transformers are over 80%, so system expansion is needed. Meanwhile, the availability factors of some transformers are less than 20%. Therefore, movement of these should be considered, when system expansion is planned.

Table 8.1.7 shows the transmission lines of which availability factors are more than 60%.

Table 8.1.7 Transmission lines of which AF are more than 60% (In 2000)

Voltage	Numbers of circuit
500kV	0
150kV	50
70kV	15

Source: EVALUASI OPERASI SISTEM TENAGA LISTRIK JAWA BALI 2000

(4) Voltage

The voltages of the system are regulated by controlling the reactive power of generators, by switching shunt capacitors and shunt reactors, and by on-load tap changing transformers.

The allowable range of voltages is between +5% and -10%. According to "PENGUSAHAAN SISTEM JAWA BALI 2001", there is no voltage problem in the 500kV system at present. However, in the 150kV and 70kV systems the voltages drop 10% or more at 30 substations, and the voltage rises more than 10% at one substation.

In case of a shortage of spinning reserve or under frequency, brown outs are sometimes implemented. During a brown out, the operators drop the voltages of the system intentionally to reduce demand.

(5) Short circuit capacity

Table 8.1.8 shows the nominal short circuit current of the equipment in the Java Bali system.

Table 8.1.8 Nominal short circuit current

Voltage (kV)	Nominal short circuit current (kA)	Remarks
500	50,40	50kA: Paiton only
150	50,40,31.5,25, etc	
70	40,25,20,12.5, etc	

According to "PENGUSAHAAN SISTEM JAWA BALI 2001", the short circuit current is less than the nominal short circuit current of the equipment in each 500kV substation at present. In the 150kV and 70kV systems, the nominal short circuit currents of equipment are less than short circuit currents at 30 substations.

At these substations, a failure cannot be removed by the main protective relay when short circuit occurs. Consequently, the failure continues for a long time because it must be removed by a back up relay. This is a big problem for worker security and equipment. Therefore, the equipment should be replaced as soon as possible at these substations.

(6) Frequency

1) Normal Condition

The frequency of the Java Bali system is controlled by the Java Control Center, and the allowable range of frequency under normal conditions is 50±0.2Hz. The frequency during normal conditions is usually within the allowable range, so there is no problem during normal conditions.

The main power stations, which are operated for LFC (Load Frequency Control), are the large hydropower stations, such as Cirata and Saguling, and thermal power stations, such as Suralaya and Paiton.

2) Contingency Condition

When the frequency drops due to the failure of a generator or other reason, the frequency is controlled by the following method.

- 49.8Hz or less than 49.8Hz: Brown Out
- 49.5Hz or less than 49.5Hz: Load Shedding (The amount of load shedding depends on the amount and speed of the frequency drop)

According to "EVALUASI OPERASI SISTEM TENAGA LISTRIK JAWA BALI 2000", the frequency dropped to less than 49.5Hz 55 times in the Java Bali system in 2000, load shedding was executed 20 times out of 55.

The units of generators in the Java Bali system are large in comparison with the system capacity. So, due to a generator fault, the frequency drops greatly and load shedding is needed. Generator faults occur often, so the number of times load is shed is high.

8.1.5 Protective Relay and Telecommunication Facilities

At present, two sets of distance relays are adopted to protect each 500kV transmission line in the Java Bali system. Single-phase reclosing using PLC (Power Line Carrier) is also adopted.

For telecommunication, mainly PLC has been used so far. However, the amount of data that can be communicated by PLC is relatively small. A telecommunication system with optical fiber has been developed recently using OPGWs (Ground Wire with Optical Fiber) or telecommunication lines.

8.2 PLN Transmission Planning

8.2.1 Criteria of PLN for Transmission Planning

Transmission planning is needed to supply high quality electricity to customers. The voltages and frequency should be maintained appropriately, and the number of times and duration of blackouts should be maintained on a low level. Therefore, appropriate redundancy should be considered against failure of facilities with respect to transmission planning.

PLN generally develops the transmission plan for the Java Bali system to accommodate an N-1 level of contingency. According to this criterion, even if one piece of equipment (one circuit of transmission line or one transformer) is removed either due to failure or planned maintenance, an interruption of power supply will not occur or it will be restored immediately. This criterion is adopted internationally. If it is not adopted, interruptions will occur and continue with the failure of one piece of equipment in the system, and equipment maintenance will be difficult. PLN should keep this criterion for transmission planning.

8.2.2 PLN Transmission Planning

Every year, PLN plans the Java Bali system for five years. According to "TINJAUAN SISTEM JAWA BALI TAHUN 2002-2006", the outline of the PLN transmission plan (Medium demand Case) is as follows.

Table 8.2.1 500kV Transmission lines (km-cct)

	Transmission lines	Total
2002	Paiton - Kediri (210.4) Kediri - Pedan (205.0)	415.4
2003	Paiton - Kediri (210.4) Kediri - Pedan (205.0) Mandiracan Incomer(0.6)	416.0
2004	Pedan - Tasikmalaya (612.0) Tasikmalaya - DepokIII(502.0) Tanjung Jati B - Ungaran(phase1)(180.0)	1294.0
2005	Tanjung Jati B - Ungaran(phase2)(94.0) Tambun Incomer (18.0)	112.0
2006	Grati- Surabaya Selatan(160.0) Balaraja Incomer (10.0) Rawalo Incomer (150.0) Ngimbang Incomer (10.0)	330.0
Total	-	2567.4

Table 8.2.2 500/150kV substations (MVA)

	Area 1	Area 2	Area 3	Area 4	Total
2002					0
2003		Cirebon(500)	Klaten (500)	Kediri (500)	1,500
2004	DepokIII (500)	Tasikmalaya (500)		Kediri (500)	1,500
2005	Tambun(500)				500
2006	Balaraja (1000)		Rawalo(500)	Ngimbang (500) Surabaya Selatan(1000)	3,000
Total	2,000	1,000	1,000	2,500	6,500

Table 8.2.3 Transmission lines and substations under 150kV

	150kV and 70kV Transmission lines (km-cct)	150/70kV, 150/20kV and 70/20kV substations (MVA)
2002	1,386	1,770
2003	935	1,300
2004	256	250
2005	72	0
2006	362	720
Total	3,011	3,940

(1) Bulk system

1) Southern 500kV transmission lines

To remove transmission restrictions and improve reliability in the Java Bali system southern 500kV transmission lines are under construction from the Paiton Power Station to the new DepokIII substation which is planned to be constructed in southern Jakarta. The lines go by way of the new Kediri substation, the existing Klaten substation and the new Tasikmalaya substation.

The section from Paiton to Klaten is planned to be completed in 2003, and the section from Klaten to DepokIII is planned to be completed in 2004.

Due to the delay of Kediri substation, the one circuit of the transmission lines from Paiton to Klaten have been in operation since April 2002 in advance, by bypassing Kediri substation.

Additionally, construction of the section from Klaten to Depok III might be delayed because of difficulties in acquiring land near the Depok III substation.

2) Tanjung Jati B Power Station

Construction of the Tanjung Jati B Power Station in central Java is expected in 2005. To transmit its power, a 500kV transmission line between Tanjung Jati B and Ungaran is under planning.

(2) Localized transmission system

1) Jakarta Area

Demand in the Jakarta area is supplied by the 500kV Bekasi, Cawang and Gandul substations. As a measure against the demand increase, construction of the 500/150kV DepokIII substation (500MVA x 1) is planned for 2004 along with the southern 500kV transmission lines.

The capacity of the 70kV system that supplies the Jakarta area will be short because of the demand increase, so new 150kV transmission lines are planned from DepokIII to Tambun by upgrading existing 70kV transmission lines. Additionally, to increase capacity, the 70kV substations (Gandaria, Miniatur, Poncol) are planned to be upgraded to 150kV.

To cope with the demand increase, the Tambun substation is planned to be upgraded to 500kV and a transformer (500MVA x 1) will be installed.

2) Bandung Area

Demand in the Bandung area is supplied by the 500kV Bandung Selaten substation (500MVA x 2). As a measure against the demand increase, construction of the 500/150kV Tasikmalaya substation (500MVA x 1) is planned for 2004 along with the southern 500kV transmission lines.

In addition to the construction of the Tasikmalaya substation, new 150kV transmission lines between Bandung Selaten and new Tasikmalaya (Bandung Selaten- Kamojang-Daraja-Garut-Tasikmalaya- new Tasikmalaya) are planned to be reinforced.

3) Cirebon Area

Demand in the Cirebon area is supplied by the 500kV Cirebon substation (500MVA x 1). As a measure against the demand increase, installation of the second 500/150kV transformer (500MVA x 1) at Cirebon is planned for 2003.

The 70kV transmission lines will have a capacity shortage, so along with installation of the second transformer at Cirebon substation, new 150kV transmission lines between Cirebon and Tasikmalaya are planned by upgrading the existing 70kV transmission lines and substations (Babakan, Kuningan Malangbong). And the 150kV lines between Cirebon, Rancaekok, and Ujungerung are also planned to be reinforced and expanded.

4) Surabaya Area

The demand in Surabaya area is supplied by the 500kV Krian substation (500MVA x 2). As a measure against the demand increase, construction of the 500kV Kediri substation (500MVA x 2) is planned for 2003 along with the southern 500kV transmission lines.

Construction of the 500kV Surabaya Selaten substation (500MVA x 2) was planned for 2004. However, land acquisition for the transmission line is difficult. To cope with this problem, a new 150kV transmission from the Ujung substation to the Perak power plant is planned, and construction of the Surabaya Selaten substation is put off until 2006.

To cope with the demand increase in industrial areas to the northwest of the Krian substation, the 500/150kV Ngimbang substation (500MVA x 1) is planned for 2006.

5) Central Java

Demand in the southern coast area of central Java is supplied by the 500kV Klaten substation (500MVA x 1). As a measure against the demand increase, installation of the second 500/150kV transformer (500MVA x 1) at the Klaten substation is planned for 2003.

Also as a measure against the demand increase, construction of the 500/150kV Rawalo substation (500MVA x 1) is planned for 2006.

6) West Java

Demand in West Java is supplied by the 500kV Ciregon substation (500MVA x 2). As a measure against the demand increase, construction of the 500/150kV Balaraja substation (500MVA x 2) is planned for 2006.

8.3 Transmission Planning (Short-term)

In this section, short-term transmission planning (approximately until 2007) is studied to verify the transmission plan of PLN and to evaluate the constraint of generation caused by transmission limit of the 500kV trunk lines by stability.

8.3.1 Programs and Conditions for System Analysis

(1) Programs

The following programs are used for system analysis.

Power Flow analysis	L method (Newton-Raphson method) (by Central Research Institute of Electric Power Industry)
Transient Stability analysis	Y method (by Central Research Institute of Electric Power Industry)
Short Circuit Capacity analysis	Program developed by CEPCO

(2) Conditions

The following are the conditions for system analysis.

Fault		3LG-O (3 phase ground fault : Criteria of P3B)
Fault Clearing time		100ms(500kV), 150ms(150kV)
Demand		Peak (Case 1) Load-Voltage characteristic $L=P_0(V/V_0)^{\alpha}+Q_0(V/V_0)^{\beta}$: $\alpha=1.0$, $\beta=2.0$
Simulated Generators		500kV system: All power stations 150kV system: Large scale thermal power stations (Muara Karang, Tanjung Priok, Tambak Rolok, Gresik, Grati)
Parameters of Transmission lines and transformers		P3B data or manufacturer data (Partly standard data)
Generator data		P3B data or manufacturer data (Partly standard data)
	AVR	Standard data (Thyristor-type, Self-excitation)
	Governor	Standard data
	PSS	Not included

Basically, data from P3B or data from the manufacturers are used for system analysis. Standard data are used for AVRs (Automatic Voltage Regulator) and governors. PSSs (Power System Stabilizer) at some power stations are not used, so PSSs are not included in this study. It is assumed that appropriate shunt capacitors and shunt reactors are to be installed to maintain the voltage adequately.

8.3.2 Transmission of the Power Stations in East Java and Tanjung Jati B

At present transmission of power generated by power stations in East Java, such as Paiton, is restricted due to stability problems.

System stability is studied every year up until the southern 500kV transmission lines are completed. Stability is also studied for the Tanjung Jati B Power Station, which is expected to be completed in 2005. The case in which there is a delay in completing the southern 500kV transmission lines is also studied.

The following cases are studied:

Case 1	2002	No southern 500kV transmission lines
Case 2	2002	Operation of one circuit between Paiton and Klaten
Case 3	2003	Operation of two circuits between Paiton and Klaten
Case 4	2003	Operation of two circuits between Paiton and Klaten (After Double π connection at Cirebon)
Case 5	2004	Operation of entire southern 500kV transmission lines
Case 6	2005	Operation of Tanjung Jati B
Case 7	2005	Delay of southern 500kV transmission lines (Operation of Tanjung Jati B)

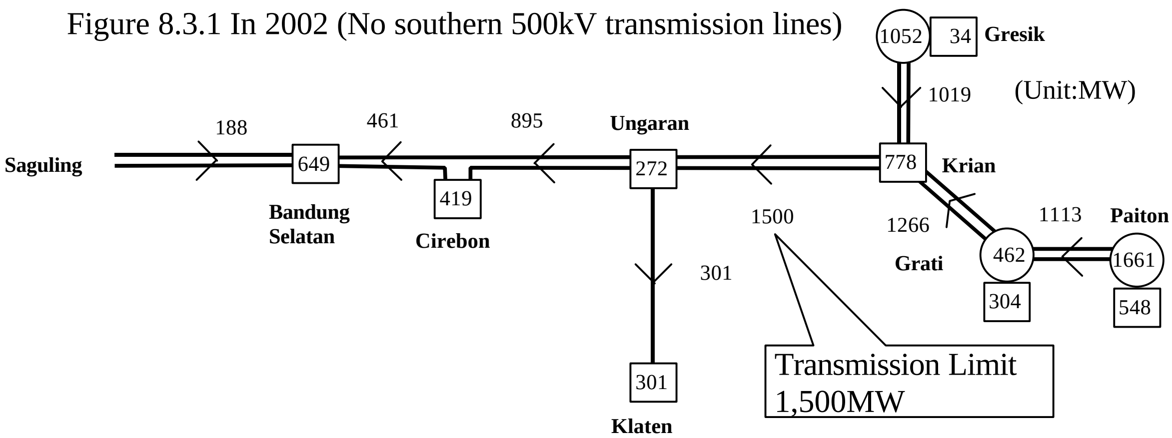
(1) Case 1 (In 2001: No southern 500kV transmission lines)

In 2002, without southern 500kV transmission lines, the power flow between Ungaran and Krian is restricted. The transmission limit is 1,500MW.

Table 8.3.1 Transmission limit in 2002(No southern 500kV transmission lines)

Worst fault		Transmission limit	
Fault Transmission line	Fault terminal	Section	Power flow
Ungaran – Krian	Krian	Ungaran - Krian	1,500MW

Figure 8.3.1 In 2002 (No southern 500kV transmission lines)



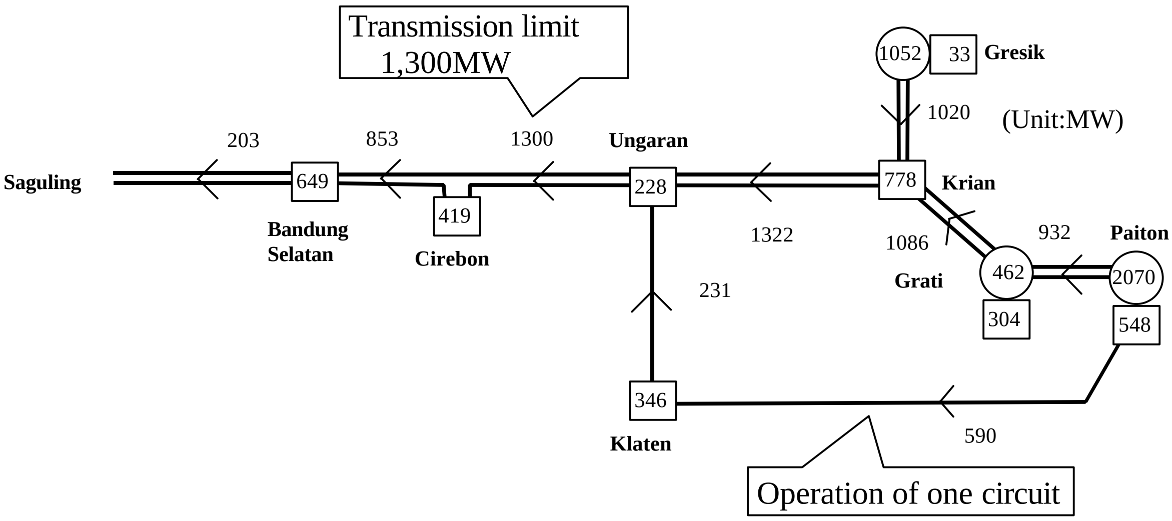
(2) Case 2 (In 2002: Operation of one circuit between Paiton and Klaten)

By bypassing the delayed Kediri substation and temporarily connecting at the Paiton Power Station, the one circuit between Paiton and Klaten has been in operation since April 2002. In this case, the power flow between Ungaran and Cirebon is restricted, and the transmission limit is 1,300MW.

Table 8.3.2 Transmission Limit in 2002(Operation of one circuit between Paiton and Klaten)

Worst fault		Transmission limit	
Fault Transmission line	Fault terminal	Section	Power flow
Cirebon- Ungaran	Ungaran	Cirebon - Ungaran	1,300MW

Figure 8.3.2 In 2002 (Operation of one circuit between Paiton and Klaten)



(3) Case 3 (In 2003: Operation of two circuits between Paiton and Klaten)

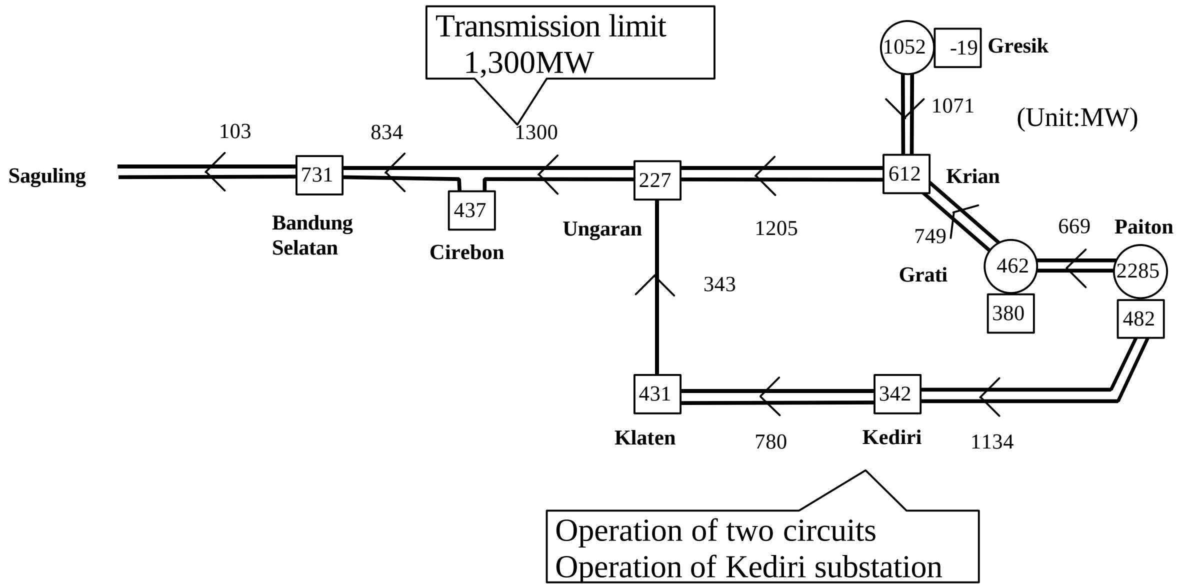
In 2003, the two circuits of the transmission lines between Paiton and Klaten will be completed, but the transmission limit is the same as in the case of one circuit.

The transmission limit between Ungaran and Cirebon is 1,300MW.

Table 8.3.3 Transmission limit in 2003
(Operation of two circuits between Paiton and Klaten)

Worst fault		Transmission limit	
Fault Transmission line	Fault terminal	Section	Power flow
Cirebon-Ungaran	Ungaran	Cirebon-Ungaran	1,300MW

Figure 8.3.3 In 2003 (Operation of two circuits between Paiton and Klaten)



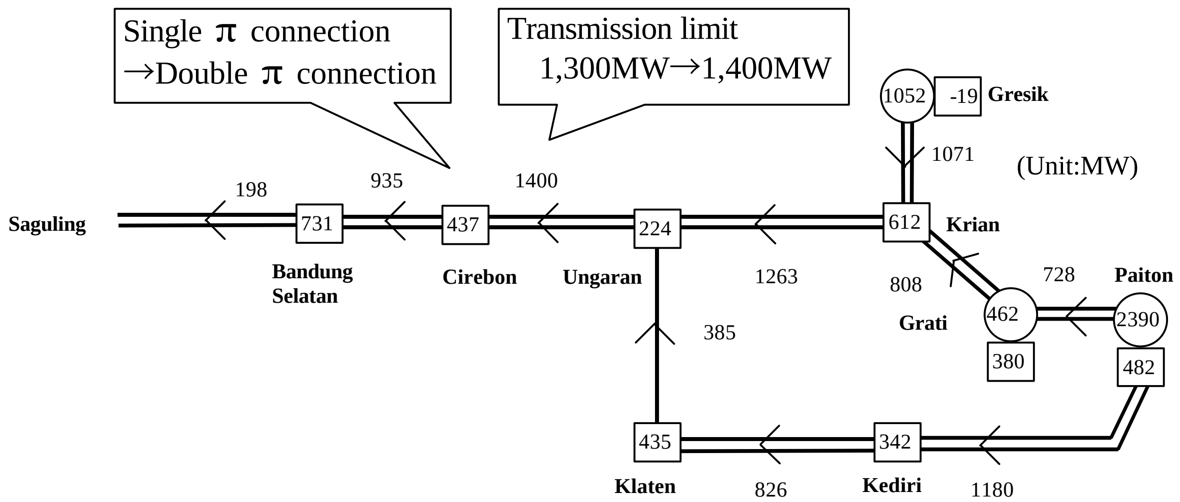
(4) Case 4 (In 2003: After double π connection at Cirebon)

By changing the connection of the 500kV transmission line at Cirebon substation from single π configuration to double π configuration, the transmission restriction will be relieved. The effect of double π connection is about 100MW, and the transmission limit will be improved to 1,400MW

Table 8.3.4 Transmission limit in 2003 (Double π connection at Cirebon)

Worst fault		Transmission limit	
Fault Transmission line	Fault terminal	Section	Power flow
Cirebon - Ungaran	Ungaran	Cirebon - Ungaran	1,400MW

Figure 8.3.4 In 2003 (Double π connection at Cirebon)



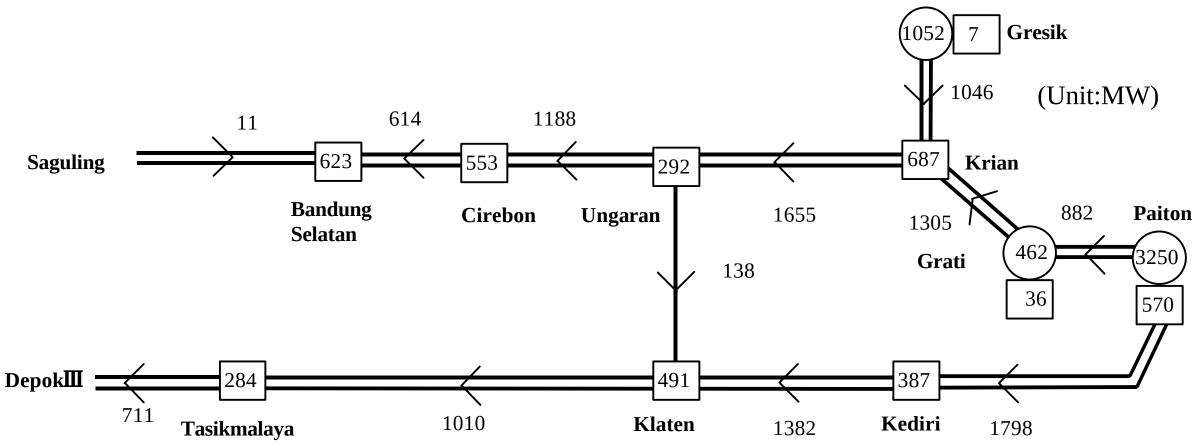
(5) Case 5 (In 2004: Operation of entire southern 500kV transmission lines)

In 2004, the entire southern 500kV transmission lines from Paiton to Depok III are planned to be completed. After completion of the entire southern 500kV transmission lines, the restriction caused by stability will be removed.

Table 8.3.5 Transmission limit in 2004 (Operation of entire southern 500kV transmission lines)

Worst fault	Transmission limit
-	No restriction

Figure 8.3.5 In 2004 (Operation of entire southern 500kV transmission lines)



(6) Case 6 (In 2005: Operation of Tanjung Jati B)

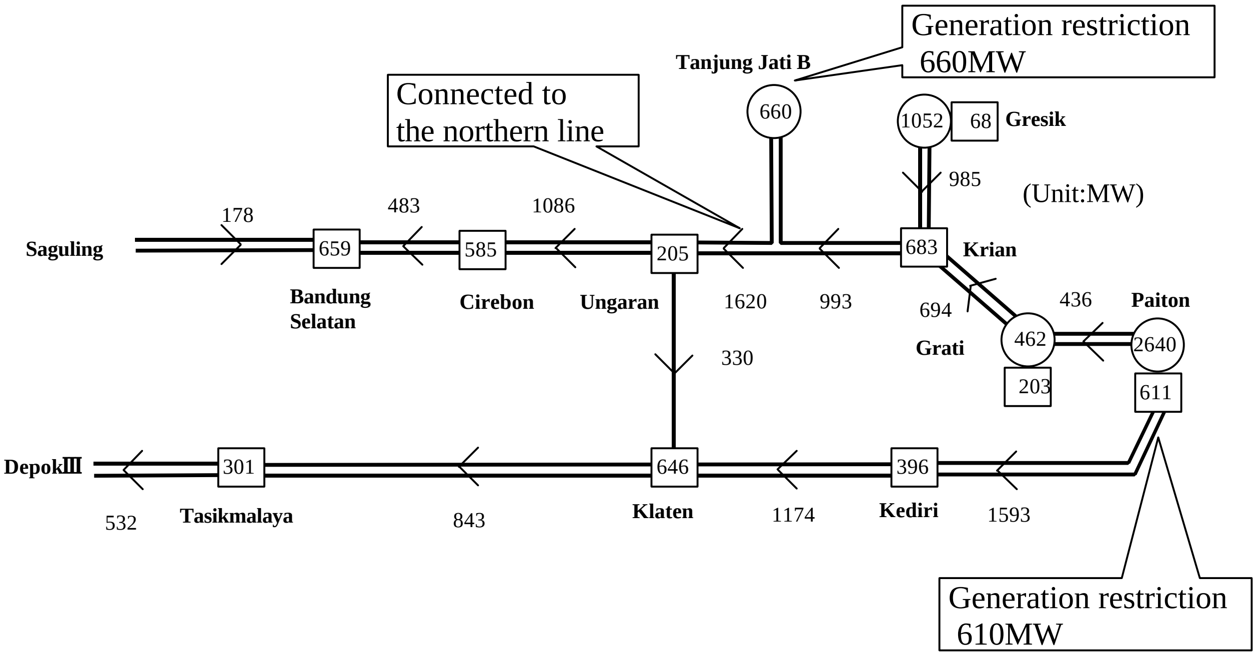
After completion of the entire southern 500kV transmission lines, if the 500kV transmission line from Tanjung Jati B is connected to the northern 500kV transmission line near Pruwodadi, one generator at Paiton and one generator at Tanjung Jati B will be restricted, because the system become unstable with the fault of the transmission lines between Krian and Ungaran, and between Tanjung Jati B and Ungaran.

Table 8.3.6 Generation restriction in 2004

(Operation of Tanjung Jati B: Connected to the northern line)

Worst fault		Generation limit	
Fault Transmission line	Fault terminal	Power station	Power flow
Krian- Ungaran	Krian	Paiton	610MW
Tanjung Jati B - Ungaran	Tanjung Jati B	Tanjung Jati B	660MW
-	-	Total	1,270MW

Figure 8.3.6 In 2005 (Operation of Tanjung Jati B :Connected to the northern line)

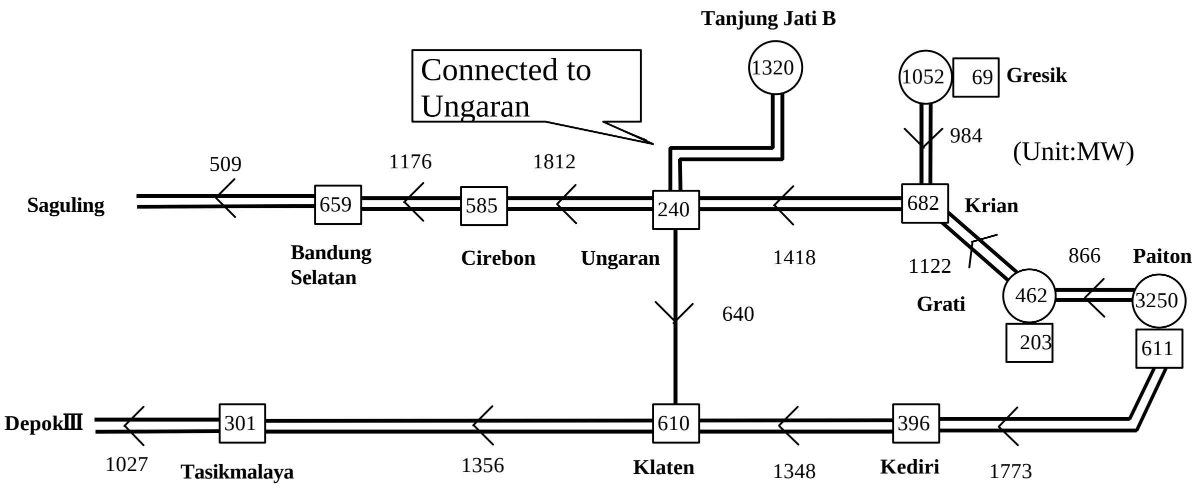


Therefore, completion of the transmission line between Tanjung Jati B and Ungaran will be needed in 2005, and the generation restriction caused by stability will be removed.

Table 8.3.7 Transmission Limit in 2005
(Operation of Tanjung Jati B: Connected to Ungaran)

Worst fault	Transmission limit
-	No restriction

Figure 8.3.7 In 2005 (Operation of Tanjung Jati B :Connected to Ungaran)



(7) Case 7 (In 2005: Delay of southern 500kV transmission lines and operation of Tanjung Jati B)

If the southern 500kV transmission lines are delayed, the power flow between Ungaran and Cirebon will be restricted even if Tanjung Jati B is completed. If one unit at Tanjung Jati B is operated, the limit will be under 1,700MW. If two units at Tanjung Jati B are operated, the limit will be under 1,800MW.

If two units at Tanjung Jati B are shut down, the limit will be under 1,300MW.

Table 8.3.8 Transmission limit in 2005 (Delay of southern 500kV transmission lines and Operation of Tanjung Jati B)

Worst fault		Transmission limit	
Fault Transmission line	Fault terminal	Power station	Power flow
Cirebon - Ungaran	Ungaran	Cirebon - Ungaran	1,300～1,800MW

Figure 8.3.8 Delay of southern transmission lines (Operation of Tanjung Jati B: one unit)

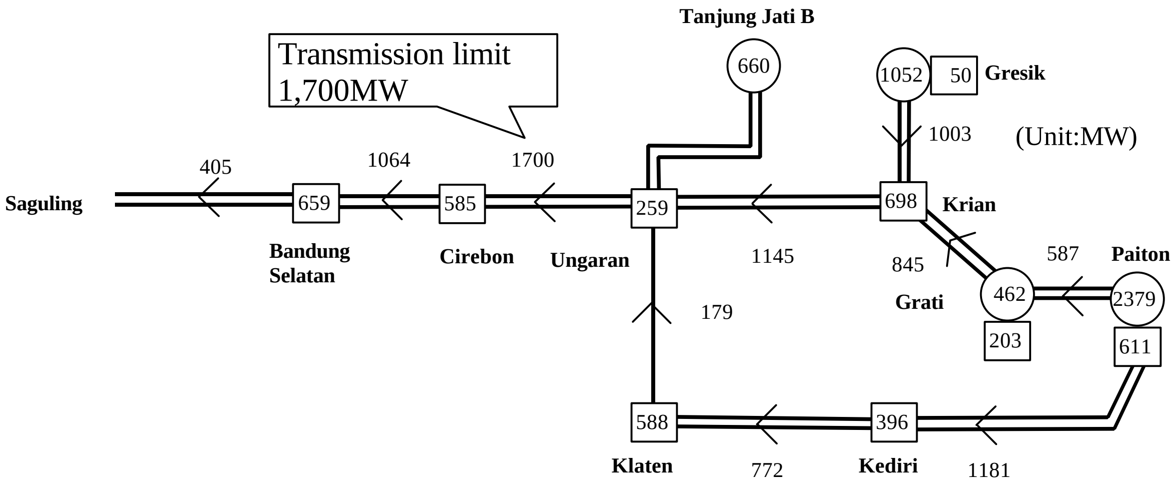
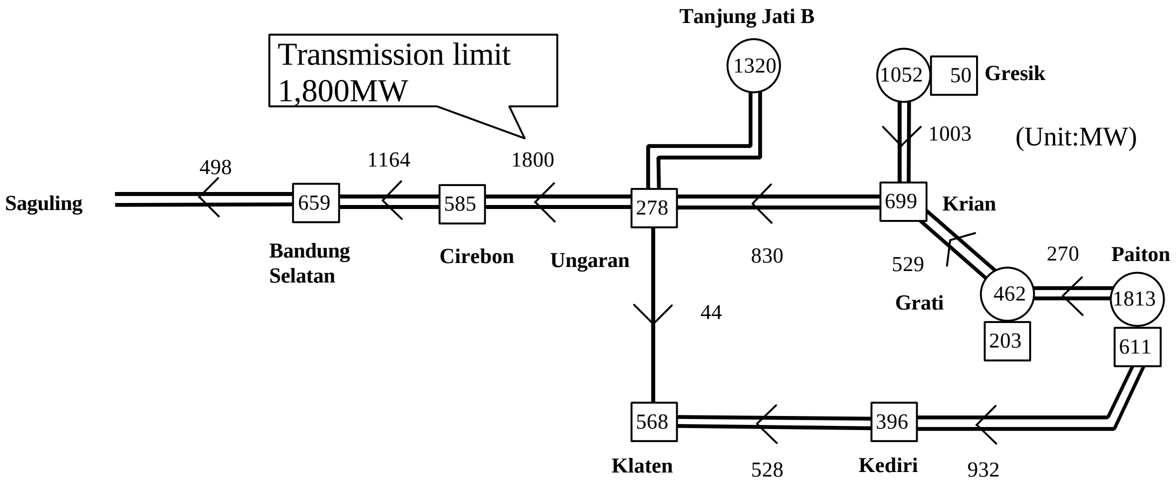


Figure 8.3.9 Delay of southern transmission lines (Operation of Tanjung Jati B: two units)



8.3.3 Transmission Planning for Repowering at the Muara Karang Power Station

Transmission planning is studied for the Muara Karang Power Station (existing capacity: 1,209MW) in northern Jakarta, where repowering (capacity increase: 420MW) is expected in 2006 and 2007.

(1) Results of power flow analysis

The results of the power flow analysis after repowering are shown in Figure 8.3.10 and Figure 8.3.11.

Even though the power flow through the 150kV transmission lines between Muara Karang and Duri Kosambi (two routes), and between Duri Kosambi and Petukangan will be great at peak load, generation at the Muara Karang Power Station will not need to be restricted even when there is a fault with one circuit of the transmission lines (see. Table 8.3.9).

However, during off-peak periods (the load is 70% of the peak load) generation at the Muara Karang Power Station will need to be restricted when there is a fault with one circuit of the transmission lines (see Table 8.3.10).

(It has to be recognized that the amount of restriction depends largely on the demand forecast for that area. The demands of the substations for power flow analysis are forecasted based on the power flow diagram in "PENGUSAHAAN SISTEM JAWA BALI 2001" and the demand forecast for the entire Java Bali system (Case 1).)

The following measures can be considered for removing this restriction.

(A) Reinforcement of the existing 150kV transmission lines between Muara Karang and Duri Kosambi (2 routes), and between Duri Kosambi and Petukangan by reconductoring to sag suppression electric conductors (such as thermo-resistant ACSR, gap-type ACSR and extra thermo-resistant aluminum alloy conductor galvanized invar-reinforced series).
(Economical comparisons should be studied in detail to select the best type of sag suppression electric conductors.)

(B) Expansion of the 150kV system to increase the demand that is directly supplied from Muara Karang and Duri Kosambi along with the demand increase in Jakarta city.

(A) would be a drastic measure. (B) would be an efficient measure, if it were also used as a measure against the demand increase in Jakarta city. It is difficult to remove the entire restriction during off-peak only with (B). Therefore it is more desirable to adopt (A) as a drastic measure. However, in light of the following items, consideration should be given to reducing the amount of generation restriction with (B), and to cope with N-1 contingency by operational spinning reserve.

- There will be no restrictions at peak load, and no restrictions during off-peak without contingency.
- It will be possible to reduce generation at Muara Karang during off-peak periods, because it is a power station intended for middle and peak loads.
- The amounts of generation restrictions will decrease if periodic inspections and repairs are taken into consideration.
- The amounts of generation restrictions will decrease in accordance with the demand increase in the area.

Figure 8.3.10 Normal condition (Peak in 2007)

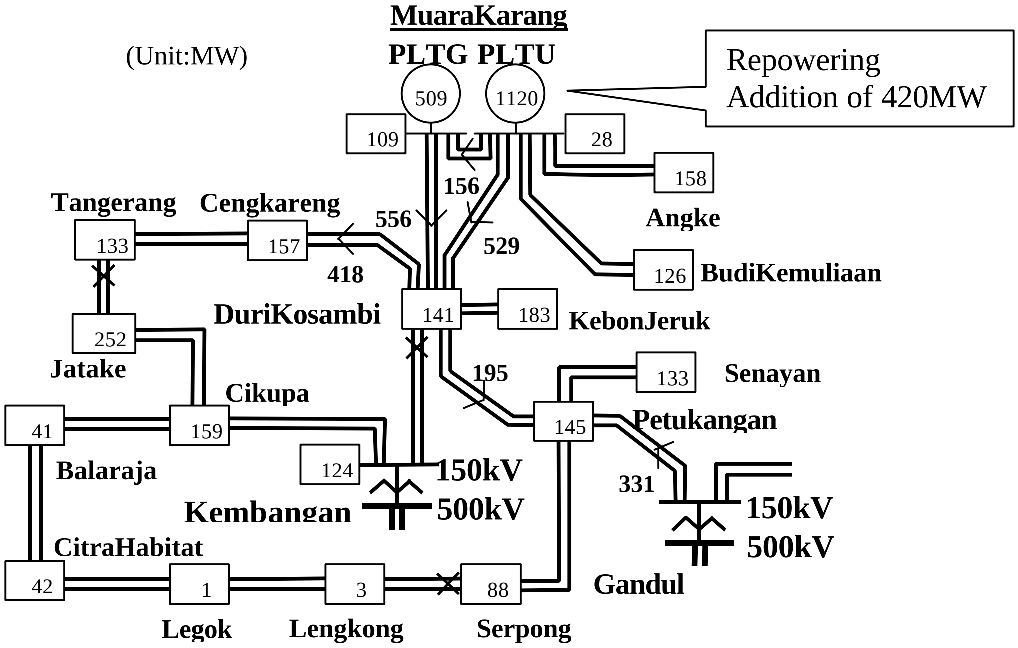


Table 8.3.9 Power flow in normal condition and with N-1 contingency (Peak in 2007)

Contingency	Transmission lines	Capacity (MVA)	Power flow (MW)	Availability Factor*1	Restriction of generation (MW)
Normal	M.K. PLTU-D.Kosambi	810 (2×405)	529	69%	0
	M.K. PLTGU-D.Kosambi	810 (2×405)	556	72%	0
	D.Kosambi-Petukangan	810 (2×405)	195	25%	0
M.K. PLTU -D.Kosambi 1cct-fault	M.K. PLTU-D.Kosambi	405 (1×405)	351	91%	0
	M.K. PLTGU-D.Kosambi	810 (2×405)	734	95%	0
	D.Kosambi-Petukangan	810 (2×405)	193	25%	0
M.K. PLTGU -D.Kosambi 1cct-fault	M.K. PLTU-D.Kosambi	810 (2×405)	710	92%	0
	M.K. PLTGU-D.Kosambi	405 (1×405)	376	98%	0
	D.Kosambi-Petukangan	810 (2×405)	193	25%	0
D.Kosambi -Petukangan 1cct-fault	M.K. PLTU-D.Kosambi	810 (2×405)	529	69%	0
	M.K. PLTGU-D.Kosambi	810 (2×405)	556	72%	0
	D.Kosambi-Petukangan	405 (1×405)	195	51%	0

*1 : Calculated on the assumption that the power factor is 95%.

Figure 8.3.11 Normal condition (Off-peak in 2007)

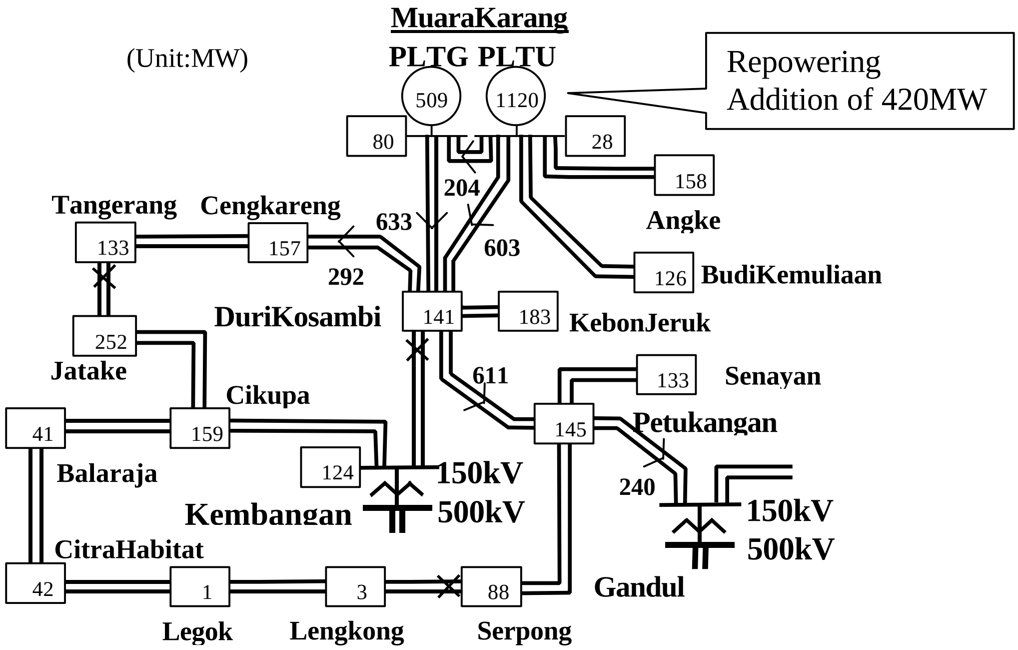


Table 8.3.10 Power flow in normal condition and with N-1 contingency (Off-peak in 2007)

Contingency	Transmission lines	Capacity (MVA)	Power flow (MW)	Availability Factor*1	Restriction of generation (MW)
Normal	M.K. PLTU-D.Kosambi	810 (2×405)	603	78%	0
	M.K. PLTGU-D.Kosambi	810 (2×405)	633	82%	0
	D.Kosambi-Petukangan	810 (2×405)	611	79%	0
M.K. PLTU -D.Kosambi 1cct-fault	M.K. PLTU-D.Kosambi	405 (1×405)	**400**	**104%**	**46**
	M.K. PLTGU-D.Kosambi	810 (2×405)	**837**	**109%**	**101**
	D.Kosambi-Petukangan	810 (2×405)	608	75%	0
M.K. PLTGU -D.Kosambi 1cct-fault	M.K. PLTU-D.Kosambi	810 (2×405)	**809**	**105%**	**59**
	M.K. PLTGU-D.Kosambi	405 (1×405)	**428**	**111%**	**130**
	D.Kosambi-Petukangan	810 (2×405)	608	79%	0
D.Kosambi -Petukangan 1cct-fault	M.K. PLTU-D.Kosambi	810 (2×405)	603	78%	0
	M.K. PLTGU-D.Kosambi	810 (2×405)	633	82%	0
	D.Kosambi-Petukangan	405 (1×405)	**608**	**158%**	**223**

*1: Calculated on the assumption that the power factor is 95%.

(2) Results of stability analysis

The results of the stability analysis show that there will be no problems after the Muara Karang repowering. However, the stability will be severe in case of the transmission line fault between Muara Karang and Duri Kosambi, so loop operation between Tangerang and Jatake could be possible to improve stability.

(3) Results of short circuit analysis

Table 8.3.11 shows the results of short circuit analysis. After repowering of the Mura Karang Power Station, the situation will be very severe in the Gandul 150kV subsystem in terms of short circuit capacity. Therefore, a split operation of the 150kV system and upgrading of the facilities will be needed.

Table 8.3.11 Short circuit current (Unit:kA)

	Nominal short circuit current*1	Short circuit current*2							
		2006 (Before Repowering)				2007 (After Repowering)			
		Case1	Case2	Case3	Case4	Case1	Case2	Case3	Case4
M.KarangBaru (PLTGU)	40	37	31	30	26	**43**	37	36	32
M.KarangLama (PLTU)	31.5	**37**	31	30	26	**44**	**37**	**36**	**32**
DuriKosambi	31.5	**42**	31	30	25	**46**	**36**	**34**	30
Petukangan	40	34	31	28	26	36	33	30	29
Gandul150kV	40	40	40	32	32	**42**	**41**	34	33
Kembangan150kV	40	**41**	27	27	22	**45**	27	27	22

*1 Source: "TINJAUAN SISTEM JAWA BALI TAHUN 2002-2006" October 2001 PLN

*2 The transient reactance (Xd') of the generators are used

Table 8.3.12 Cases for short circuit analysis(Conditions of circuit breakers)

	Case1	Case2	Case3	Case4
Kembangan - DuriKosambi	On	Off	Off	Off
Tangerang - Jatake	On	On	On	Off
Gandul150kV - Cibinong150kV	On	On	Off	Off
Gandul150kV - Cawang150kV	Off	Off	Off	Off

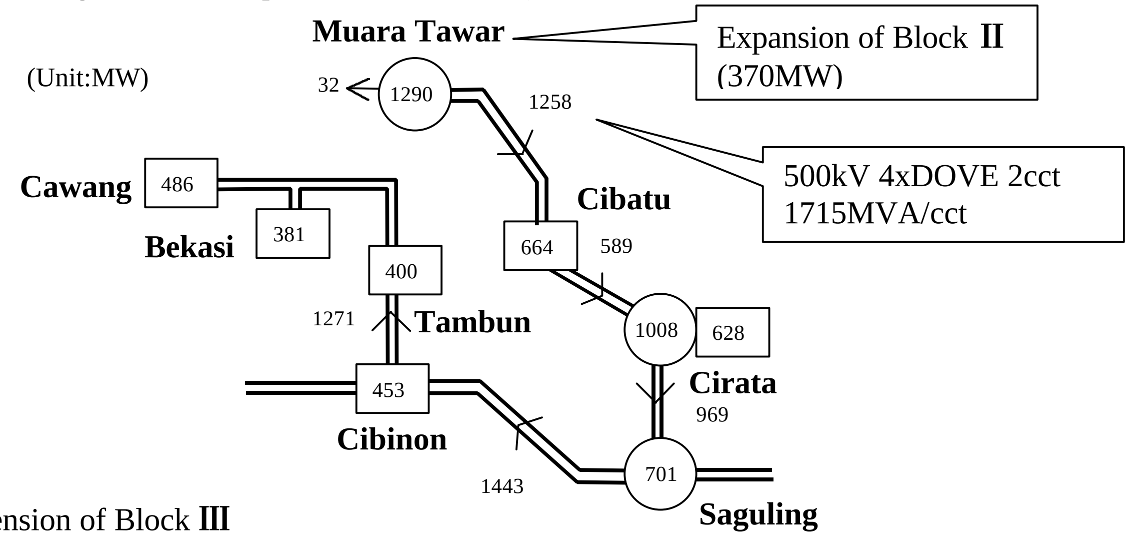
8.3.4 Transmission Planning for Muara Tawar Power Station

Transmission planning is studied for the Muara Tawar Power Station (existing capacity : 920MW) near Jakarta, where the expansion of Block Ⅱ (370MW) or the extension of Block Ⅲ(750MW) is expected in 2006 and 2007.

(1) Expansion of Block Ⅱ

Figure 8.3.12 shows the expected power flow diagram at peak load in 2007 after expansion of Block Ⅱ(370MW). The power flow of each transmission line will be within the thermal capacity of one circuit, therefore there will be no overload even when there is a fault with one circuit. There will also be no problems in regard to stability.

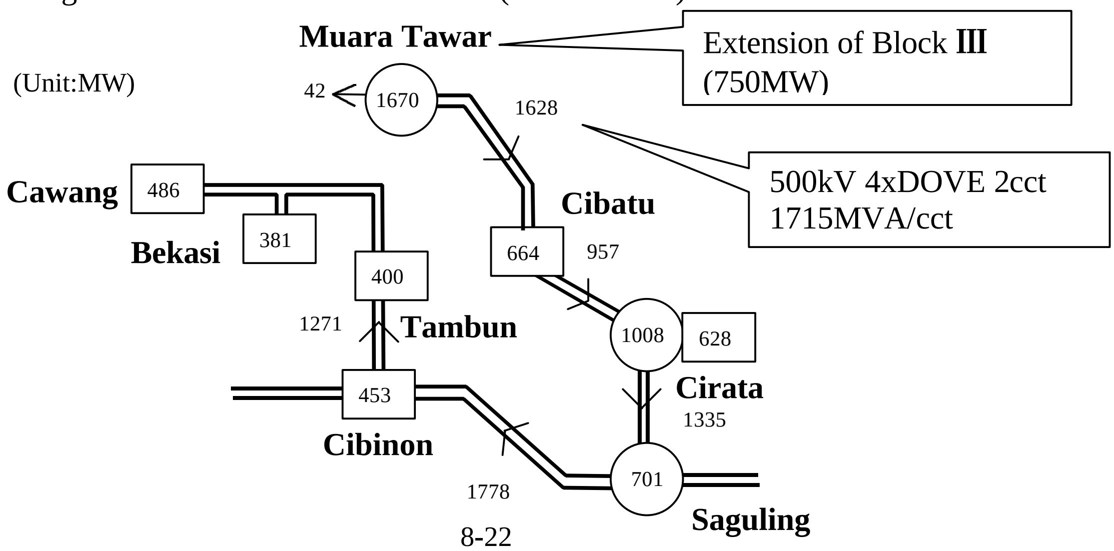
Figure 8.3.12 Expansion of Block Ⅱ(Peak in 2007)



(2) Extension of Block Ⅲ

Figure 8.3.13 shows the expected power flow diagram at peak load in 2007 after extension of Block Ⅲ(750MW). The power flow of each transmission line will be within the thermal capacity of one circuit, therefore there will be no overload even when there is a fault with one circuit. There will also be no problems in regard to stability.

Figure 8.3.13 Extension of Block Ⅲ(Peak in 2007)



(3) Expansion of Block Ⅱ and Extension of Block Ⅲ (reference)

Figure 8.3.14 shows the expected power flow diagram, in case the Block Ⅱ is expanded (370MW) and the Block Ⅲ is extended (750MW) in 2007. In this case, the power flow between Muara Tawar and Cibatu will be great. Therefore, in the event of a fault with one circuit of the transmission line, the power flow will exceed the thermal capacity of one circuit, so it will be necessary to restrict generation at the Muara Tawar Power Station. The following measures can be considered for removing this restriction.

(A) Construction of a new 500kV transmission line from the Muara Tawar power station to the new 500kV Tambun substation (see Figure 8.3.15). With this measure, power generation by the extension of Block Ⅳ can also be transmitted.

(B) Reducing the power of Muara Tawar when there is a fault of the transmission line, and making use of the operational spinning reserve.

Block Ⅳ expansion plan should be considered to decide the measure.

Figure 8.3.14 Expansion of Block Ⅱ and Extension of Block Ⅲ (Without measure)

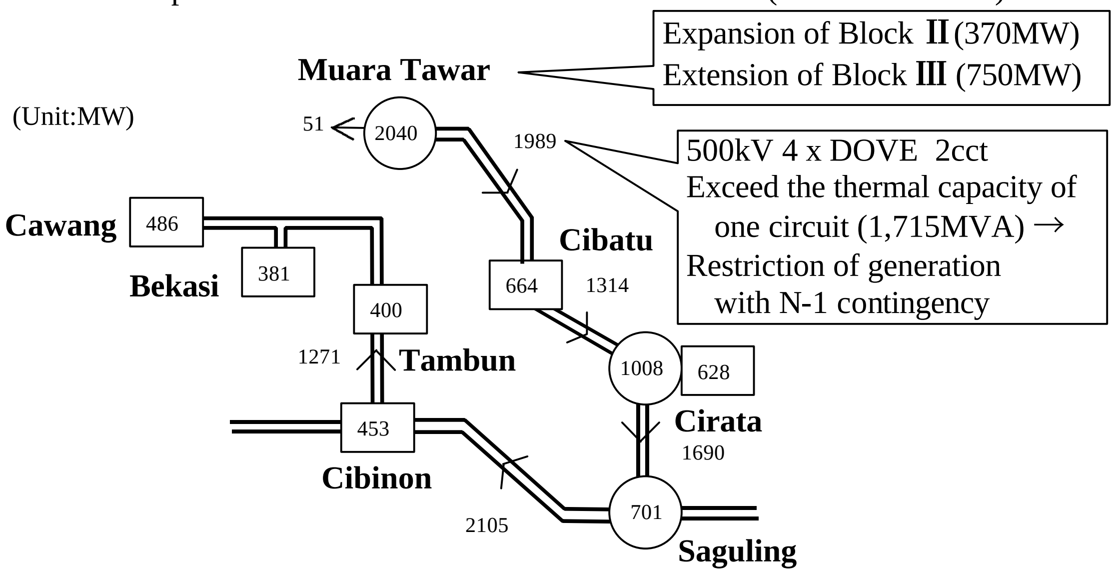
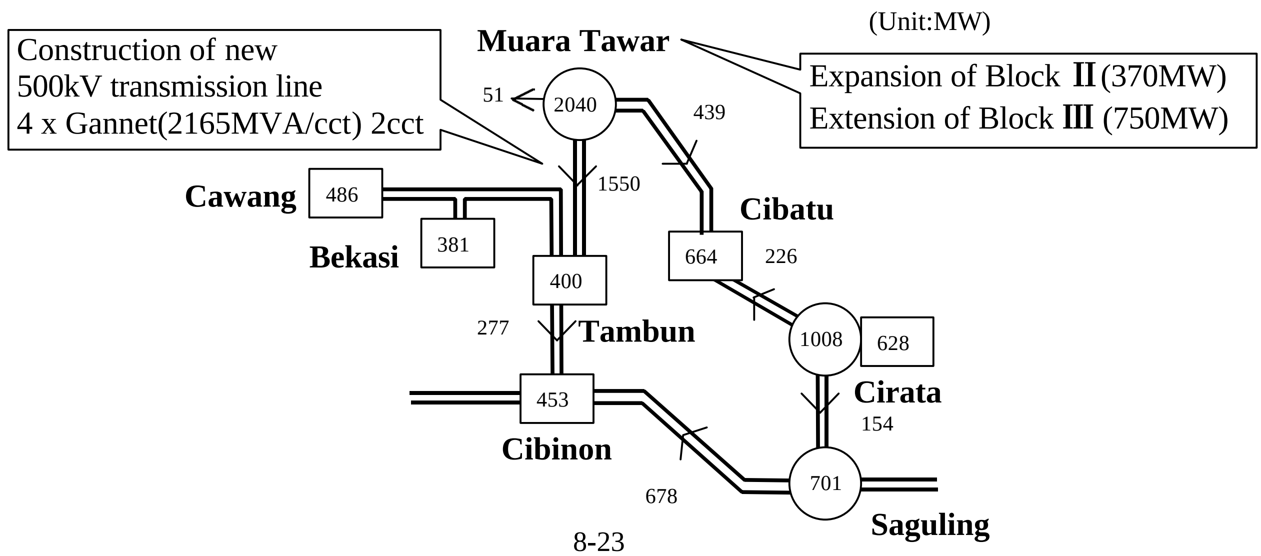


Figure 8.3.15 Expansion of Block Ⅱ and Extension of Block Ⅲ (With measure)



8.3.5 Short Circuit Capacity

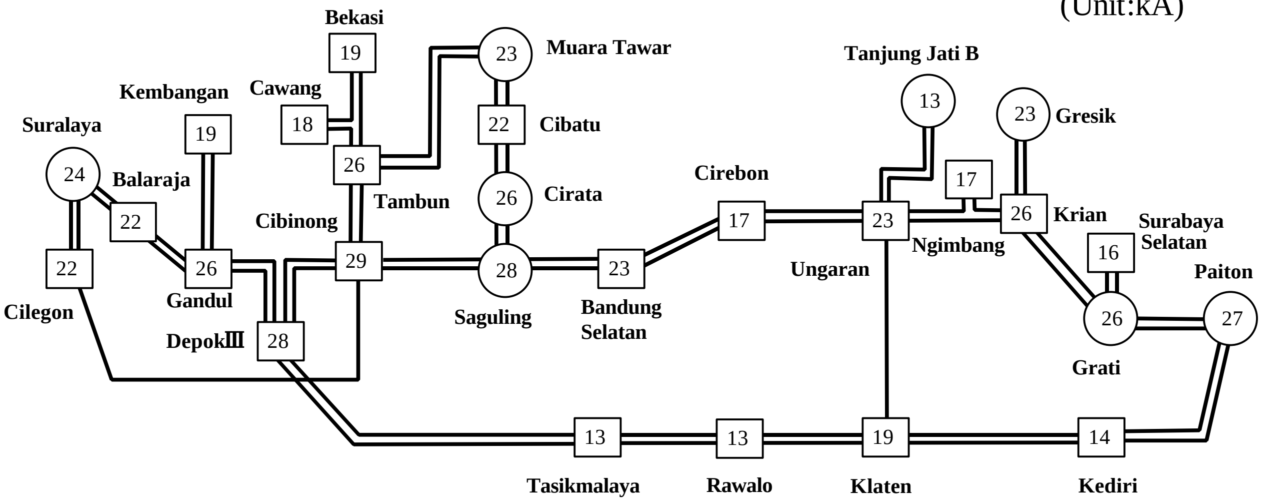
Figure 8.3.16 shows the result of a short circuit analysis in the 500kV Java Bali system in 2007. There will be no problem in terms of short circuit capacity in the 500kV system.

The conditions for short circuit analysis are as follows.

- All generators in 500kV system are considered
- Large scale thermal power stations (Gresik, Grati, Muara Karang, Tanjung Priok, Tambak Rolok) are considered
- In terms of new power stations, Tanjung Jati B, repowering of Muara Karang and expansion of Muara Tawar(Block Ⅲ) are considered
- All generators are connected to the system
- The transient reactance (Xd') are used for calculation, considering fault clearing time of circuit breaker
- The data from P3B are used in terms of the short circuit current from 150kV subsystems (except the large scale thermal power stations)

Figure 8.3.16 Short Circuit Current (2007)

(Unit:kA)



However, according to "TINJAUAN SISTEM JAWA BALI TAHUN 2002-2006", the short circuit currents will exceed the nominal short circuit currents of equipment at 32 substations in the 150kV and 70kV systems. Therefore, the equipment of the substations will have to be replaced.

8.3.6 Frequency

By increasing the unit capacity of the generators, the benefit of economies of scale increases. But the larger the unit capacity of a generator becomes, the larger the drop in frequency and the amount of load shedding will be in the case of a generator failure.

At present, the largest unit in the Java Bali system is 615MW at Paiton. In 2005 the largest will be 660MW with the operation of Tanjung Jati B.

Through the least squares method and using the data of "EVALUASI OPERASI SISTEM TENAGA LISTRIK JAWA BALI 2000", the relation between the rate of generation loss(=(generation loss) /(system capacity)) and the drop of frequency in the Java Bali system is as follows:

$$\Delta f = 0.146 \times \Delta P$$

Figure8.3.17 Characteristic of frequency in Java Bali system

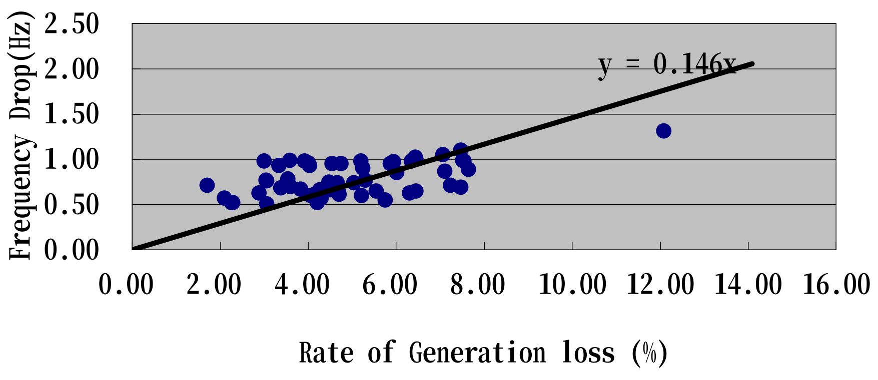


Table 8.3.13 shows the frequency drop that is calculated by this equation when the largest generator parallels out. It shows the amount of load shedding necessary for the frequency to recover to 49.5Hz.

Table 8.3.13 Frequency drop and load shedding

	2000		2005(Case1)	
	Peak	Minimum	Peak	Minimum
Load (MW)	12,231	3,936(32%)	16,185	5,179(32%)
Largest Unit (MW)	615(Paiton)		660(Tanjung Jati B)	
Frequency Drop (Hz)	△0.73	△2.28	△0.59	△1.86
Load shedding (MW)	203	497	109	500

8.3.7 Conclusions and Recommendations

(1) Removal of transmission restrictions in East Java

1) Completion of southern 500kV transmission lines

The entire southern 500kV transmission lines have to be completed to remove all the transmission restriction caused by system stability in East Java. These lines should be constructed as soon as possible.

The land acquisition problems near the DepokIII substation should be solved as soon as possible in order to complete the entire southern 500kV transmission lines in 2004.

If the land acquisition problems are not solved, a temporary connection of the southern 500kV transmission line to the northern 500kV transmission line near Bandung Selaten or near Upper Cisokan should be studied.

2) Double π connection at Crebon substation

After completion of the section from Paiton to Klaten, the power flow between Ungaran and Cirebon will be restricted by stability considerations. Therefore, the connection of the 500kV transmission line at the Cirebon substation should be changed from a single π configuration to a double π configuration to alleviate the transmission restrictions.

(2) Transmission planning for Tanjung Jati B Power Station

To stably transmit the power of the Tanjung Jati B Power Station, construction of a new transmission line between Tanjung Jati B and Ungaran will be needed.

The entire southern 500kV transmission lines have to be completed to remove the generation restriction caused by stability considerations at the Tanjung Jati B Power Station. Therefore, the entire southern 500kV transmission lines should be constructed in 2004.

(3) Transmission planning for repowering at Muara Karang Power Station

After repowering of the Muara Karang Power Station, its generation will be restricted when there is a fault with one circuit of the transmission lines. To remove this restriction, it is desirable to reinforce the existing 1,50kV transmission lines between Muara Karang and Duri Kosambi(two routes), and between Duri Kosambi and Petukangan by reconductoring to sag suppression electric conductors (such as thermo-resistant ACSR, gap-type ACSR and extra thermo-resistant aluminum alloy conductor galvanized invar-reinforced series).

However, considerations should be given to expanding the 150kV system in order to increase the demand that is directly supplied from Muara Karang and Duri Kosambi in accordance with the demand increase in Jakarta city. Therefore, this alternative should be studied in detail, including demand forecast for this area.

With respect to short circuit capacity, after the repowering of the Muara Karang Power Station, the situation will be very severe in the Gandul 150kV subsystem. Therefore, a split operation of the 150kV system and upgrading of the facilities will be needed.

(4) Transmission planning for Muara Tawar Power Station

With respect to the expansion of Block Ⅱ (370MW) and the extension of Block Ⅲ (750MW) at the Muara Tawar power station, the power can be transmitted by the existing 500kV transmission lines with N-1 contingency as long as one of the plans is carried out.

(5) Improvement of system stability

1) Using PSSs

At present, the PSSs(Power System Stabilizer) are not used at some power stations. Therefore, the PSSs should be adjusted and used to improve stability.

2) Adoption of differential relay for trunk lines

At present, two sets of distance relays are adopted to protect each 500kV transmission line in the Java Bali system. Single-phase reclosing by using PLC (Power Line Carrier) has also been adopted. Distance relays have been technically established and their reliability is relatively high, and so it is used in many countries.

Recently, optical fiber communications have been introduced in the Java Bali system, and so differential relay should be introduced to protect trunk lines in the future.

Differential relays have high reliability, and the fault clearing time can be shortened and multi-phase reclosing can be achieved by utilizing differential relays. In this manner stability can be improved.

(6) Largest generator unit in relation to system capacity

At present, the largest generator unit in the Java Bali system is 615MW at the Paiton Power Station. It is relatively large in comparison with the system capacity (13,041MW in 2001). Therefore, if a fault occurs at the largest generator, the frequency drops sharply and load shedding is needed.

There are plants to install two 660MW units at the Tanjung Jati B Power Station in 2005. If a larger capacity unit is installed, the amount of load shedding will increase. Thus, installation of a larger unit has to be carefully considered.

(7) Margin of the transmission stability limit

In this stability analysis, standard data are used for the generators. A 3-phase ground fault of one circuit is adopted, but generally a 1-phase ground fault for two circuits is a stricter fault. Only the peak-load is studied, and not off-peak load or minimum load.

Therefore, a sufficient transmission stability margin should be kept for system operations.

8.4 Transmission Planning (Mid- and Long-term)

Mid- and long-term transmission plans for 2010 (approximately 25,000MW) and for 2015 (approximately 35,000MW) are studied in this section, in order to cope with the power development until approximately 2015. The study accounts for the various distribution patterns for the new power stations (balanced development , development mainly in West Java, development mainly in East Java, development heavily in East Java).

8.4.1 Demand Forecasts

For transmission planning, Case 2 for which the rate of increase is larger in comparison with Case 1, was adopted. The demand for each area is as follows (see Figure 8.4.1).

Table 8.4.1 Demand forecast (Unit:MW)

	Area1	Area2	Area3	Area4	Total
2001	5,495 (42%)	2,316 (18%)	2,057 (16%)	3,173 (24%)	13,041 (100%)
2010	10,077 (41%)	4,543 (19%)	3,689 (15%)	5,988 (25%)	24,297 (100%)
2015	14,413 (41%)	6,601 (19%)	5,282 (15%)	8,504 (25%)	34,800 (100%)

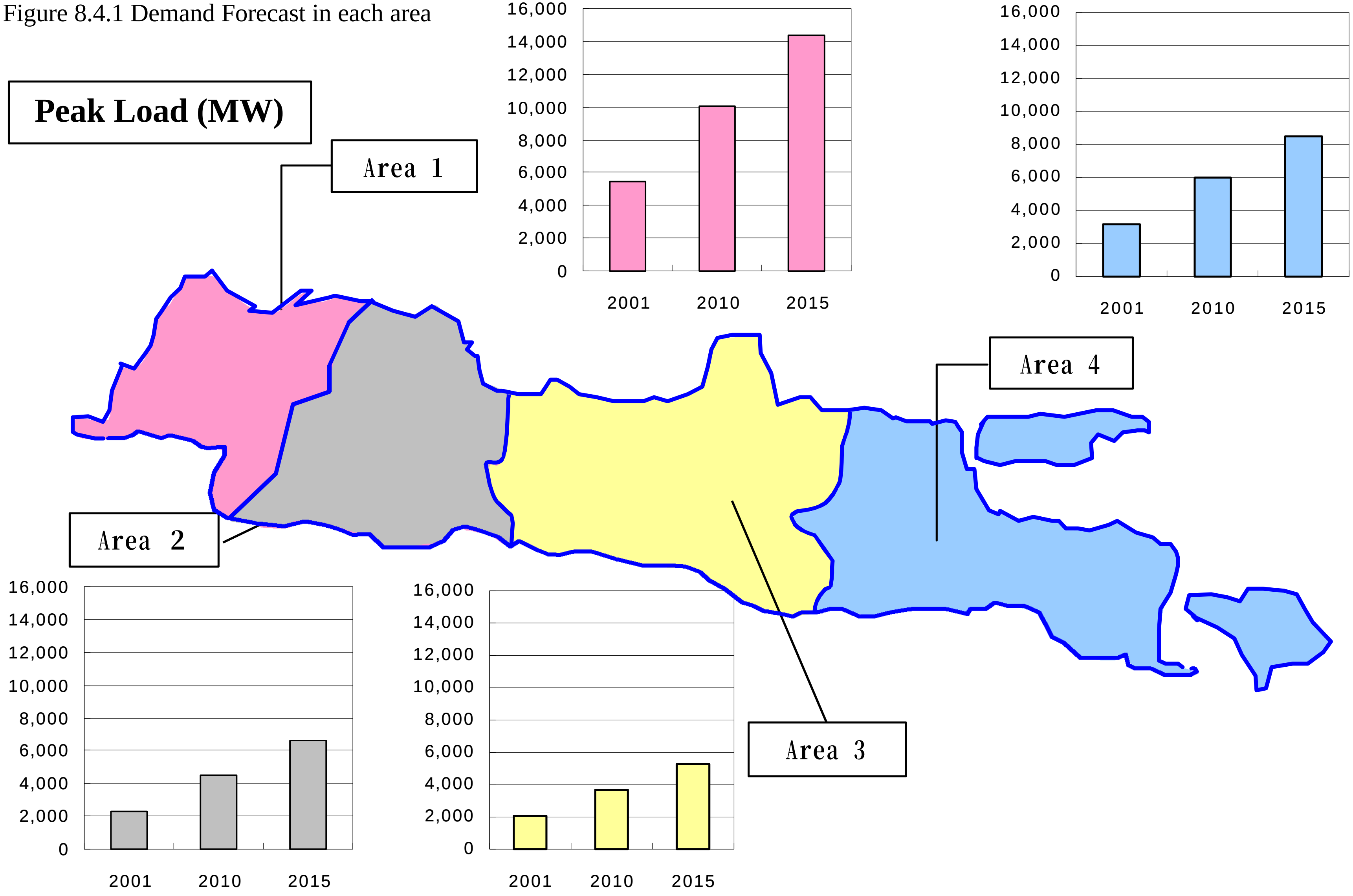
8.4.2 Power Development Plan

In terms of the power development plan, the Base Case (Demand-JICA/LPE Case2) was adopted for transmission planning.

Table 8.4.2 Power development plan for transmission planning

	2001-2010	2010-2015	Total
Coal (600MW)	12	17	29
Combined Cycle (600MW)	6	1	7
Gas Turbine (120MW)	6	2	8
Pumped Storage (250MW)	0	6	6

Figure 8.4.1 Demand Forecast in each area



8.4.3 Study Cases

The years 2010 and 2015 were studied for the transmission planning. The distribution of the new power stations is assumed as follows.

Table 8.4.3 Distribution patterns for the new power stations

Balance Case	The power stations are developed in accordance with the demand in each area
West Case	The power stations are developed mainly in West Java
East Case	The power stations are developed mainly in East Java
Heavy-East Case	The power stations are developed heavily in East Java

Table 8.4.4 Power development plan in each area (2001-2010) (Unit:MW)

			Area1	Area2	Area3	Area4	Total
Demand (2010)			10,077 (41%)	4,543 (19%)	3,689 (15%)	5,988 (25%)	24,297 (100%)
Generation	Existing (2001)		7,395 (40%)	2,373 (13%)	1,755 (9%)	7,005 (38%)	18,528 (100%)
	Balance Case	New	5,120 (**43%**)	3,600 (**31%**)	2,520 (**21%**)	600 (**5%**)	11,840 (100%)
		Total	12,515 (41%)	5,973 (20%)	4,275 (14%)	7,605 (25%)	30,368 (100%)
	West Case	New	8,720 (**74%**)	1,200 (**10%**)	1,920 (**16%**)	0 (**0%**)	11,840 (100%)
		Total	16,115 (53%)	3,573 (12%)	3,675 (12%)	7,005 (23%)	30,368 (100%)
	East Case	New	3,920 (**33%**)	2,400 (**20%**)	3,120 (**27%**)	2,400 (**20%**)	11,840 (100%)
		Total	11,315 (37%)	4,773 (16%)	4,875 (16%)	9,405 (31%)	30,368 (100%)
	Heavy East Case	New	2,720 (**23%**)	0 (**0%**)	3,720 (**31%**)	5,400 (**46%**)	11,840 (100%)
		Total	10,115 (33%)	2,373 (8%)	5,475 (18%)	12,405 (41%)	30,368 (100%)

Note : With respect to existing generation, reduction by repowering is considered.
(Muara Karang : Δ80)

Table 8.4.5 Power development plan in each area (2001-2015) (Unit:MW)

			Area1	Area2	Area3	Area4	Total
Demand (2015)			14,413 (41%)	6,601 (19%)	5,282 (15%)	8,504 (25%)	34,800 (100%)
Generation	Existing (2001)		7,295 (40%)	2,373 (13%)	1,655 (9%)	6,905 (38%)	18,228 (100%)
	Balance Case	New	10,160 (**41%**)	6,300 (**26%**)	4,320 (**18%**)	3,600 (**15%**)	24,380 (100%)
		Total	17,455 (41%)	8,673 (20%)	5,975 (14%)	10,505 (25%)	42,608 (100%)
	West Case	New	13,760 (**56%**)	5,100 (**21%**)	4,320 (**18%**)	1,200 (**5%**)	24,380 (100%)
		Total	21,055 (49%)	7,473 (18%)	5,975 (14%)	8,105 (19%)	42,608 (100%)
	East Case	New	8,960 (**37%**)	5,100 (**21%**)	4,920 (**20%**)	5,400 (**22%**)	24,380 (100%)
		Total	16,255 (38%)	7,473 (18%)	6,575 (15%)	12,305 (29%)	42,608 (100%)
	Heavy-East Case	New	5,360 (**22%**)	5,100 (**21%**)	5,520 (**23%**)	8,400 (**34%**)	24,380 (100%)
		Total	12,655 (30%)	7,473 (17%)	7,175 (17%)	15,305 (36%)	42,608 (100%)

Note : The generators that will be removed by 2015 are excluded from the existing generation(**Δ** 300).

Table 8.4.6 Power development plan in each area

(Unit:MW)

Area	Type	Name of Power Station	Unit No.	2010 Balance	2010 West	2010 East	2010 Heavy-East	2015 Balance	2015 West	2015 East	2015 Heavy-East
Area1	Coal	ST11	1	600	600			600	600	600	
			2	600	600			600	600	600	
			3		600			600	600		
		ST12	1		600			600	600	600	600
			2		600			600	600	600	600
			3								
		ST13	1		600			600	600	600	
			2		600			600	600	600	
			3		600			600	600		
		ST14	1						600		
			2						600		
			3						600		
		ST15	1						600		
			2						600		
			3								
		Sumatra	1					600	600	600	600
			2					600	600	600	600
			3						600		
	Combined Cycle	Muara Karang	Block 2	500	500	500	500	500	500	500	500
		Muara Tawar	Block 3	750	750	750	750	750	750	750	750
			Block 4	750	750	750	750	750	750	750	750
			Block 5	600	600	600		600	600	600	
			Block 6	600	600	600		600	600	600	
	GT			720	720	720	720	960	960	960	960
	PS										
	Subtotal			5,120	8,720	3,920	2,720	10,160	13,760	8,960	5,360
Area2	Coal	ST21	1	600		600		600	600	600	600
			2	600		600		600	600	600	600
			3	600		600		600	600	600	
		ST22	1	600	600	600		600	600	600	600
			2	600	600			600	600		600
			3	600				600	600		
		ST23	1					600		600	600
			2					600		600	600
			3								
		ST24	1								
			2								
			3								
	CC										
	GT										
	PS	Upper Cisokan						1,000	1,000	1,000	1,000
		PS21						500	500	500	500
	Subtotal			3,600	1,200	2,400	0	6,300	5,100	5,100	5,100
Area3	Coal	Tanjung Jati B	1	660	660	660	660	660	660	660	660
			2	660	660	660	660	660	660	660	660
			3	600		600	600	600	600	600	600
		ST31	1					600	600	600	
			2					600	600	600	
			3								
		ST32	1			600	600			600	600
			2			600	600			600	600
			3							600	
		ST33	1								600
			2								600
			3								
	Combined Cycle	CC31	1	600	600		600	600	600		600
			2					600	600		600
			3								
	GT										
	PS										
	Subtotal			2,520	1,920	3,120	3,720	4,320	4,320	4,920	5,520
Area4	Coal	Paiton	3	600		600	600	600	600	600	600
			4			600	600	600	600	600	600
		ST41-1	1			600	600	600		600	600
			2				600	600		600	600
			3				600			600	600
		ST41-2	1				600				600
			2				600				600
			3								
		ST42	1					600			
			2					600			
			3								
		ST43	1							600	600
			2							600	600
			3								
		ST44	1								600
			2								600
			3								600
	Combined Cycle	CC41	1			600	600			600	600
			2				600			600	600
			3								
	GT										
	PS										
	Subtotal			600	0	2,400	5,400	3,600	1,200	5,400	8,400
Total				11,840	11,840	11,840	11,840	24,380	24,380	24,380	24,380

Note : In terms of Muara Tawar Block3,4, the capacity of the unit is 2x750MW for transmission planning ,in spite of 2x600MW for WASP.

8.4.4 Conditions

The conditions for the study are as follows.

- Based on the N-1 rule that is adopted by PLN, transmission planning is developed to ensure that there are no interruptions in the power supply when there is a failure involving just one piece of the equipment (a failure of one circuit in the transmission line).

  Transmission planning is developed to accommodate stability when there is a transmission fault (3LG-O: 3-phase short circuit).
- Transmission planning is studied at the peak demand.
- The programs for system analysis and other conditions are the same as those used for short-term transmission planning (cf. 8.3.1 Programs and Conditions for System Analysis).
- Table 8.4.7 shows the ratio of periodic repair (PR) and balance stop (BS) of the generators for system analysis (power flow analysis, transient stability analysis).

With respect to the Balance Case, the ratios of PR and BS of the generators in each area are the same. With respect to the West Case, the ratio of PR and BS is 10% in West Java, considering the dispersion of PR and BS. With respect to the East and Heavy-East cases, the ratio of PR and BS is 10% in East Java for the same reason.

Table 8.4.7 Ratio of PR and BS of generators for study

	Area	Ratio of PR and BS
Balance Case	Area 1-4	20%
West Case	Area 1	10%
	Area 2-4	25-30%
East Case Heavy-East Case	Area 1-3	20-25%
	Area 4	10%

In this study, the power stations are assumed to be developed scattered in each area based on the location and the amount of the demand. Therefore, if the generation is developed heavily in one site, or if the generation and the demand are not balanced in each area, other countermeasures might be needed in the area.

8.4.5 Study Results

(1) Power flow diagram

Figures 8.4.2 to 8.4.13 show the power flow diagrams for each case (Balance, West, East, and Heavy-East) for 2010 and 2015.

(2) Summary

Table 8.4.8 shows the summary of the results.

Table 8.4.8 Summary of result

		Balance Case	West Case	East Case	Heavy-East Case (Without measure)	Heavy-East Case (With measure)
2010	Power flow	No problem	No problem	No problem	Generation interruption with a transmission fault	No problem
	Stability	Stable	Stable	Stable	Unstable	Stable
	Short Circuit	No problem	Need for Measure	No problem		No problem
	Transmission Losses	Small	Medium	Large		Largest
	500kV Third route	No need	No need	No need	Needed	
2015	Power flow	No problem	No problem	No problem	Generation interruption with a transmission fault	No problem
	Stability	Stable	Stable	Stable	Unstable	Stable
	Short Circuit	Need for Measure	Need for Measure	Need for Measure		Need for Measure
	Transmission Losses	Small	Medium	Large		Largest
	500kV Third route	No need	No need	No need	Needed	

Figure 8.4.2 Power Flow Diagram of Java-Bali system (2010 Balance case)

No problem on power flow, stability, and short circuit capacity

Unit:MW

The circles show the power stations,
and the rectangles show the substations.

The thick lines show the new facilities after 2005.

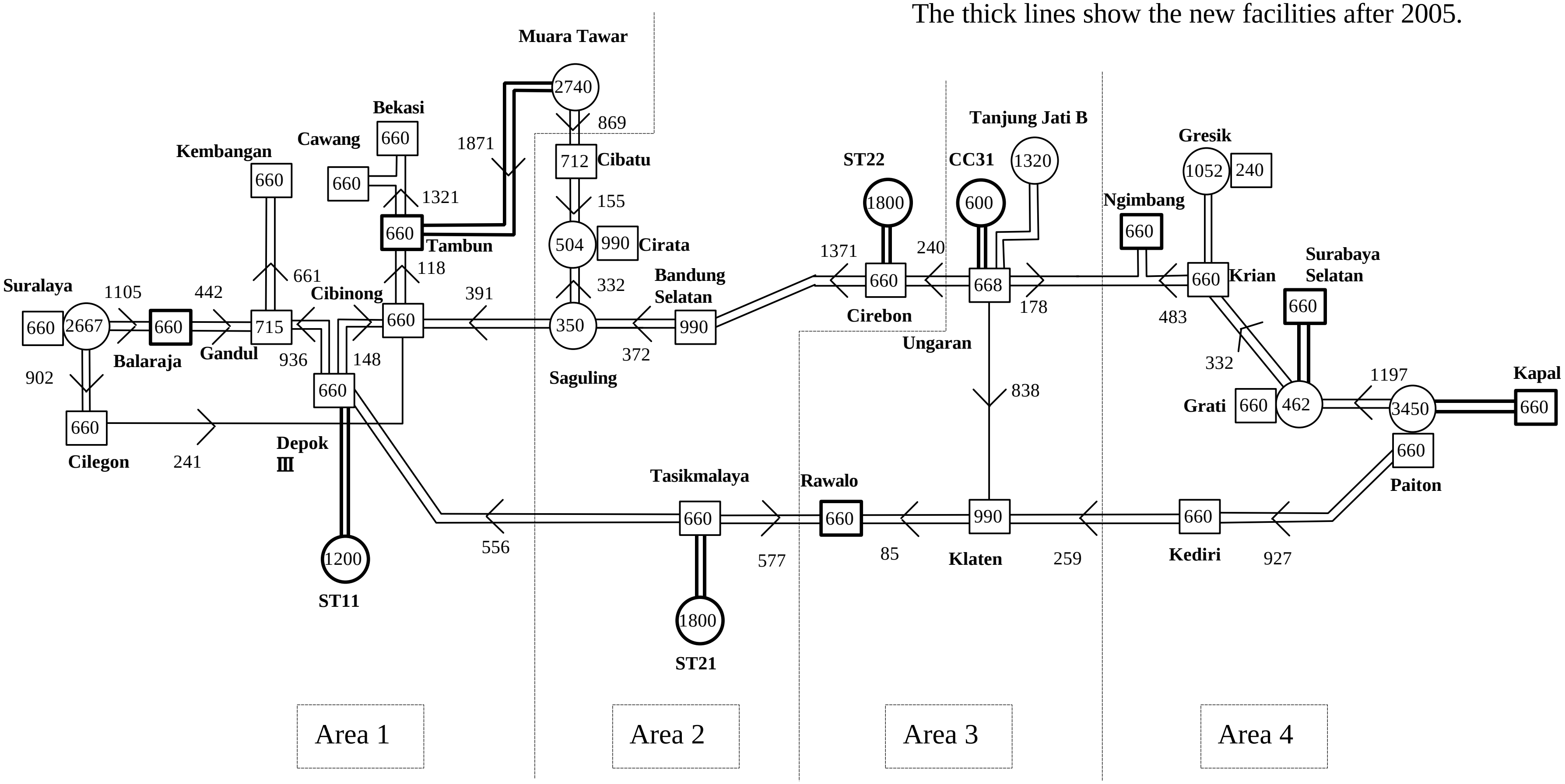


Figure 8.4.3 Power Flow Diagram of Java-Bali system (2010 West case)

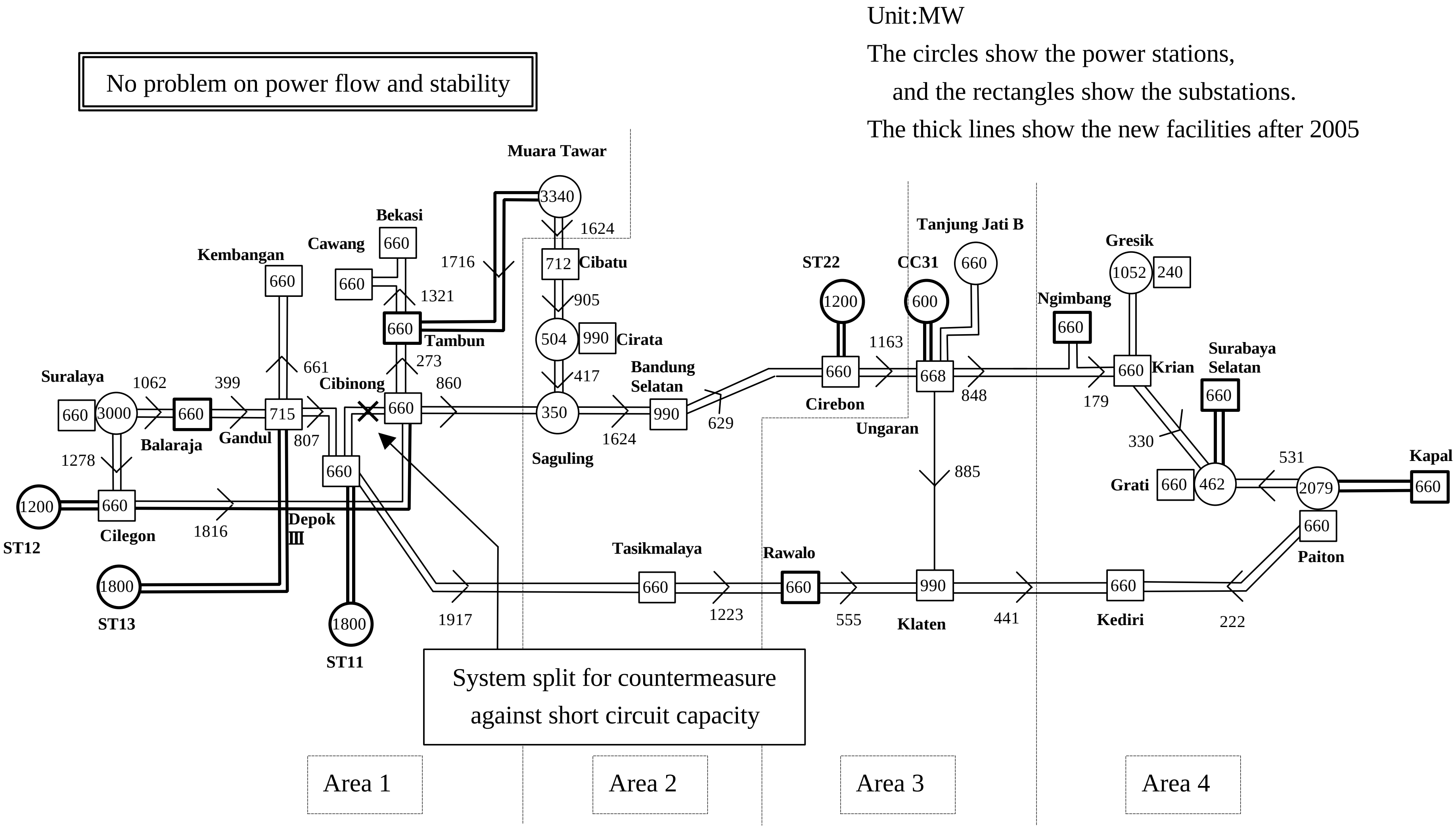


Figure 8.4.4 Power Flow Diagram of Java-Bali system (2010 East case)

Unit:MW

The circles show the power stations,

and the rectangles show the substations.

The thick lines show the new facilities after 2005.

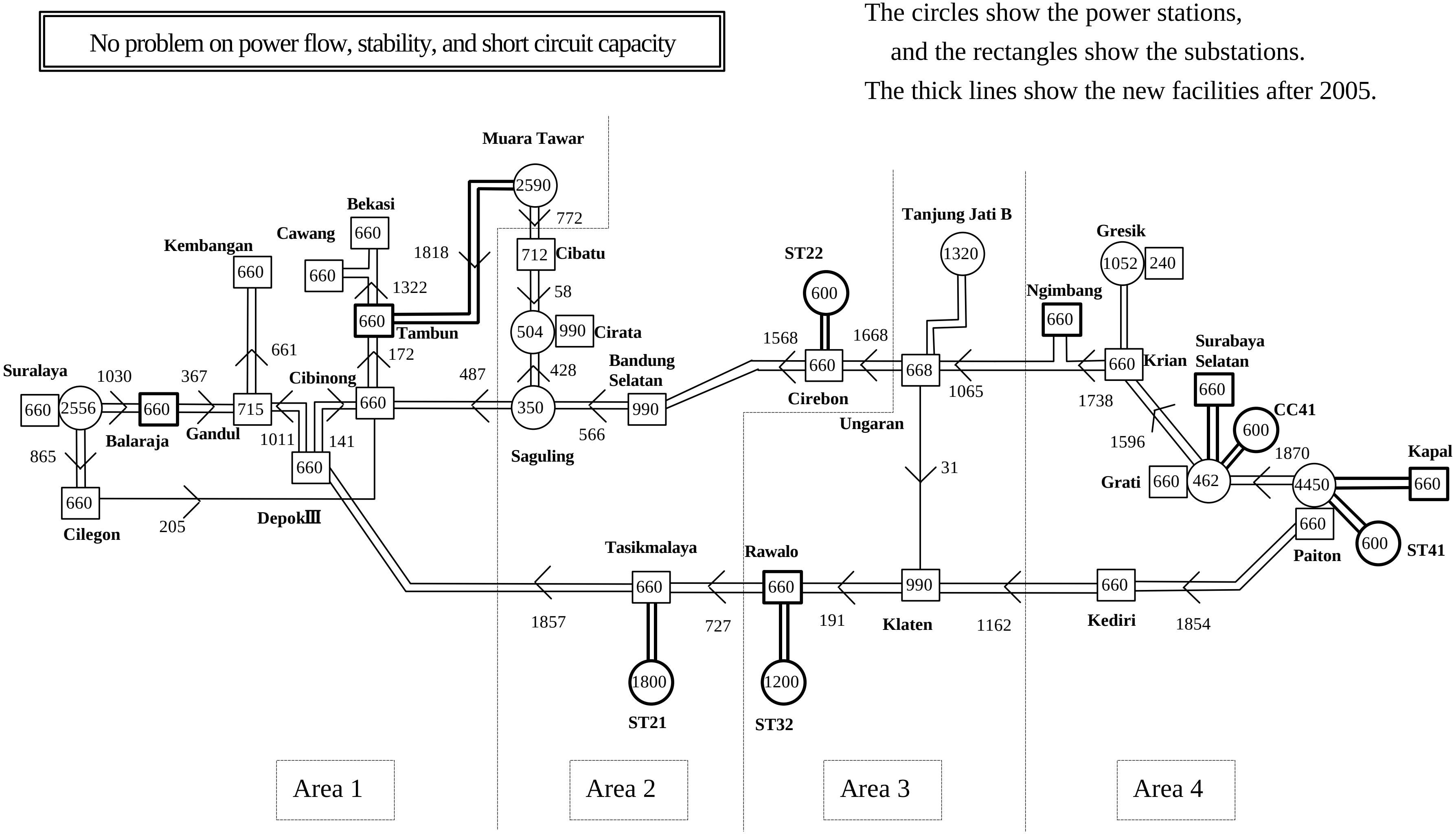


Figure 8.4.5 Power Flow Diagram of Java-Bali system (2010 East case2 (+1200MW at Paiton))

Unit:MW

The circles show the power stations,

and the rectangles show the substations.

The thick lines show the new facilities after 2005.

Blue color : Over stability limit

Green color : Over-load with one-circuit fault

Red color : Over stability limit and over-load with one-circuit fault

- Problems on power flow and stability
- No problem on short circuit capacity

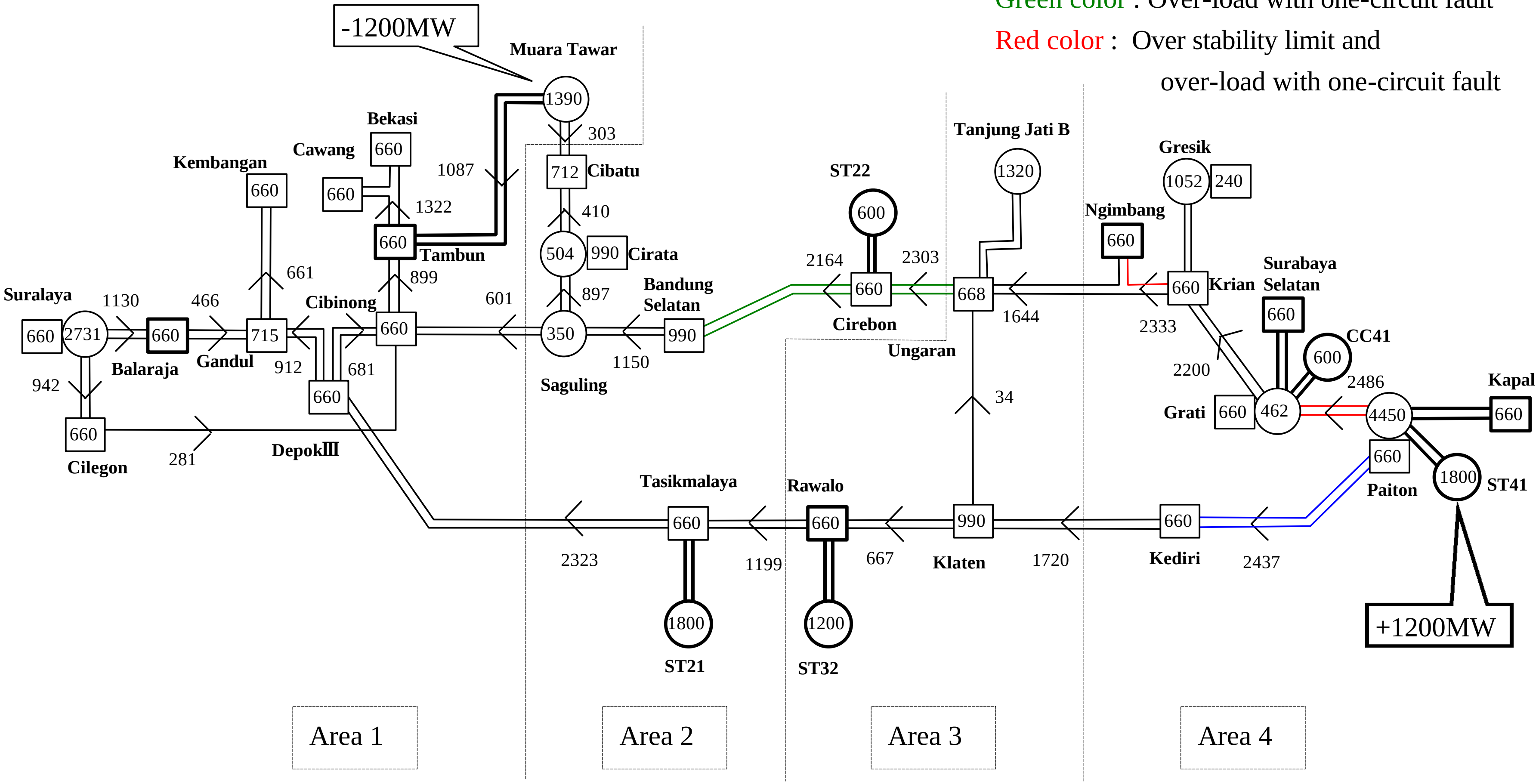


Figure 8.4.6 Power Flow Diagram of Java-Bali system (2010 Heavy-east case : without measures)

Unit:MW

The circles show the power stations,
and the rectangles show the substations.

The thick lines show the new facilities after 2005.

Blue color : Over stability limit

Green color : Over-load with one-circuit fault

Red color : Over stability limit and over-load with one-circuit fault

- Problems on power flow and stability
- No problem on short circuit capacity

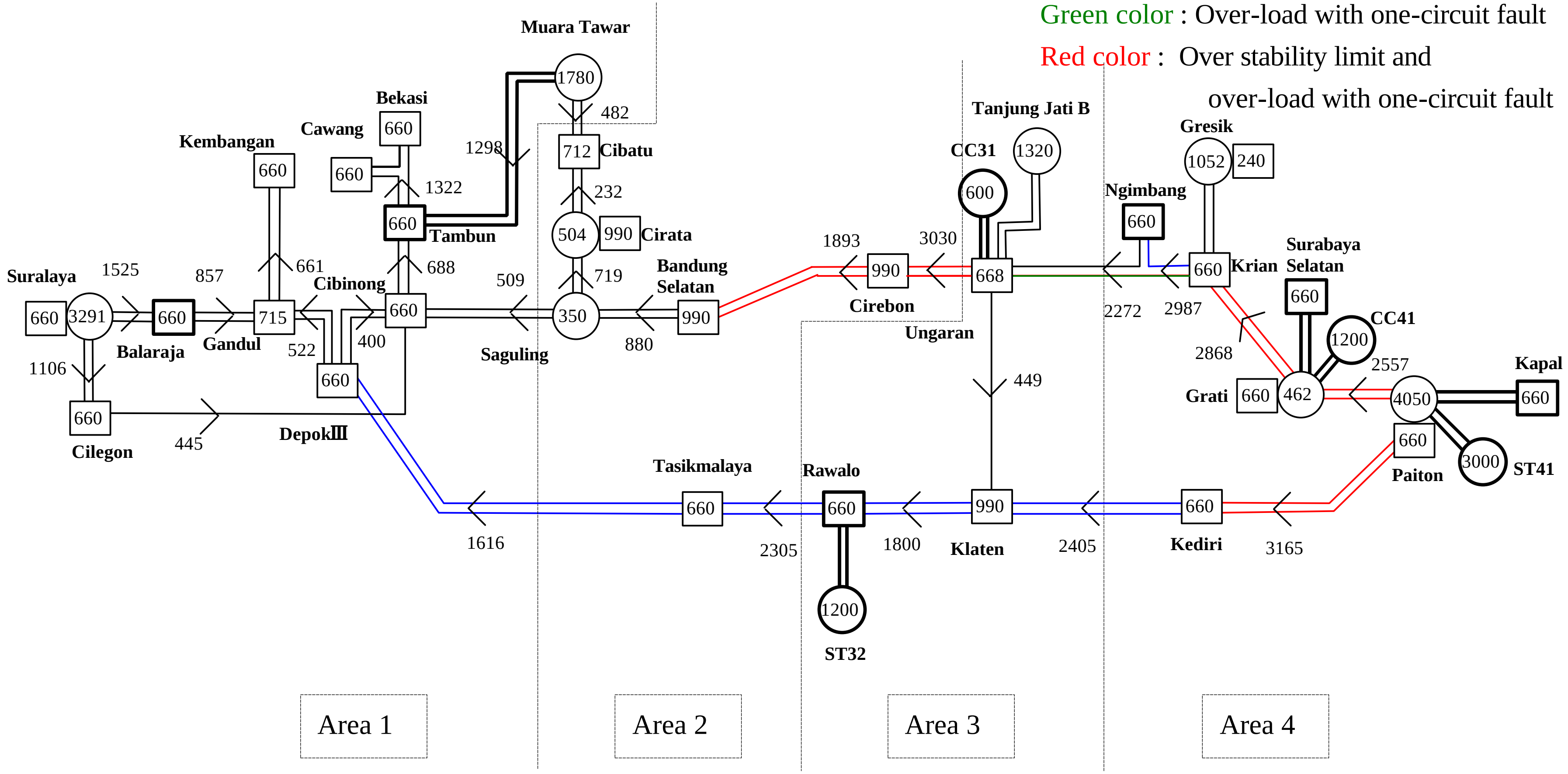


Figure 8.4.7 Power Flow Diagram of Java-Bali system (2010 Heavy-east case : with measures)

No problem on power flow, stability, and short circuit capacity

Unit:MW

The circles show the power stations,

and the rectangles show the substations.

The thick lines show the new facilities after 2005.

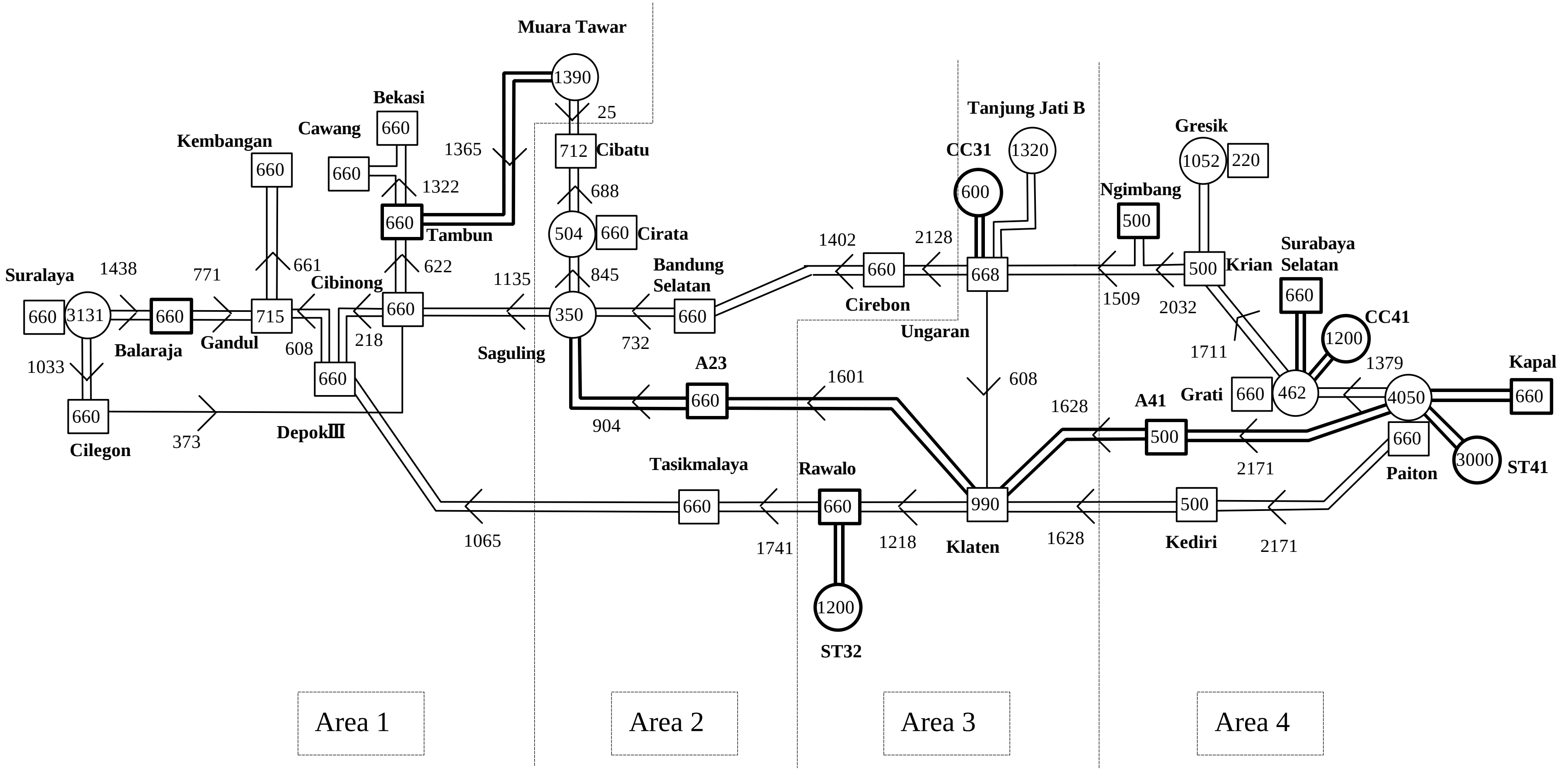


Figure 8.4.8 Power Flow Diagram of Java-Bali system (2015 Balance case)

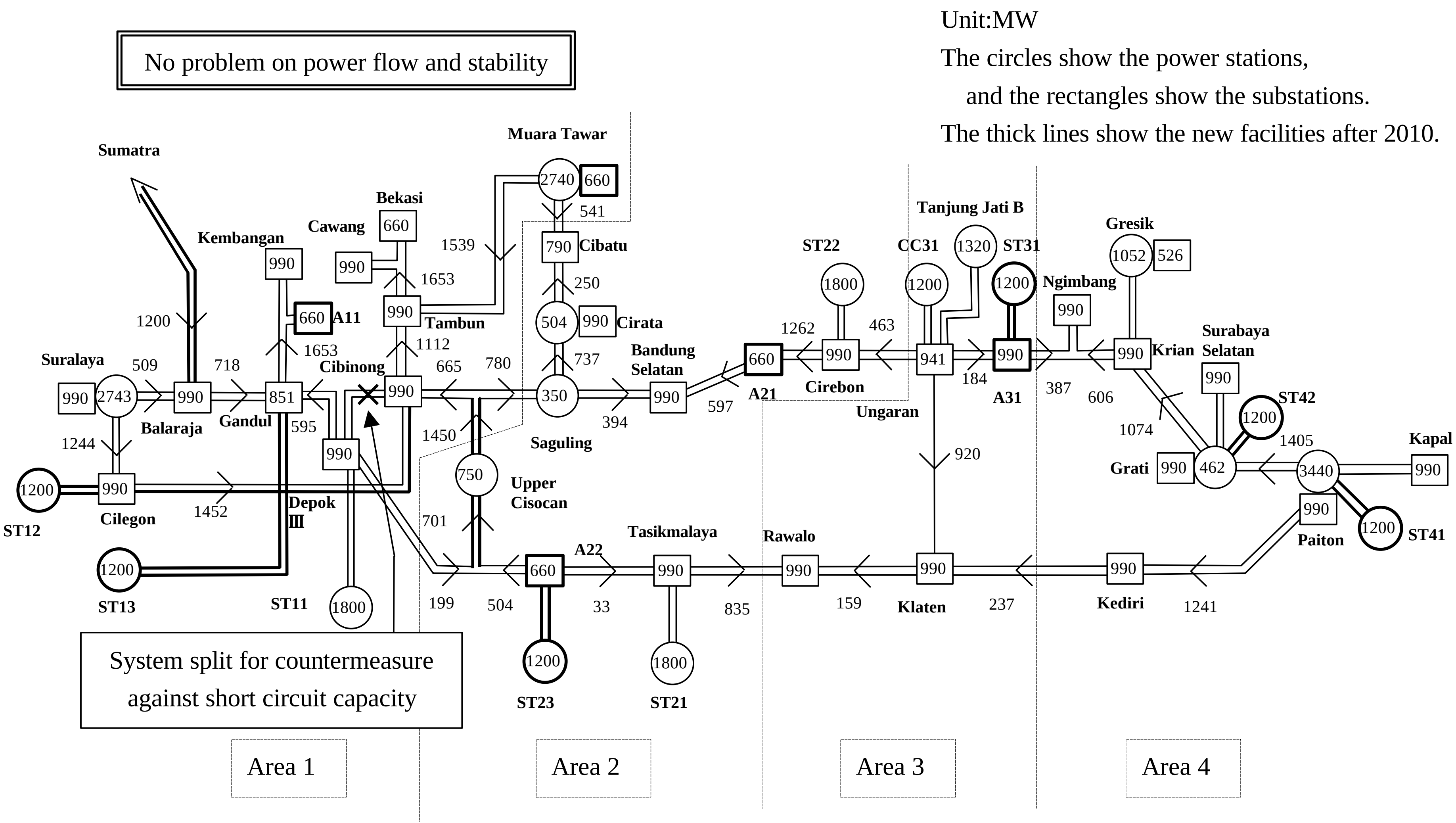


Figure 8.4.9 Power Flow Diagram of Java-Bali system (2015 West case)

No problem on power flow and stability

Unit:MW

The circles show the power stations,

and the rectangles show the substations.

The thick lines show the new facilities after 2010

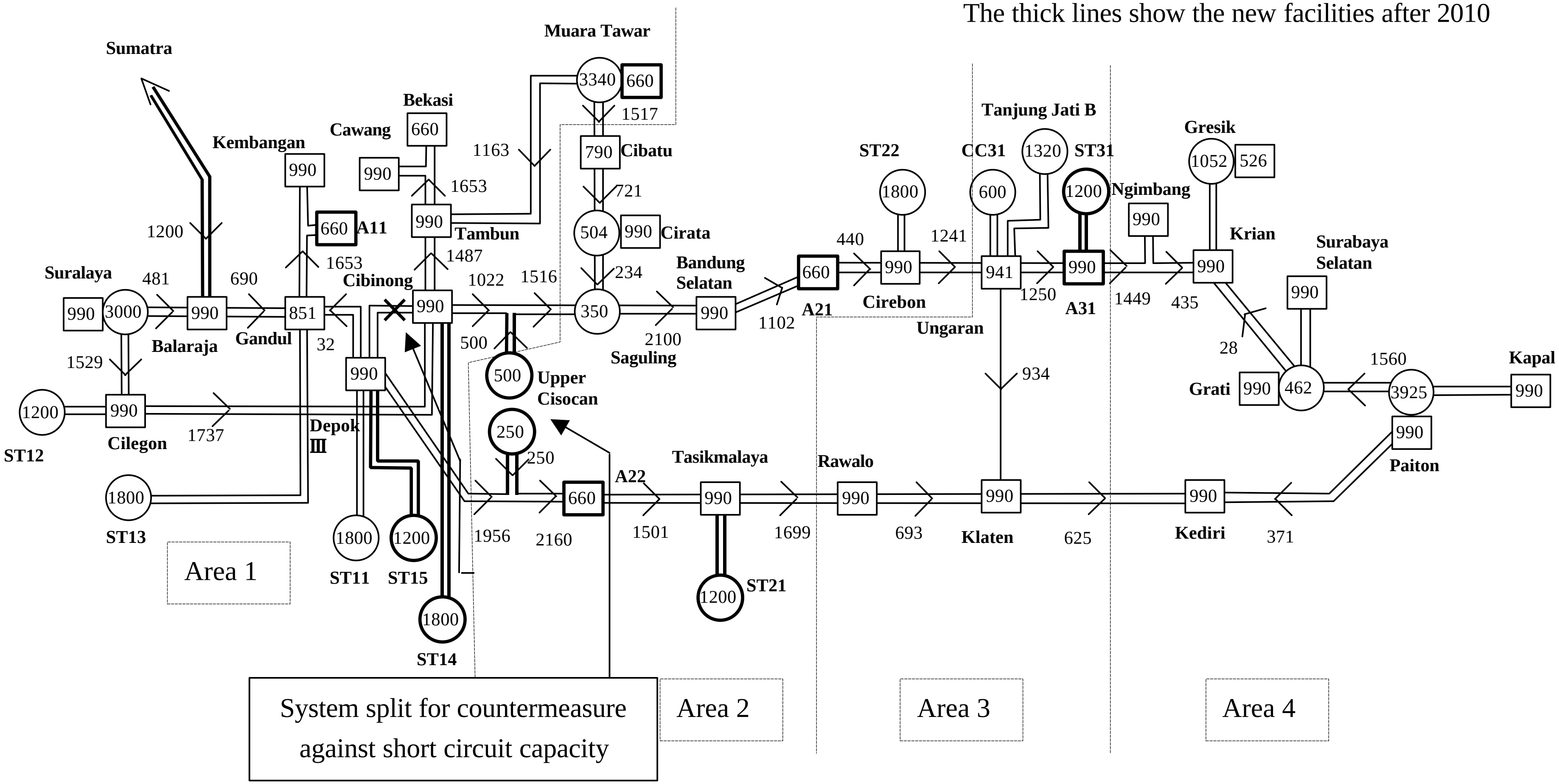


Figure 8.4.10 Power Flow Diagram of Java-Bali system (2015 East case)

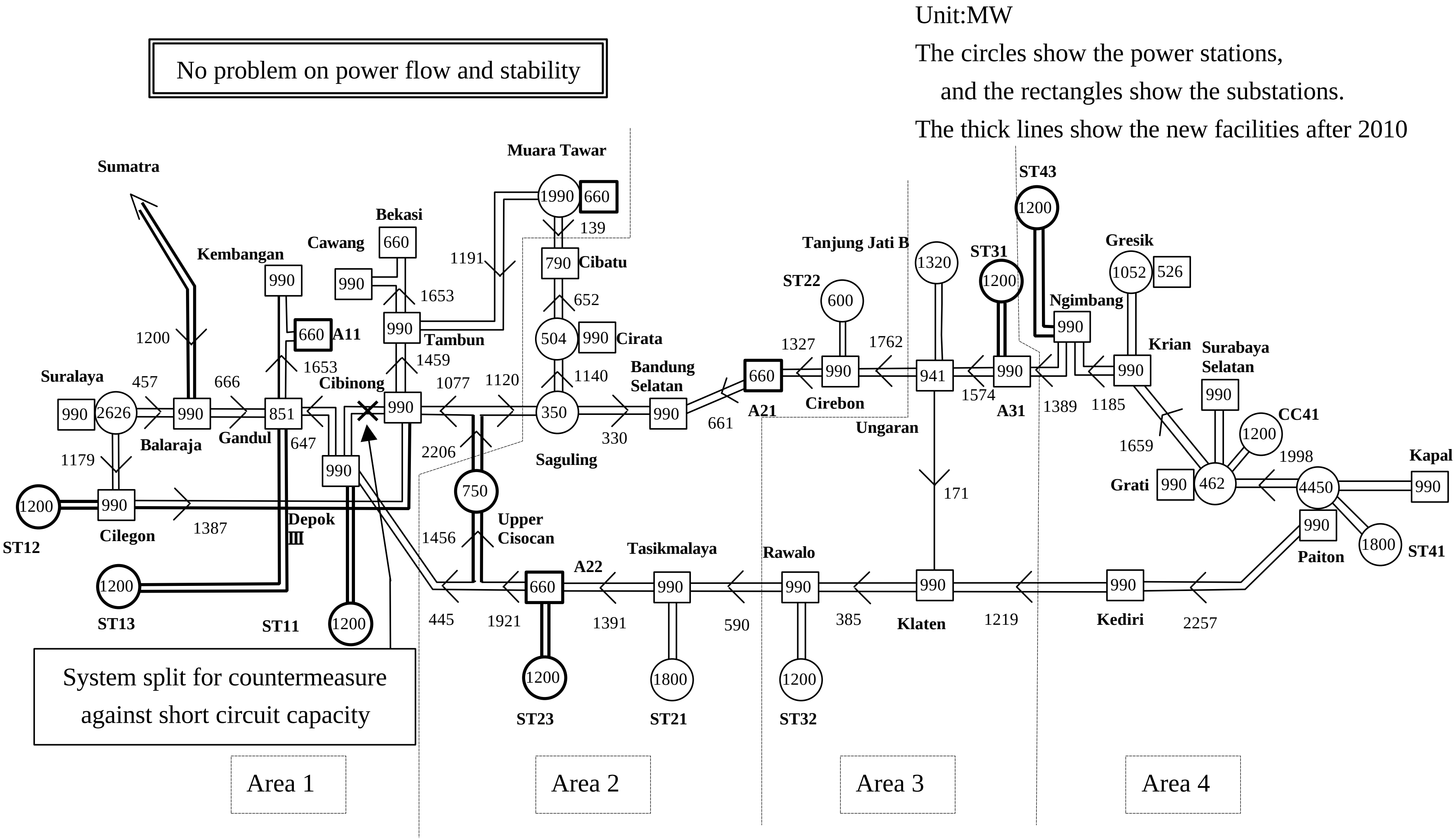


Figure 8.4.11 Power Flow Diagram of Java-Bali system (2015 East case2 (+ 1200MW at Paiton))

- Problems on power flow and stability

Unit:MW
The circles show the power stations,
and the rectangles show the substations.
The thick lines show the new facilities after 2010.
Blue color : Over stability limit
Green color : Over-load with one-circuit fault
Red color : Over stability limit and over-load with one-circuit fault

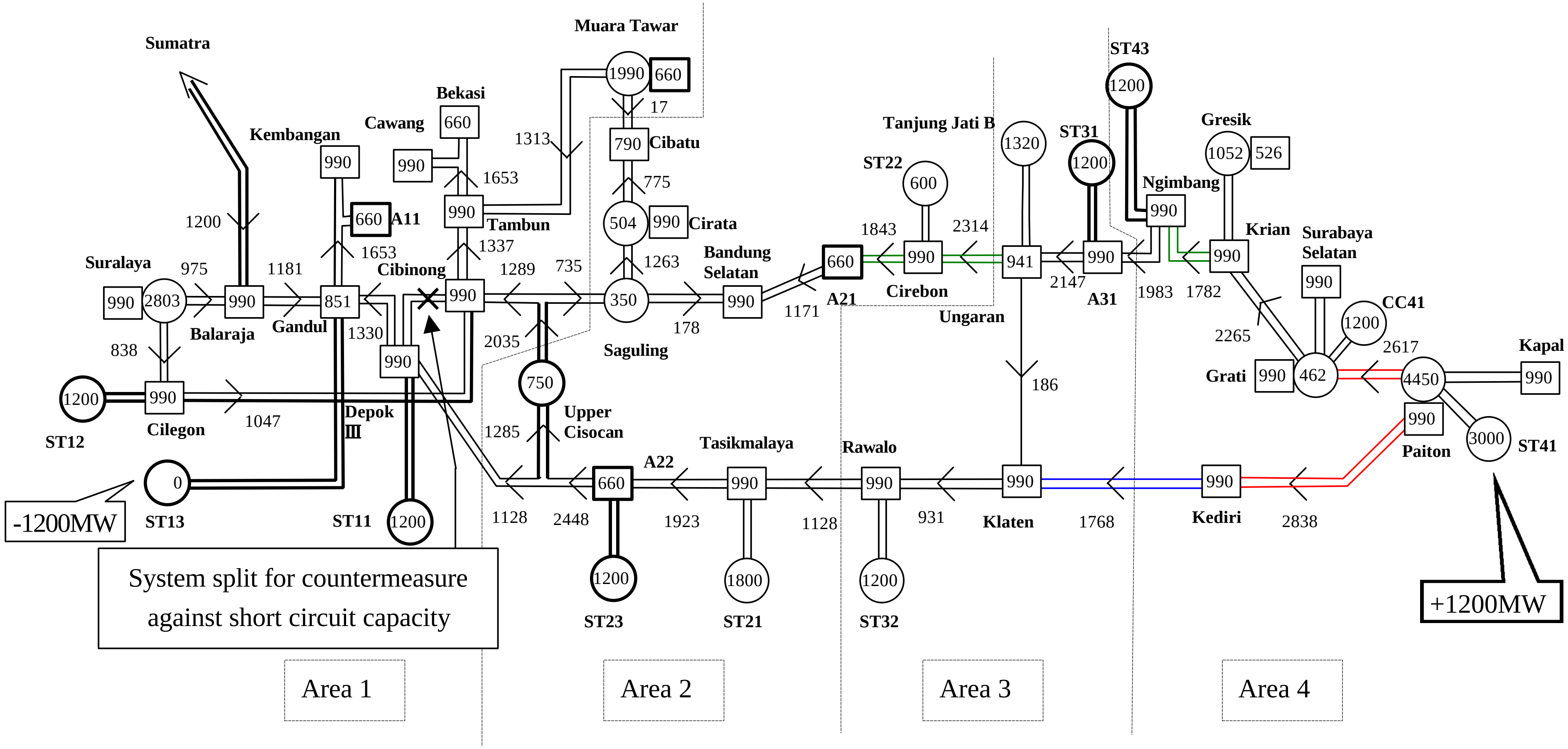


Figure 8.4.12 Power Flow Diagram of Java-Bali system (2015 Heavy-east case : without measures)

Problems on power flow and stability

Unit:MW

The circles show the power stations,

and the rectangles show the substations.

The thick lines show the new facilities after 2010.

Blue color : Over stability limit

Green color : Over-load with one-circuit fault

Red color : Over stability limit and over-load with one-circuit fault

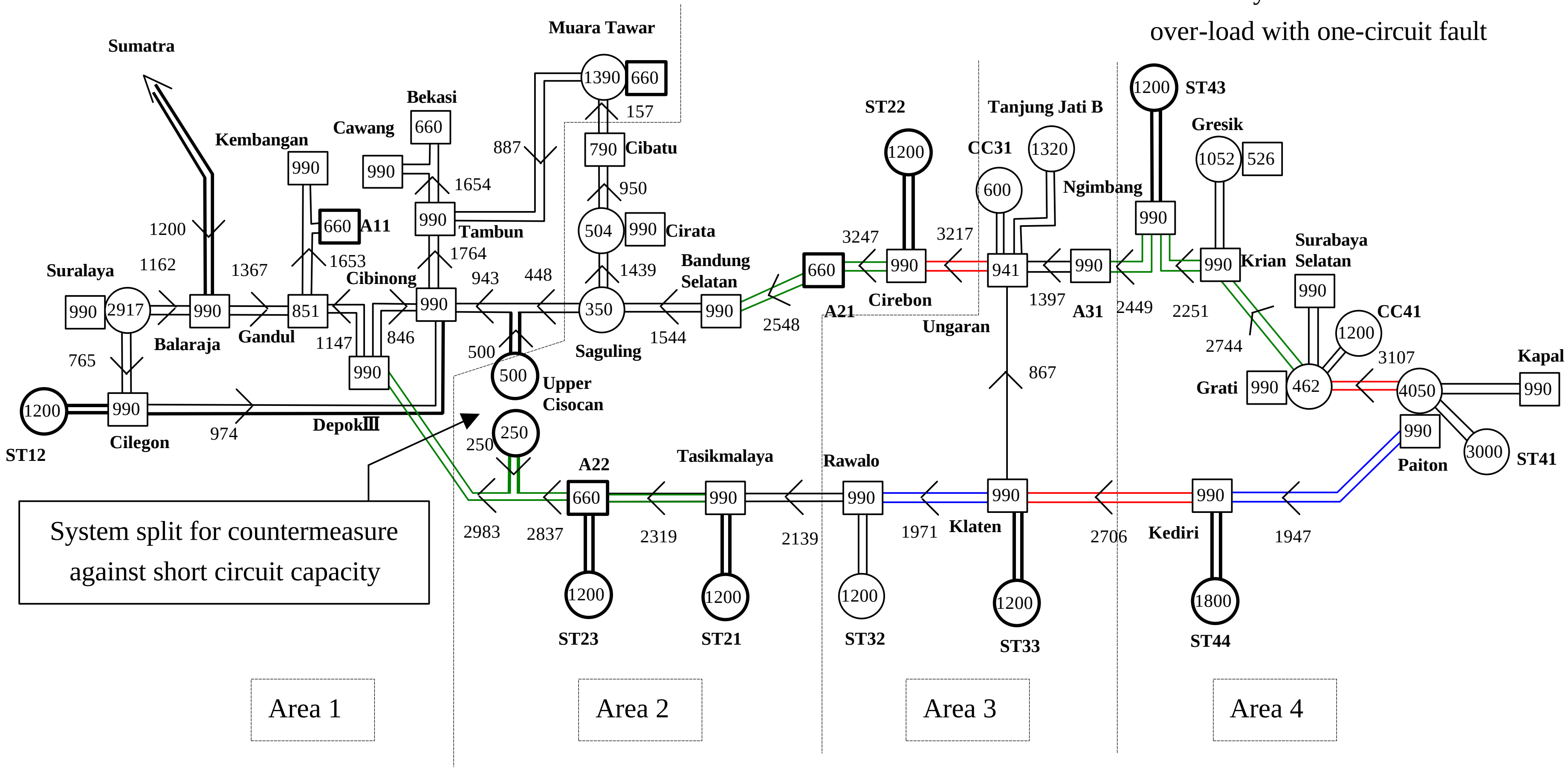
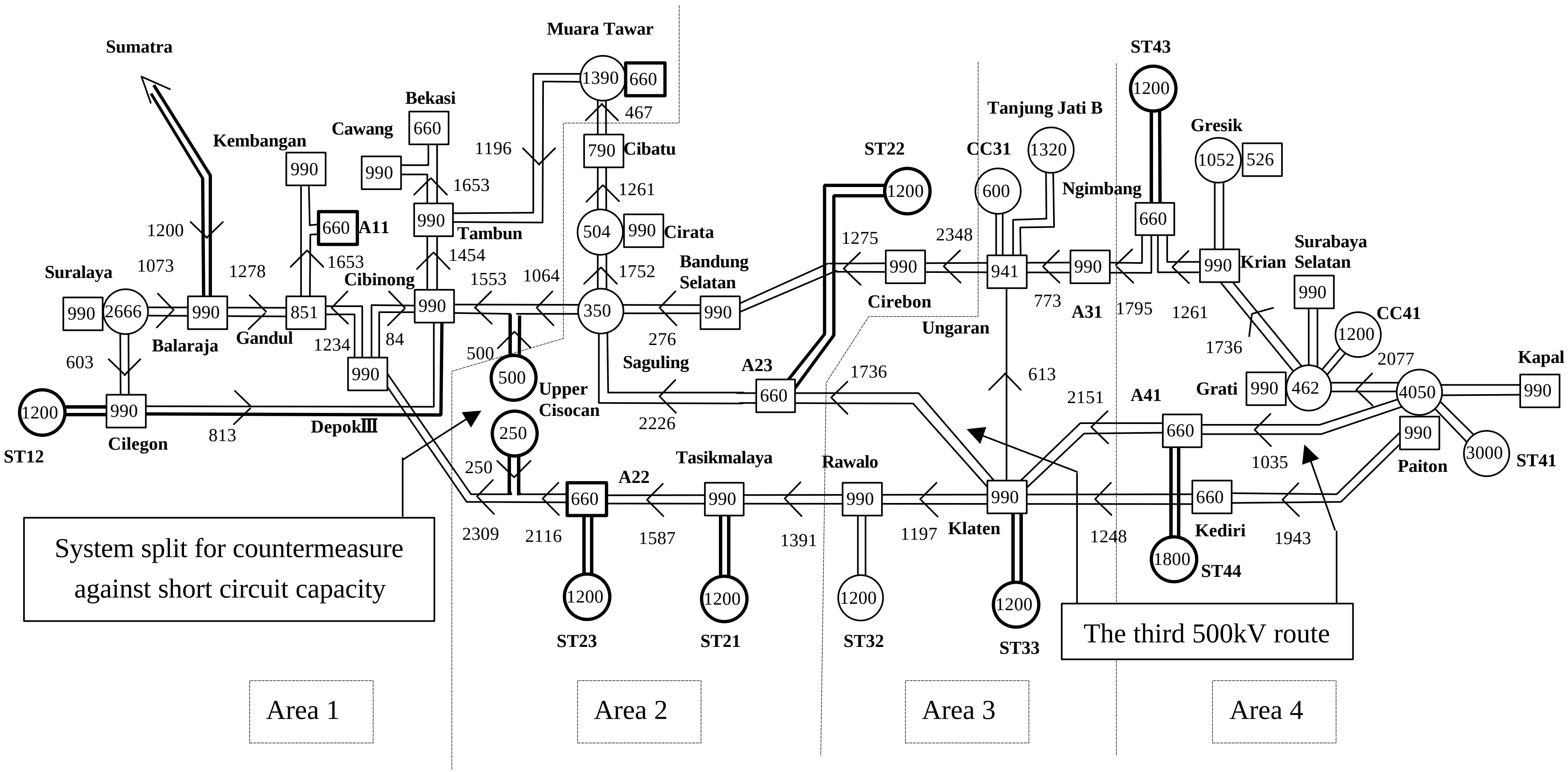


Figure 8.4.13 Power Flow Diagram of Java-Bali system (2015 Heavy-east case : with measures)

No problem on power flow and stability

Unit:MW
The circles show the power stations,
and the rectangles show the substations.
The thick lines show the new facilities after 2010.



1) Balance Case

There will be no problem in terms of power flow and stability, because the demand is in balances with the generation in each area and the power flows of the trunk lines are small. The losses in the 500kV system are also small.

With respect to short circuit capacity, there will be no problems in 2010. However, there will be problems in West Java in 2015. Therefore, a split of the system or some other measure will be needed.

2) West Case

There will be no problem in terms of power flow and stability.

With respect to short circuit capacity, there will be problems in West Java in 2010. Therefore, a split of the system or some other measure will be needed.

If the development of power stations in West Java exceeds the amount in this case, the power flows of the 500kV trunk lines (from DepokIII to Tasikmalaya and from Saguling to Bandung Selaten) will be great and there will be problems in terms of power flow. In this case, the transmission capacity per route will be limited to approximately 2,100MW by the thermal capacity, even though this will depend on the configuration of the system and other conditions.

3) East Case

There will be no problem in terms of power flow and stability.

With respect to short circuit capacity, there will be no problem in 2010. However, there will be problems in West Java in 2015. Therefore, a split of the system or some other measure will be needed.

As shown in Figure 8.4.5 and Figure 8.4.11, if the development of power stations in East Java exceeds the amount in this case, the power flows of the 500kV trunk lines will be great and there will be problems in regard to power flow and stability. In this case, the transmission capacity per route will be limited from approximately 1,700MW to 2,300MW by the thermal capacity or stability, even though this will depend on the configuration of the system and other conditions.

4) Heavy-East Case

There will be problems in terms of power flow and stability. Therefore, the third 500kV transmission line (approximately 1,000km) from area 4 (Paiton) to area 1 (Near Saguling) will be needed as a drastic countermeasure.

The cost will be 220 million US dollars, based on the southern 500kV transmission lines(from Klaten to Depok III).

(This does not include the cost for land acquisition, compensation for right of way and construction of the substations.)

With respect to short circuit capacity, there will be no problem in 2010. However, there will be problems in West Java in 2015. Therefore, a split of the system or some other measure will be needed.

(3) Detail of system analysis

1) Result of power flow analysis

Table 8.4.9 shows the transmission lines for which power flow exceeds its one-circuit capacity with one-circuit fault.

Table 8.4.9 Transmission lines for which power flow exceeds its one-circuit capacity with one-circuit fault

	Balance Case	West Case	East Case	Heavy-East Case	
				(Without measure)	(With measure)
2010	None	None	None	Paiton-Kediri Paiton-Grati Grati-Krian Krian-Ungaran Ungaran-Cirebon Cirebon- BdngSelatan	None
2015	None	None	None	Paiton-Grati Grati-Krian Krian-Ngimbang Ngimbang-A31 Ungaran-Cirebon Cirebon-A21 A21-BdngSelatan Kediri-Kalten Tasikmalaya-A22 A22-DepokIII	None

2) Result of stability analysis

Table 8.4.10 shows the transmission lines for which a one-circuit fault (3LG-O) would make the system unstable.

Table 8.4.10 Transmission lines of which one-circuit fault make the system unstable

	Balance Case	West Case	East Case	Heavy-East Case	
				(Without measure)	(With measure)
2010	None	None	None	Paiton-Grati Grati-Krian Krian-Nimbang Ungaran-Cirebon Cirebon-Bandung S Paiton-Kediri Kediri-Klaten Klaten-Rawalo Rawalo-Tasikmalaya Tasikmalaya-DepokIII	None
2015	None	None	None	Paiton-Grati Ungaran-Cirebon Paiton-Kediri Kediri-Klaten Klaten-Rawalo	None

After the completion of all of the southern 500kV transmission lines in 2004, the stability problem will be removed from the Java Bali system. However, in the Heavy-East Case, if the power stations are developed heavily in East Java, the system will be unstable.

The stability can be improved to some extent by the following measures. However, these measures are not enough in the Heavy-East Case, therefore, a third 500kV transmission line from area 4 (Paiton) to area 2 (Near Saguling) will be needed as a drastic measure.

a. Adoption of ultra high-response excitation systems and PSSs (Power System Stabilizer)
b. Adoption of low impedance equipment
c. Construction of intermediate switching station
d. Adoption of high-speed fault clearing
e. Installation of series capacitors
f. Installation of System Damping Resistors (SDR)
g. Installation of early valve actuation (EVA)
h. Installation of transient stability controllers (TSC)
i. Adoption of FACT (Flexible A.C. Transmission System)

3) Result of short circuit analysis

Table 8.4.11 shows the power stations and substations in the 500kV system, of which short circuit capacities exceed the rated short circuit capacities of their equipment (40kA[50kA only at Paiton]).

Table 8.4.11 Result of short circuit analysis (Unit : kA)

	Balance Case	West Case	East Case	Heavy-East Case (With measure)
2010	None	Cibinong(43) DepokIII(42)	None	None
2015	Cibinong(48) DepokIII(47) Saguling(42) Gandul(42) Tambun(41)	Cibinong(54) DepokIII(53) Saguling(43) Gandul(46) Tambun(43) M-Tawar(41)	Cibinong(46) DepokIII(44) Saguling(41)	Saguling(42)

Note : The figures in the parentheses show the short circuit current

As shown above, as the 500kV system is connected like a mesh in West Java, there will be problems in terms of on short circuit capacity along with the development of power stations.

Countermeasures against short circuit capacity are as follows.

a. Split of the system
  - Stop loop operation of the 500kV system and 150kV system
  - Split of the 500kV system

b. Upgrading the equipment (Upgrading the circuit beakers)

c. Adoption of current-limiting reactors

No investment is needed for splitting systems, however the reliability will be lower. Meanwhile, measures such as upgrading the equipment or current-limiting reactors will not cause a drop in reliability, but this would involve some additional investment.

Table 8.4.12 shows the results of the short circuit analysis if a system split is adopted.

Table 8.4.12 Result of short circuit analysis (in case of split of the system) (Unit:kA)

		Balance Case	West Case	East Case	Heavy-East Case (With measure)
2010	Place of split	—	DepokIII -Cibinong	—	—
	Short circuit current	—	Cibinong(29) DepokIII(25)	—	—
2015	Place of split	DepokIII -Cibinong	DepokIII -Cibinong UpperCisokan Bus	DepokIII -Cibinong	UpperCisokan Bus
	Short circuit current	Cibinong(35) DepokIII(30) Saguling(40) Gandul(31) Tambun(33)	Cibinong(37) DepokIII(31) Saguling(35) Gandul(32) Tambun(34) M-Tawar(35)	Cibinong(34) DepokIII(27) Saguling(39)	Saguling(38)

The short circuit capacity of the 150kV sides at the Gandul, Bekasi and Ungaran substations, where the large-scale thermal power stations (Muara Karang, Tanjung Priok and Tambaklorok) are connected respectively, installation of the third 500/150kV transformer will make their short circuit capacity exceed 40kA, therefore a split of the system or some other countermeasure will be needed.

And at the 500/150kV substations there will be the possibility that the installation of the forth 500/150kV transformers will make their short circuit capacity exceed 40kA, therefore a split of the system or some other countermeasure will be needed.

4) Transmission losses

Table 8.4.13 shows the transmission loses in the 500kV system.

Table 8.4.14 shows the cost of transmission losses per year.

Table 8.4.13 Transmission losses (500kV system)

		Balance Case	West Case	East Case	Heavy-East Case (With measure)
2010	Power Losses (MW)	108	210	246	545
	Energy Losses (GWh/year)	513	993	1,166	2,578
2015	Power Losses (MW)	174	316	317	557
	Energy Losses (GWh/year)	825	1,498	1,501	2,637

Table 8.4.14 Cost of transmission losses （Unit : Million US＄/year）

		Balance Case	West Case	East Case	Heavy-East Case (With measure)
2010	Power Loss	14	26	31	68
	Energy Loss	6	12	14	31
	Total	20	38	45	99
2015	Power Loss	22	39	40	69
	Energy Loss	10	18	18	32
	Total	32	57	58	101

The Balance Case, in which the generation and demand are balanced, is the most economical because of low losses.

The conditions for calculating loss cost are based on the coal thermal power stations as follows.

Construction Cost		900 US＄/kW
Fuel Cost		0.01 US＄/kWh
Discount Rate		12%
Plant life		25Years
O/M cost	Fixed	10 US$/kW Year
	Variable	0.002 US$/kWh Year

Energy Loss (GWh) = Power Loss (MW)×8760(h)×Loss Factor/1000

Loss Factor = $0.3 \times f + 0.7 \times f^2$ (f : Load factor=69%)

8.4.6 Conclusions and Recommendations

(1) Distribution of new power stations

1) From the viewpoint of the transmission system, it is important to avoid the construction of new 500kV trunk lines and to avoid reinforcement of the existing 500kV trunk lines for power development.

Furthermore, it is desirable to minimize the power flows of the 500kV trunk lines to reduce the transmission losses.

Therefore, it is desirable to choose the sites of the new power stations to balance the generation with the demand in each area and to balance the power flows of the northern 500kV transmission lines with the power flows of the southern 500kV transmission lines.

- In area 1 (West Java), the generation is presently in balance with demand. However, the ratio of the area's demand to the total demand of the Java-Bali system is large (40%). Therefore, power development in coordination with the demand increase is desirable.
- In area 2(middle West Java), the demand exceeds the generation at present, and so it is desirable to promote more power development.
- In area 3 (central Java), though the demand exceeds the generation at present, construction of Tanjung Jati B will bring generation into balance with the demand. Therefore, it is desirable to develop power in accordance with the increase in demand.
- In area 4 (East Java), the generation greatly exceeds demand at present, therefore it is desirable to develop power in other areas.

2) If power stations with capacities greater than 2,400MW are developed in area 4 (East Java) and power stations with capacities greater than 3120MW are developed in area 3 (central Java) by around 2010, the power flows on the trunk lines will be heavy and power interruption will occur when there is a transmission fault, resulting in stability problems. Therefore, a third 500kV trunk line with a distance of almost 1,000km will be needed.

If power stations with capacities greater than 5,400MW are developed in area 4 (East Java) and power stations with capacities greater than 4,920MW are developed in area 3 (central Java) by around 2015, a third 500kV trunk line will also be needed.

Therefore, it is important to avoid the concentration of power development in East Java.

If construction of a third trunk line is needed, it could be a DC transmission line. Therefore, a detail study will be needed.

3) If the demand and the generation are not balanced in each area, partial reinforcement of the 500kV trunk lines or partial third 500kV trunk lines or 500kV transmission lines between the northern 500kV trunk line and the southern 500kV trunk line might be needed. Therefore, it is desirable to balance the demand with the generation in each area.

4) In terms of the new transmission lines from the new power stations to the existing 500kV system, it is desirable to shorten its distance as much as possible to reduce the construction costs and transmission losses and to improve transient stability. Therefore, it is desirable to choose the new sites as close to the demand (500/150kV substation) as possible when developing new power stations.

From the viewpoint of reliability, it is desirable to avoid concentration of power development at one site.

(2) Short circuit capacity

If power stations are developed heavily in West Java, there will be the problem of short circuits in the 500kV system. Therefore, a splitting of the system or other such measures (e.g. upgrading the equipment, current-limiting reactor) will be needed.

Measures against short circuit capacity should be determined by considering reliability and costs in comparison with the split of the system and other measures.