The Republic of Indonesia

PT.PLN (Persero)

The Study on Power Supply Reliability Improvement in Jakarta

Final Report

June 2013

Japan International Cooperation Agency (JICA)

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Nippon Koei Co., LTD

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Abbreviation

Abbreviations	Words (Original)
AQR	Automatic Reactive Power Regulator
ACC	Area Control Center
ACE	Area Control Error
AIS	Air Insulated Switchgear
AVR	Automatic Voltage Regulator
BAPPENAS	*Badan Perencanaan Pembangunan Nasional*
ELD	Economic Load Dispach
EMS	Energy Management System
GIS	Gas Insulated Switchgear
GPS	Global Positioning System
IEC	International Electrotechnical Commission
IPP	Independent Power Producer
JCC	Java-Bali Control Center
LFC	Load Frequency Control
LOLP	Loss of Load Probability
MEMR	Ministry of Mining and Energy
MOF	Ministry of Finance
MSOE	Ministry of State Owned Enterprises
NASPI	North American Synchrophasor Initiative
OEL	Over Excitation Limit
OPF	Optimal Power Flow
P3B	*Penyaluran dan Pusat Pengatur*
P3B JB	*P3B Java Bali*
PLN	*PT.Perusahaan Listrik Negara(Persero)*
Plt	Perception of flicker long term
PMU	Phasor Measurement Unit
Pst	Perception of flicker short term
PSS/E	Power System Simulator for Engineering
PSVR	Power System Voltage Regulator
RUKN	*Rencana Umum Ketenagalistrikan Nasional*
RUPTL	*Rencana Usaha Penyediaan Tenaga Listrik*
SAS	Substation Automation System

SC	Static Capacitor
SVC	Static Var Compensator
VQC	Voltage and Reactive Power Controller
WAMPAC	Wide Area Monitoring, Protection and Control
WAMS	Wide Area Monitoring System

Executive Summary

S-1 Introduction

In recent years, there is the issue of bus voltage drop at 500 kV key substations in Jakarta Metropolitan Area. It has been observed that the voltage drops below the operational range during the area's demand peak time. This study aims to identify the issues possibly inherent in the power system, which supplies power to Jakarta Metropolitan Area, and to analyze the cause of voltage drop at the substations. The study finally proposes measures for stable power supply in the region.

S-2 Laws and Regulations related to the Grid Operation in Indonesia

S-2.1 Policies, Laws and Regulations related to the Power Sector

Under the supervision of the Ministry of Energy and Mineral Resources (MEMR), PLN, a state-owned electric power company, is mainly responsible for power supply in overall Indonesia. Though PLN is still the largest supplier, private sectors are allowed to enter the electricity business under the laws and regulations.

S-2.2 Regulations related to Voltage Control in Grid Code

P3B, which PLN established as its internal business unit, manages the transmission system in the Jakarta Metropolitan Area. In using the system, Grid Code stipulates the operation rules which is applied to PLN, P3B and other users such as generation companies, distribution companies, large electricity consumers, and companies working for the aforementioned network users as development and/or maintenance contractors etc.

S-2.3 Organizational Structure

The main Governmental organizations involved with the Power Sector are the Ministry of Finance (MOF), Ministry of Energy and Mineral Resources (MEMR), Ministry of State Owned Enterprise (MSOE) and the National Development Planning Agency (BAPPENAS). PLN is in charge of power supply for overall Indonesia and P3B administers the transmission system.

S-2.4 Financial and Budget Condition

The revenues, expenses and profits of P3B are on the increase. The bulk of P3B JB's net worth is fixed assets and the amount of net assets is steadily increasing each year. On the other hand, debt ratio is about 1%, and it can be said that P3B JB tends to make investments based on the operating revenues from PLN.

S-2.5 Management

Although total number of staff is decreasing, P3B JB intends to increase well-educated staff to develop expertise. The facilities under P3B JB's management are increasing each year while the number of malfunctioning facilities have declined or remained.

S-3 Current Voltage Control in Jakarta System

S-3.1 Main Specification of Power System Facilities

The power grid configuration around Jakarta consists of semicircular 500kV bulk power transmission lines and 115k transmission branches connected to the center of Jakarta. The 500kV transmission line applies DOVE, GANNET as a conductor, and the capacity of 500kV/150kV transformer is typically 300MVA or 250MVA. For the reactive power sources, PLN operates Shunt Reactors with a capacity up to 200MVar for transmission line compensation, and capacitor banks for 150 kV, 70 kV, and 20 kV Buses.

S-3.2 Capacity and Location of Reactive Power Control Equipment

PLN has already developed its plan to expand its capacitor banks via self-financing for the countermeasure against the persisting grid's low operation voltage. According to the plan, PLN is now increasing 475 MVar reactive power sources by installing capacitor banks at 500kV and 150kV substations, and has secured a budget for additional 1,070 MVar. PLN is now conducting a detailed engineering study on this 1,070 MVar expansion to review available spaces in substations and cost-effective designs of facilities.

In this study, capacitor banks will be basically connected to 150kV bus-bars and the capacity of the individual capacitor bank is 50MVA as a standard form. This equipment will be purchased with the specifications based on IEC relevant standards, and the circuit breakers for the capacitor banks are specified as the M2 Class for frequent operations.

S-3.3 Voltage Control Practice in Power Station

If the system voltage drops significantly due to the demand increase, JCC (Java Bali Control Center) and ACC (Area Control Center) request power stations to increase the reactive power output by telephone.

Generally, off-load tap changer are applied to generator step-up transformers except for a few transformers. Typically, a nominal tap position is selected for the step-up transformer of new and additional generators.

S-3.4 Voltage Control Practice in the Substation

In 500/150kV and 150/50kV substations, on-load tap changer is applied to the transformers. Generally the tap positions of the transformers are fixed to reasonable positions throughout the day. The tap positions of the transformers in some substations are adjusted in accordance with the demand cycle. The tap positions of the transformers are controlled by operators in substations based on manual instructions received from JCC or ACC by telephone.

The shunt capacitors are always-on throughout the day on weekdays and always-off throughout the day on weekends and holidays. The shunt capacitors connected to the system within ACC operating area can be switched on and off manually via EMS in ACC.

S-3.5 System Monitoring and Control

The Study Team interviewed staffs in JCC, ACC 1and 2 about the monitoring of the electric system. SCADA or EMS in JCC and ACC 2 were updated with the systems that have State Estimators and Optimal Power Flow Algorithm which are functioning every five minutes. SCADA of ACC 2 is now under renewal. It was said that those functions could not work well due to insufficient data maintenance.

The Study Team recommends appropriate data maintenance, calibration of telemeters and system monitoring and control under the consideration for the restriction of equipment.

S-3.6 Operation Record of Jakarta System

Twenty (20) out of total twenty-six (26) 500 kV substations in Java Bali system experienced voltage drop lower than 475 kV stipulated in the country’s grid code. Low-voltage phenomenon has been observed mainly in the western area of the system during peak time of Jakarta. Examination conducted by the Study Team showed that availability factor of most transformers in Java Bali system is above the target level of 80%. Such heavy loading of transformers could have increased the reactive power loss, and decreasing the system voltage. On the other hand, there is a strong correlation between the voltage drop and reactive power balance per the subsystem. P3B JB’s countermeasure against the voltage drop is to place reactive power suppliers intensively to the subsystems whose reactive power balance is low or negative. In the case of Suralaya coal-fired power station, their terminal voltage has kept low since the amount of supplied reactive power already exceeds the units’ upper limit. As for the voltage operation at substations, tap positions are set at its maximum position for 500/ 150 kV transformers. The Study Team confirmed that the voltage control facilities at the power stations and substations are operating at their maximum capability.

S-3.7 Power Supply Balance Perspective

In Java Bali system, installed capacity of the steam turbine power station accounts for 50% as of 2011. Especially for the IPP, the ratio reaches above 70%. According to RUPTL 2012-2021, PLN plans to increase the share of steam turbine year by year up to 2021. The peak demand is expected to be 42,461 MW in 2021, 90% increase from 2011. During these 10 years, the ratio of installed capacity to peak demand would drop to the lowest level in 2015. Moreover, the margin of installed capacity would be lower than the target of 35% from 2014 to 2017. Thus, the target of the loss of load probability mentioned in RUPTL may not be achieved during this period.

S-3.8 Plan of the Transmission System

The RUPTL 2012-2021 nominates the following major projects to reinforce the 500 kV transmission system.

- Duri Kosambi～Muara Karang line, which will be completed in 2013
- Cawang Baru～Muara Karang line, which will be completed in 2016
- Paiton～New Kapal (Bali～Java）line, which will be completed in 2015 (150 kV)、in 2016 (500 kV)
- Ungaran～Pemalang～Mandirancan～Indramayu line, which will be completed in 2016
- Southern Smatela～Java Bali System HVDC 500 kV line (3000MW)
- XBogol 500 kV Substation Newly constructed
- XBogol～Tasik、XBogol～Depok、XBogol～Cilegon、XBogol～Cibinon line, which will be completed in 2016

S-4 Current Jakarta System Model and Analysis

The purpose of this chapter is to study the possibility of the blackout by evaluating upper limit of the power demand from the viewpoints of voltage instability in Jakarta power system by using the simulation model of Java-Bali system.

S-4.1 Simulation Model

The system analysis model is made based on the data sets received from P3B JB with updated information collected through the survey, emulating the actual bus voltage status at the 500/150 kV substations in Region 1. The validity of the simulation model has been examined by comparing the simulation results with actual record of the bus voltage at the substations. As a result, both the calculated primary and the secondary voltages of the 500 kV substations located in Region 1 showed a small deviation from their corresponding actual record within the range from minus 1% to plus 1% (Figure 4.1). Therefore, the developed models are confirmed to be appropriate for further evaluation of the voltage conditions of the current Java Bali system. Furthermore, the calculated results of the 500 kV power flow of the Java Bali system shows a deviation from the actually-observed record within plus/minus 10 %. For these reasons, the validity of the developed model is confirmed. The calculation of the reactive power balance per the 500 kV substation block or sub-system in Region 1 shows that the secondary bus bar voltage (150 kV) at the 500/ 150 kV substations tends to be low in the subsystems whose reactive power balance is low.

S-4.2 Result of the voltage stability analysis of the current system

This subsection employed 2012 model to evaluate the voltage stability limit which could lead to a widespread blackout. For this purpose, the Study Team utilized PV (active power – system voltage) Curve analysis approach to calculate the upper limit of the Jakarta power demand. Under normal conditions, the margin between the upper limit of the Jakarta demand and the peak-time operation point (8,520 MW, Region 1) was 537.50 MW, or 6 % of the Region 1's operating peak demand, while the N-1 condition case shows that the margin was reduced to 131.25 MW (around 1% of the total demand of Region 1) specifically for the out-of-service of the one circuit of the transmission section bridging Central and West Java i.e. Ungaran 500 kV substation and Mandirancan 500 kV substation. Since the demand could deviate from its forecasted value within such range, the current system is under severe status in terms of the voltage stability in N-1 condition. As seen in the value of the margin in N-1 condition per target transmission section, it was found that the locations outside of the Region 1 such as Central Java could affect the voltage drop in Jakarta. Therefore, it is recommended to pay close attention to the whole Java Bali system from a viewpoint of voltage stability until the completion of the current voltage improvement project by P3B JB.

S-5 Modeling and Analysis of Jakarta system in the Near Future (Year 2015)

S-5.1 Engineering Design of Capacitor Banks

To secure substation's supply reliability in case of equipment trouble, it is necessary to arrange the capacitor banks so as not to prevent any future expansion, repairs, troubleshooting work, which usually necessitate on-site dismantling and disassembling. It is also required to consider the construction working space around the equipment themselves. By considering these fundamental requirements and on-site study results, the team suggested utilizing the conventional capacitor banks as the basic construction design to save cost and applying compact and high-reliable capacitor banks which is standard in Japan selectively to the substation that requires frequent operation of the circuit breaker. In addition, the team suggested the employment of power cables for the flexibility of the installation design and securing sites for capacitor expansions.

S-5.2 Evaluation of Effect of Additional Shunt Capacitors

As for the voltage analysis, it is highly important to estimate the reactive power load precisely. In this study, reactive power loads were estimated using the correlation equations between the active and reactive power loads calculated based on the P&Q values measured from the peak demand in Jakarta in 2012.

The voltage analysis was performed based on the forecast for peak demand in Jakarta, generation expansion plan and system development plan for 2015. It was found that 2,495 MVar of shunt capacitors including existing, on-going and planned were not enough and additional 1,445MVar were required to maintain system voltage appropriately under normal and N-1 contingency conditions.

From the results of voltage stability analysis using PV curves, it was confirmed that limits of power demand under some case of N-1 contingencies in the 500kV transmission line were smaller than the peak demand estimated for Jakarta in 2015 with 2,495MVar of shunt capacitors. Thus additional shunt capacitors are required to ensure voltage stability.

The Study Team examined the relationship between voltage stability limits and interconnection power flows. It was confirmed that the interconnection power flows between Region 2 and Region 3 showed a high correlation with voltage stability limits in Java Bali system in 2015. Consequently, monitoring the power flow between Region 2 and Region 3 is considered to be effective for monitoring voltage stability.

The voltage analysis under off-peak demand was also performed in this study. It is expected that the shunt capacitors of 280MVar (17 units) are necessary to be switched on to meet the increasing demand in the morning and to be switched off after peak demand in order to maintain the system voltage appropriately.

S-6 Analysis and Countermeasures of Voltage in the Future Jakarta System (in 2021)

In this chapter, the long term voltage situations are analyzed by modeling the 2021 system as the future Jakarta system. The effects of the installation of the power generators and transmission lines on the upper limit of power demand are also analyzed.

S-6.1 Study and Analysis for Installing Shunt Capacitors

Active power is applied to the PSS/E data at the peak time (13:00) in Jakarta in 2021 provided by P3B JB. (The total load is supposed to be 36,700MW.) The load in 2015 is applied to the reactive load derived from the regression analysis of the measured active and reactive load. The power factor and generator output applied to 2021 is same as that of 2015.

Capacitor banks are supposed to be installed in accordance with the “Program Peningkatan Kualitas Tegangan (Voltage Quality Improvement Program)“ which is issued by P3B JB. The existing, on-going, planned capacitor and capacitor compensating for reactive power of HVDC are supposed to be installed.

To maintain the voltage following the Grid Code under normal and N-1 contingency conditions, an additional capacitor bank of 1,735MVar should be installed in 2021.

S-6.2 Validation of the Installation of Additional Shunt Capacitors

Due to the strengthening of the system, 500kV system meets the Grid Code requirements even before the installation of capacitors. However, the installation of the capacitors improves the system voltage further.

According to the study of the reactive power balance and the voltage stability limitations, it was found as follows,

- The level of the interface flow from region 3 to 2 cannot settle the voltage stability limit of the system in 2021.
- The bottleneck of the voltage stability in Java Bali system does not exist in Region 1.
- The loss of active power is reduced by 35.4MW in Java Bali system.

S-6.3 Effects of the Installation of the Power Plant and Power Transmission Lines

The effects of the installation of power generators and power transmission lines around Jakarta metropolitan area on the voltage maintenance were evaluated based on the results of the calculation of the power transmission capability (the upper limit of power demand in Jakarta) with/without target projects using the P-V curve of the 2021 system model. Lontar power plant has the highest effect in terms of decreasing of upper limit of power demand in Jakarta per 1MW of the power output. Possible reason is that Lontar power station is located near the demand center of Jakarta and the power station is directly connected to the 150 kV system of Jakarta.

The effects of the reinforcement of the power transmission system in the northern area of Jakarta is considered to be large based on the results of the studies on installation of 500 kV Muara Tawar substation and 500 kV Priok substation with surrounding transmission lines.

S-6.4 Effects of the installation of Capacitors on the Increase in Power Flow

The reactive power compensation at the power-receiving end in Region 1 is found to have a large effect on expanding the upper limit of Jakarta’s power demand in case of supplying the power of Region 2 and 3 to the incremental load of Jakarta (load of Region 1).

The reactive power compensation on the route of the 500 kV transmission line in south Java at the border between Region 2 and 3 is found to have a large effect on expanding the upper limit of the power demand of Jakarta and west Java in case of supplying the power of Region 3 to the incremental load of Region 1 and 2.

Given that the limit of the power demand far exceeds peak demand in 2021, the results of the study in this section do not present the necessity of additional new countermeasures apart from the recommended ones for expanding the limit of power demand.

S-7 Countermeasures against a Voltage Drop

This chapter describes the countermeasures against the voltage drops including the introduction of new methodologies of the system voltage control that can be applied to the Jakarta metropolitan area.

S-7.1 Introduction of a new voltage control scheme

In Java Bali system, it is estimated that the voltage control operation handled by system operators will increase. This may lead to ineffective operations of voltage control equipment. To avoid these prospects, voltage control improvement is strongly needed.

- Local VQC

  Local VQC controls V & Q control equipment so as to keep the voltage and reactive power to the predetermined reference value in each substation.

- PSVR (Power System Voltage Regulator)

  PSVR controls the high side voltage of step-up transformer which is near to the system..

- Central VQC

  Based on the monitored online data, a voltage control signal is sent out to the power stations and substations from the central load dispatching center etc.

S-7.2 Introduction of PMU

PMU (Phasor Measurement Unit) can widely measure a time synchronized voltage phase angle by using a GPS (Global Positioning System), etc. WAMS (Wide Area Monitoring System), which is based on this PMU technology, is currently applied to many countries including Europe and the US and utilized for real-time power system monitoring. Furthermore, WAMPAC (Wide Area Monitoring, Protection and Control) is being developed, which uses the monitored system information acquired by PMU. An accuracy of State Estimation that is used for security analysis in EMS is also improved via the introduction of PMU technology.

S-7.3 Countermeasures against voltage drop

There are following countermeasures against voltage drop in the Jakarta system.

Options	Countermeasures
A	In addition to existing and planned shunt capacitors in Java Bali system (see section 3.1.3), following shunt capacitors are need to be installed: ● By 2015, 1,445 MVar in Java system (Total in 2015: 3,940 MVar) ● By 2021, Total: 6,055 MVar in Java system (Incremental amount from 2015 is 315 MVar excluding 1,800 MVar for Java-Sumatra 3,000 MW HVDC transmission line)
B	Installation of Local VQC in addition to the countermeasure A
C	Installation of Central VQC in addition to the countermeasure A

S-8 Impact of the Blackout to the Economic and Industrial Activities in Jakarta Metropolitan Area

Interviews were conducted to evaluate qualitative impacts on electricity consumers especially focusing on the industrial sector and IPP entities. These interviews show that voltage drops are one of the issues common to those who are operating in the industrial park, as well as to the power supplier. Despite its frequent occurrence, they do not necessarily have the resolution to avoid impact to their activities and operations.

According to the questionnaire study conducted by Japan External Trade Organization (JETRO), more than 30% of Japanese companies answered that the biggest business risk in Indonesia is inadequate infrastructure. Improving power quality may contribute to attract various industries such as electronics and machine to start business in Indonesia.

S-9 Technical and Economic Comparison of Implementation of Countermeasures against Voltage Drops

The countermeasures were compared among option A: Installation of shunt capacitors in Jakarta and West Java, option B: Along with the installation of shunt capacitors in Jakarta and West Java, a Local VQC scheme is applied., and option C: Along with the installation of shunt capacitors in Jakarta and West Java, a Central VQC scheme is applied.

Although it is reasonable to apply countermeasure A at present, it will be necessary to change the option to countermeasure B or C in response to system growth, network complications, and increase of control equipment. When comparing costs, Countermeasure C is less expensive than countermeasure B. When having priority over speedy recovery after a large disturbance such as a fault, the Study Team recommends installing additional shunt capacitors and independent VQCs in

Jakarta and Western Java.

In terms of cost-benefit considerations, it was found that countermeasure costs can be covered enough only by the benefit derived from transmission line loss reduction.

S-10 Recommendations

The following is recommended as the countermeasures against voltage drops in the Jakarta metropolitan system.

S-10.1 Installation of Shunt Capacitors

- Full implementation of the installation of the shunt capacitors of the on-going 475 MVar and planned 1,070 MVar by PLN and P3B
- Additional installation of the shunt capacitors of 1,445 MVar up to 2015 and 315 Mvar up to 2021
- Enhancement of power supply reliability by selecting the installation locations for the shunt capacitors through utilizing power cables from the perspective of future system configuration, confirming the specifications of circuit breakers and selecting the shunt capacitors with high endurable performance for electric surges

S-10.2 Voltage Control and System Monitoring

- Changing the rule to authorize making a decision on tap position of the step-up transformer to P3B for new and additional generators including the IPP power station
- Changing the voltage control mode of the large capacity generators from AVR to AQR
- When having priority over a speedy recovery after a large disturbance, it is recommended to install additional shunt capacitors and apply independent VQCs in Jakarta.
- Enhancing network data maintenance for SCADA system in order to have the security analysis function operate more efficiently based on the results of the state estimator

S-10.3 Management of Facility and Analysis Data, Planning of Reactive Power Sources and Installation of Power Plants and Transmission Lines in and around Jakarta

- Preparing a data book of facilities including generators, transmission lines, transformers, the shunt reactor/capacitor, etc. Establishment of a work-flow for the appropriate maintenance of analysis data.
- Annual or periodical planning of reactive power sources such as installation of shunt capacitors
- Ensure steady project implementation of power generators directly connected to the power

supply system in Jakarta Metropolitan Area and 500 kV substations in the northern part of Jakarta for maintenance of voltage stability.

S-10.4 Frequency Conditions and Recommendation

- Installation of the application program of ELD into the SCADA system
- Collection of necessary data for the ELD program
- Study of the system to realize the ELD program
- Study of the system to have the incentive to secure the appropriate spinning reserve of the Java-Bali system
- Development of the generation control system to enable LFC operation
- Consolidated list of conditions concerning LFC operation
- Changing the generation instruction from manual control via phone to direct control via SCADA
- Collecting the information on restrictions which influence generator output
- Sharing the above information among the operators

Chapter 1 Introduction

1.1 Background and Objectives

A recent concern is the issue of bus voltages at the 500 kV key Substations surrounding Jakarta Metropolitan Area, which drops below their operation range during the area's demand peak time (around 1 pm). Such a low-voltage situation might lead to further deterioration of power supply quality in the Capital of the country. Referring to the case in Japan, the wide-spread blackout at Japan's Metropolitan Tokyo area in 1987 is concluded to be caused by the voltage drop due to the fast increase of demand during daytime. In order to avoid such a catastrophic large blackout in Jakarta, it is essential to deploy countermeasures in a timely manner. A lack of urgent countermeasure may bring more economical losses than the cost of its countermeasures if blackout occurs. This study aims to identify issues possibly inherent in the power system, which supplies power to the Jakarta metropolitan Area, and to analyze the cause of voltage drop at substations. The study finally proposes measures for stable power supply in the region.

1.1.1 Contents

- To analyze the issues related to the power system which supplies power to the Jakarta Metropolitan Area and the cause of the voltage drop at substations so that the study would propose measures for future stable power supply in the area;

- To strengthen the executing agency's capacity in the power supply quality improvement through workshops and seminars during the study, finally contributing to the improvement of power supply reliability in the country.

1.1.2 Target Area

The Western Java Island including Jakarta Metropolitan Area

1.1.3 Executing Agency

PT. PLN (Persero)

1.2 Outline of the Project Schedule

Each task of this Project is carried out following three phases as shown below.

Phase 1	Review Power Supply and System Operation Plan
Phase 2	Confirm the Current Situation of System Operation
Phase 3	Develop Voltage Stabilization Plan

Tasks

Schedule

Work Phases

System Operation Planning Group

System Facilities Group

Phase 1
Review Power Supply and System Operation Plan

Inception Report

- Survey on the Policy and Legal Matters related to Power Supply
- Confirmation of Power Supply Planning & Its Current Situations
- Organizational Studies on Planning, Budgeting, and Operation & Management Capacity of System Operation Task
- Analysis of Issues related to Power Supply and Demand at Java-Bali System
- Confirm the Impact of the Blackout in the Economic and Industrial Activities in the Jakarta Metropolitan Area

First Survey in Indonesia
(Middle of Dec.2012)

Phase 2
Confirm the Current Situation of System Operation

Study of Current Operational Condition of the Power Grid near Jakarta (1)
(Voltage, reactive power, reactive power sources, load data, etc.)

Study of Current Operational Condition of the Power Grid near Jakarta (2)
(Identification of the candidate sites for reactive power sources)

Confirmation of System Operation Methods (System Supervising & Controlling Scheme, Generation Substation Voltage Control)

Power System Modeling/Preliminary Analysis with Revised System Data

First Study in Japan
(Middle of Jan. 2013)

Phase 3
Develop Voltage Stabilization Plan

- Estimation of Reactive Power Load
- Power System Modeling/Detailed System Analysis

- Study on Voltage Profile/Voltage Control Patterns
- Recommendation of System Supervising Control Scheme

- Study on Optimum Allocation of Shunt Capacitors in 500kV or lower System
- Study on the Reinforcement Plan of Main Power Transmission Line in West Java System
- Study of the Effectiveness of Power Generation Installation
- Recommendation of Multiple Countermeasures against Voltage Drops
- Consideration of the Effects on Proposed Countermeasures from Viewpoints of both Technical and Economical Aspects

Second Survey in Indonesia
(End of Jan. to Beginning of Feb.)

Draft Final Report

Second Study in Japan

Workshop

Third Survey in Indonesia
(Middle of Apr.)

Final Report

Third Study in Japan

Seminar/Training

Fourth Survey in Indonesia
(Middle of Jun.)

Recommendation of Countermeasures against Voltage Drops in Jakarta

Figure 1.1 Flowchart of the Study

1.3 Staffing for the Study

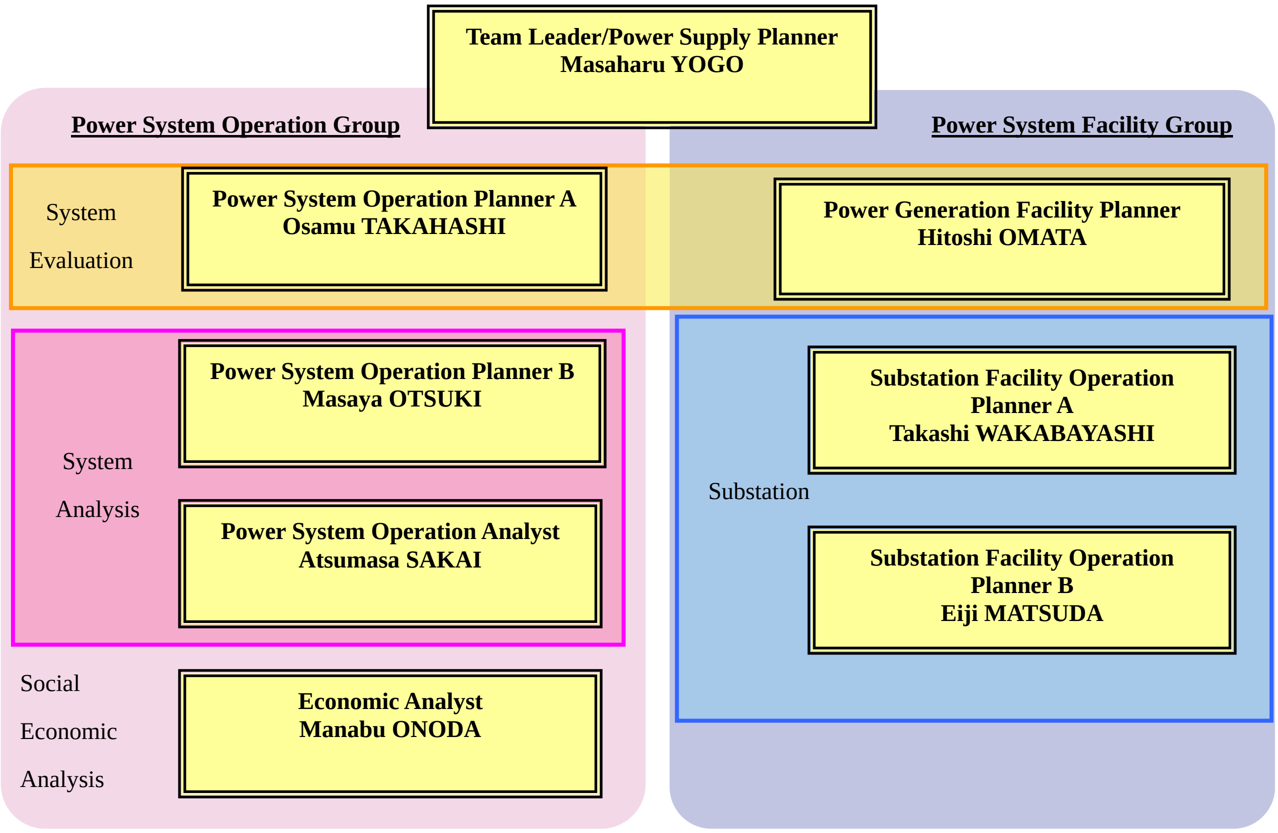


Figure 1.2 Study Team Composition

Chapter 2 Laws and Regulations related to the Grid Operation in Indonesia

2.1 Policies, Laws and Regulations related to the Power Supply

2.1.1 Policies in Power Sector

Under the direction of the Ministry of Energy and Mineral Resources (MEMR), PLN, which is a 100% state-owned electric power company almost exclusively covers all of Indonesia.

MEMR established the national energy policy (KEN, Kebijakan Energi Nasional) related to the overall energy plan in 2004, and the overall national electricity plan (RUKN, Rencana Umum Ketenaga Nasional) as the general electricity plan of Indonesia in 2008. RUKN regulates the power supply needs to ensure its volume, reasonable price and high quality.

Under the RUKN, PLN created an electricity supply business plan titled RUPTL (Rencana Usaha Penyediaan Tenaga Listrik) which MEMR approved and was publicly released in February 2013. The RUPTL shows the development plan of power stations up until 2021, and estimates that the average annual growth of power demand until 2021 will be 8.65%.

2.1.2 Laws and Regulations related to the Power Supply Business

The Government of Indonesia is conducting their Electricity Policy aiming for a low and stable supply of electricity in order to maintain the country’s high economic growth and fair societal development.

Under Law No. 15 (“Old Electricity Law”) established in 1985, a variety of electricity businesses enterprise and related organizations were subjected to restrictions. Furthermore, PLN as a holder of the electricity business authority has become the only enterprise having monopolistic control over generation, transmission and distribution.

As time goes by, Indonesia’s circumstances changed and electricity demand began gradually expanding. To cover and fulfill the growing demand, the utilization of IPPs has been expected. In 1992, the Presidential Degree No.37 was issued allowing IPPs to join the field of generation. However, due to the Asian Financial Crisis in 1997, many IPP projects except a few were shut down by the Government.

In September 2002, Law No.20 was affected and it aimed to abolish PLN’s monopoly of electricity supply and also intended for IPPs to be able to join the field of generation and retail business under the free market mechanism principle. However, the Constitutional court judged that Law No.20 was unconstitutional and was thus voided on 15 December, 2004. After the unconstitutional judgment, Law No. 15 (“Old Electricity Law”) again became effective. In September 2009, the New

Electricity Law was enacted and expected to encourage new entries.

In August 2007, the government established the Energy Law to supervise the energy sector comprehensively, because the previous management structure managed individual energy sources. The Energy Law stipulates that the government is responsible for energy resources management and puts domestic energy supplies before energy exports. The New Electricity Law (2009) regulates that the government capping PLN is responsible for continuous power supply, in addition to allowing the private sector to enter the electricity business.

2.2 Regulations related to Voltage Control in Grid Code

The P3B which PLN established as its internal business unit manages the transmission system in the Jakarta Metropolitan Area. The usage policy of the transmission system is regulated in the Grid Code, which plays an important role in Indonesia to ensure fair use of all users including the P3B. This subchapter shows the contents of the Grid Code focusing on the regulations related to Voltage Control.

2.2.1 Objective of the Grid Code

The purpose of the Grid Code is to establish standards for all network users connected to the transmission system from both a technical and operational perspective. The grid code is applied to PLN, P3B and other users such as generation companies, distribution companies, large electricity consumers, and companies working for the aforementioned network users as development and/or maintenance contractors etc.

2.2.2 Regulations Related to the Operation of Transmission System

The Grid Code mandates that all network users including PLN and P3B try as much as possible to ensure that every connection point in the following performance is fulfilled.

(a) Frequency

The nominal frequency of 50 Hz shall be arranged so it is not lower than 49.5 Hz, or higher than 50.5 Hz, and during the time of emergency and disturbance, the System frequency is allowed to be between 47.5 Hz to 52.0 Hz

(b) Voltage

The System voltage shall be maintained within the following limits:

Nominal Voltage	Normal Conditions
500 kV	+5%, -5%
150 kV	+5%, -10%
70 kV	+5%, -10%
20 kV	+5%, -10%

(c) Harmonic

The maximum total harmonic distortion in each connection point under normal operating conditions shall fulfil the following:

Nominal Voltage	Normal Condition
500 kV	(None)
150 kV	3%
70 kV	3%
20 kV	3%

(d) Voltage Unbalance

The maximum negative sequence component of the phase voltage in the System may not exceed 1%, and shall not exceed 2% during the momentary impulse voltage occurrence

(e) Voltage Fluctuation

The voltage fluctuation in every connection point with the fluctuating load must not exceed the limit of:

(i) 2% of the voltage rate for each change of step, which may occur repeatedly. Each large voltage excursion occurrence beyond the change of step may be allowed up to 3% provided that it does not cause risks against the transmission system, or the installation of network user. A non-frequently occurring voltage flicker up to 5% when running the electric motor can be tolerated.

(ii) flicker of 1.0 Pst (Perception of flicker short term) and 0.8 Plt (Perception of flicker long term) measured by a flicker meter compatible with IEC-868 specifications.

(f) Power Factor

The power factor in the connection point between the installations of network users with the System shall be minimally 0.85 lagging.

(g) Monitoring and Record

Both parties are required to install a power meter that can continuously monitor and record in the form of electronic data.

2.2.3 Procedure of the Transmission Usage

Network users have to submit an application at the latest 30 (thirty) working days prior to the date of energizing the connection point, and prove to P3B that the network user has fulfilled the requirements as specified in the Grid Code.

The P3B is obliged to conduct an examination and make a decision regarding whether the facilities of the network user has fully met the requirements in the Grid Code. When P3B declares that the condition meets the requirements of the Grid Code and is ready to be connected to the System, P3B has to issue a connection point certificate, and make an agreement with the network user pertaining to such procedures and time. After connecting the network system, all network users are obliged to not only meet the requirements of the Grid Code but also contribute to the necessary safe and reliable operations.

2.2.4 Conclusion

All network users in Indonesia including PLN need to meet the requirements as specified in the Grid Code. When P3B declares it and makes a joint agreement, network users are allowed to connect the transmission system, and obliged to not only meet the requirements of the Grid Code but also contribute to the necessary safe and reliable operations.

2.3 Organization Structure

This subchapter describes the government organization related to the power sector, PLN which is the state-owned electric power company, and P3B Java Bali (P3B JB) which is one of the business units of PLN and manages the operations and management of the transmission system in Java Island including the Jakarta Metropolitan Area.

2.3.1 Related Organization and their Role in the Power Sector

The followings are the main Governmental organizations in the Power Sector.

- Ministry of Finance (MOF)
  Controlling and supervising PLN from a finance perspective.

- Ministry of Energy and Mineral Resources (MEMR)
  Responsible for the development policy and energy plan in Indonesia

- Ministry of State Owned Enterprises (MSOE)
  Having the power to supervise all state-owned enterprises including PLN in terms of the owner
- National Development Planning Agency (BAPPENAS)
  Designing whole development plans in Indonesia.

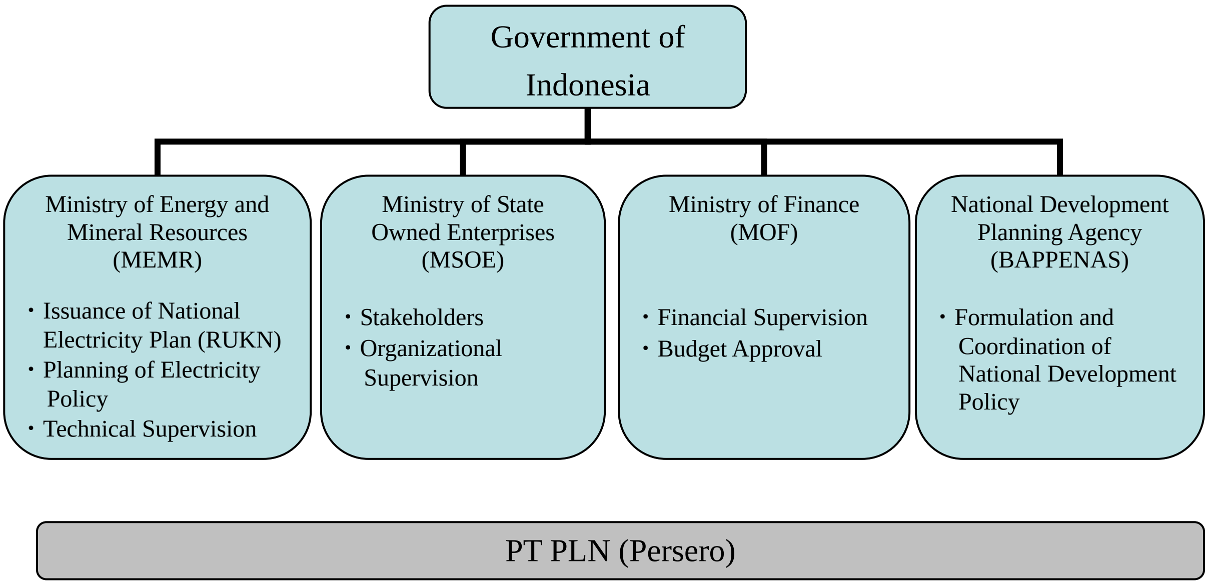
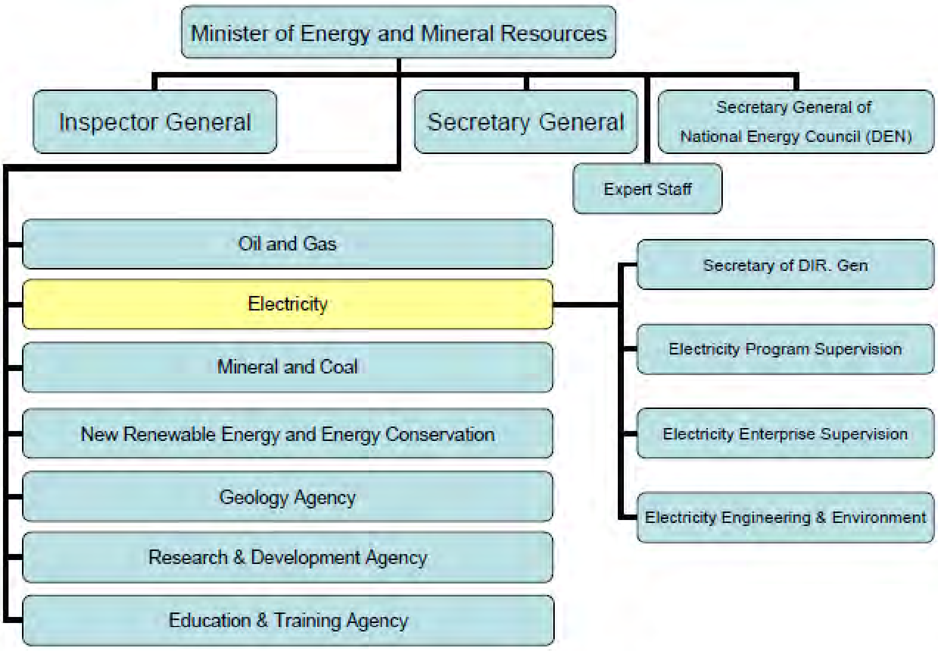


Figure 2.1 Framework of the Power Sector in Indonesia

MEMR is closely in charge of the development plan in the power sector. The following is the current organizational structure of MEMR

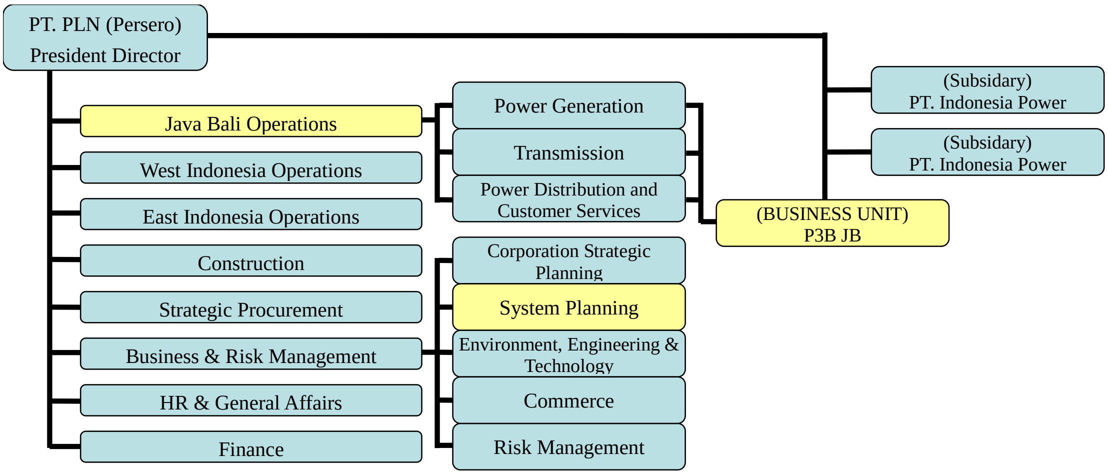


(Source: the Study Team developed based on the organization structure as of 31 Jan. 2013)

Figure 2.2 Organizational Structure of MEMR

2.3.2 PT PLN

PLN is a 100% state-owned electric power company covering all of Indonesia. The organizational structure is shown as follows and the yellow-marked items play central roles to improve voltage drops in the Jakarta Metropolitan Area.



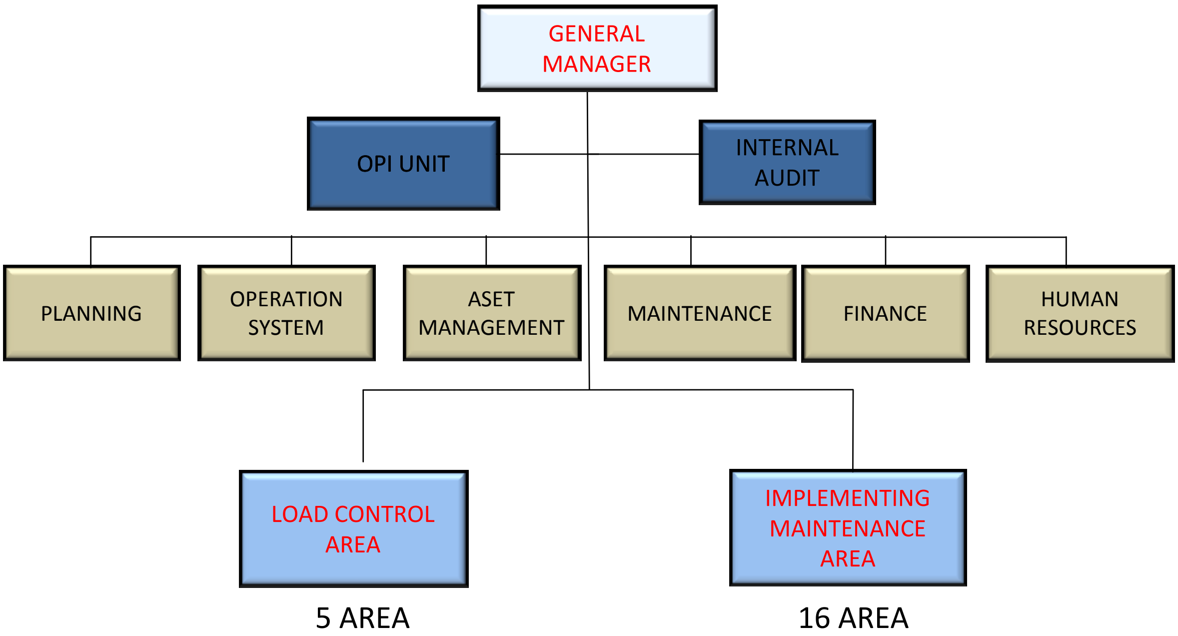
(Source: the Study Team developed based on the PLN's material "About PLN")

Figure 2.3 PLN Organization Chart

2.3.3 P3B JB

The following chart shows the structure of P3B JB which takes over, operates and maintains the transmission system. P3B JB has implemented organizational changes, and managed the whole transmission system in Java Island on behalf of the four regional centers (Jakarta & Banten Area, West Java Area, Central & Yogyakarta Area, East Java & Bali Area) which have been disestablished since 2012. P3B JB divided the East Java & Bali Area into 2 areas (East Java and Bali), and has managed a total of 5 areas. The followings are their main tasks.

- Operation of Java Bali network system
- Operation and Maintenance of transmission and substation
- Network Investment Planning



(Source: the Study Team translated the Profile P3B Jawa Bali 2012 into English)

Figure 2.4 Organization of P3B JB

2.3.4 Transmission Operation Framework

Approximately 60% of the nation’s overall population and 80% of the overall power demand is in Java Island. At Java Bali system which is the largest business, PLN, Indonesia Power (IP) and Pembangkitan Jawa-Bali (PJB) which are PLN-affiliated companies, and IPPs are involved in power generation. P3B JB which is one of the PLN’s business units is responsible for managing the transmission network and 5 regional offices manage their distribution business.

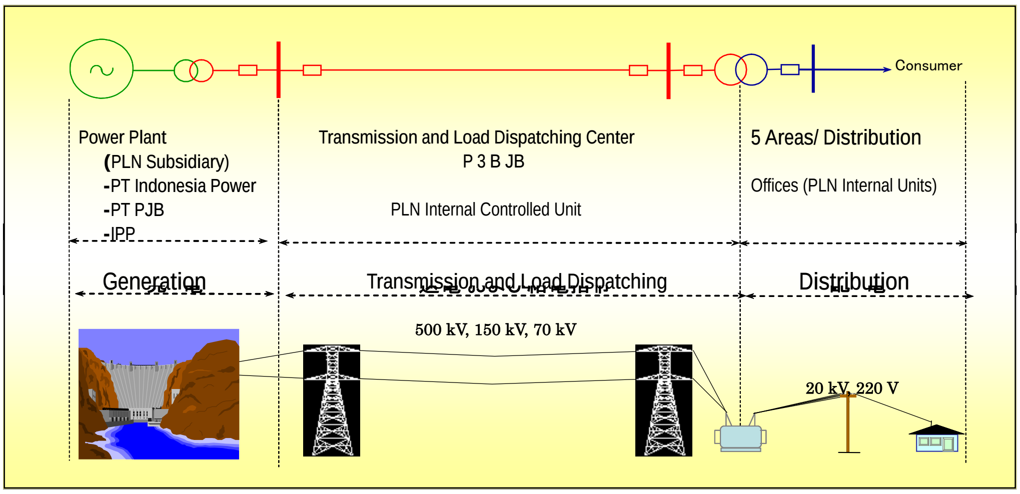
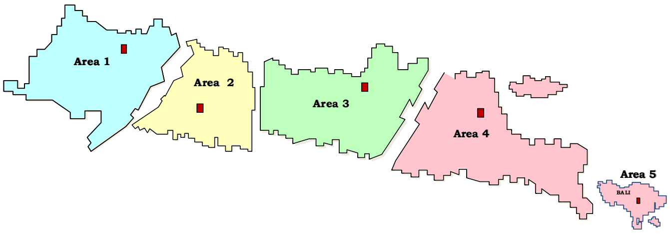


Figure 2.5 Framework of Electricity Supply in Java-Bali Area

The Java Bali system is divided into five regions and each region is under each area control center (ACC). The central control center (Java Bali Control Center: JCC) in Gandul monitors the frequency and 500kV voltage levels of the entire network system, and instructs the power stations connected to the system. Each ACC monitors the 150 kV and 70 kV networks and reports the pass on instruction from JCC to power stations. As per 20kV or less than the 20kV distribution lines, each distribution business unit is in charge.



Source: P3B JB

Figure 2.6 Five Regions controlled by ACCs

Table 2.1 P3B JB's Control Center

Area	Name	Area Control Center (ACC)	Central Control Center
Jakarta & Banten Area	Area 1	ACC Cawang	Jawa-Bali Control Center (JCC) (at Gandul 500kV SS)
West Java Area	Area 2	ACC Cigereleng	
Central & Yogyakarta Area	Area 3	ACC Ungran	
East Java Area	Area 4	ACC Waru	
Bali Area	Area 5	ACC Bali	

Source: Rencana Operasi Sistem Tenaga Listrik Jawa Bali Tahun 2013

Note: Each area shown in Table 2.1 is called the "Region" with its region number, but only Region 4 refers to both Area 4 and Area 5 together in this report.

2.4 Financial and Budget Condition

To consider the measures to improve the voltage drop in the Jakarta Metropolitan Area, it is important to figure out P3B JB's financial and budget conditions in equipment investment. This subchapter considers the feasibility of equipment investment with a historical performance based on P3B JB's data. P3B JB has tried to launch the statistics of P3B JB itself in detail and with accuracy in order to show business performance.

2.4.1 Income Statement of P3B JB

P3B JB has developed their income statement. The income statement developed in July 2012 is shown in the below table which says that the revenues, expenses and profits of P3B have continued to rise. P3B JB has earned intracompany profit from PLN based on its amount of transferred electricity and agreed on transaction prices. The depreciation has accounted for more than half of the expenditures and continued to rise, which means P3B JB funnels a large portion of its budget into equipment investments.

Table 2.2 Income Statement of P3B JB (2007-2011)

Unit: Million IDR

	2007	2008	2009	2010	2011
Operating Revenue	4,742,456	5,619,413	5,718,979	6,596,695	6,634,539
Maintenance Cost	2,517,003	2,721,911	2,809,425	3,289,098	3,194,412
Material Usage	316,244	389,340	424,078	584,775	694,689
Wholesale Service	94,299	112,850	107,443	222,711	228,956
Staffing	556,832	668,782	680,135	894,345	634,087
Depreciation	1,544,838	1,569,296	1,628,926	1,675,949	1,765,481
Administration	99,088	94,491	76,285	134,027	100,154
Profit (Loss)	2,225,453	2,897,502	2,909,554	3,307,597	3,440,127
Other Revenue	218,390	297,458	24,377	546,814	466,704
Interest Income	(1,140)	(1,567)	(1,807)	(1,472)	(1,455)
Miscellaneous Income	(19,018)	(52,185)	(75,094)	(58,447)	(24,395)
Loan Burden	138,471	106,970	77,718	369,549	355,353
Retirement Plan	16,423	21,655	24,272	27,211	30,026
Other Burden	19,650	84,382	120,442	282,158	177,338
Burden of Foreign Exchange	64,003	138,203	(121,154)	(72,185)	(70,162)
Net Profit (Loss)	2,007,063	2,600,044	2,885,177	2,760,783	2,973,422

(Source: the Study Team developed based on STATISTIK 2011 (P3B JAWA BALI))

2.4.2 Balance Sheet of P3B JB

Table 2.3 and Table 2.4 show the balance sheets of P3B JB. Table 2.3 shows that the bulk of P3B JB’s net worth are fixed assets and the net assets are steadily increasing each year. On the other hand, about 1% of the total liability to the capital ratio states that P3B JB tends to use funds to make investments based on the operating revenues from PLN.

Table 2.3 Asset Side of the Balance Sheet

Unit: Million IDR

	2007	2008	2009	2010	2011
Net Asset	34,253,025	34,099,785	34,366,762	36,067,537	36,776,660
Fixed Assets (Gross)	43,180,566	44,539,603	46,381,961	49,658,883	51,966,609
Accumulated Depreciation	(8,927,540)	(10,439,817)	(12,015,198)	(13,591,345)	(15,189,948)
Work on Implementation	137,905	1,100,885	1,785,833	1,571,725	2,280,493
Non-current Assets	266,886	210,442	268,699	337,193	391,967
Current Assets	107,758	129,137	124,823	108,682	214,421
Total Assets	34,765,576	35,540,251	36,546,118	38,085,138	39,663,544

(Source: the Study Team developed based on STATISTIK 2011 (P3B JAWA BALI))

Table 2.4 Capital and Liability Side of Balance Sheet

Unit: Million IDR

	2007	2008	2009	2010	2011
Total Capital	2,007,063	2,600,044	2,885,177	2,760,783	2,973,422
Accounts Administration	32,669,597	32,488,358	33,461,959	34,951,034	36,461,570
Long-term Liability	14,183	14,183	14,183	-	-
Short-term Liability	74,731	437,664	184,797	373,321	228,551
Total Capital and Liability	34,765,576	35,540,251	36,546,118	38,085,138	39,663,544

(Source: the Study Team developed based on STATISTIK 2011 (P3B JAWA BALI))

2.4.3 Conclusion

The income statement of P3B JB shows that the revenues, expenses and profits of P3B have continued to rise. In addition, P3B JB has put a large portion of its budget into equipment investments because the depreciation is increasing each year.

The balance sheets show that the bulk of P3B JB's net worth is fixed assets and the net asset is steadily increasing each year. On the other hand, the total liability to capital ratio is about 1%, and P3B JB tends to use funds to make investments based on the operating revenues from PLN.

The profit and fixed assets of P3B JB are steadily increasing which means that the same ratio of increase will continue shown in the below table, based on the strong growth of power demand in Indonesia.

Table 2.5 Increase of Profit and Fixed Assets

Unit: Million IDR

	Profit	Increase of Profit against the previous year	Fixed Assets (Gross)	Increase of Fixed Assets against the previous year
2007	2,007,063	-	43,180,566	-
2008	2,600,044	129,54%	44,539,603	103,15%
2009	2,885,177	100,97%	46,381,961	104,14%
2010	2,760,783	95,69%	49,658,883	107,07%
2011	2,973,422	107,70%	51,966,609	104,65%

(Source: the Study Team developed based on STATISTIK 2011 (P3B JAWA BALI))

2.5 Management

To consider the measurements to improve voltage drops, it is important for P3B JB's structure to play a role in the management of the transmission system. This subchapter evaluates transmission system management based on P3B JB's data of human resources, facility development and operations.

2.5.1 Human Resources of P3B JB

Table 2.6 shows that the total number of P3B JB's staff has declined after peaking in 2008. Table 2.7 shows that the number of areas of expertise (System, Specific) has increased instead of the Basic having declined. Table 2.8 shows that compared to those with lower education, the number of more well-educated staff has increased.

As a result, P3B JB has tried to improve their operational efficiency entirely through the development of expertise and corporate downsizing.

Table 2.6 Number of Staff in Each Unit (2007-2011)

	Kantor Induk	RJKB	RJBR	RJTD	RJTB	Total
2007	330	1,177	850	815	1,000	4,172
2008	324	1,199	900	816	1,098	4,337
2009	318	1,224	885	809	1,100	4,336
2010	338	1,196	864	788	1,061	4,247
2011	340	1,136	817	742	1,013	4,048
Kantor Induk: P3B JB’s Head Quarter, RJKB: Jakarta & Banten Area, RJBR: West Java Area, RJTD: Central & Yogyakarta Area, RJTB: East Java & Bali Area						

Source: STATISTIK 2011 (P3B JAWA BALI)

Table 2.7 Distribution of Occupation (2008-2011)

	Integration	Advanced	Optimization	System	Specific	Basic
2008	3	29	143	298	1,596	2,268
2009	2	21	127	313	1,707	2,166
2010	-	21	102	396	1,907	1,821
2011	-	20	77	401	1,976	1,574

Source: STATISTIK 2011 (P3B JAWA BALI)

Table 2.8 Educational Level of Staff (2007-2011)

	BASIC EDUCATION	DIPLOMA	BACHELOR	MASTER
2007	3,428	195	506	43
2008	3,152	588	550	47
2009	3,071	644	574	47
2010	2,921	700	578	48
2011	2,671	718	608	51

Source: STATISTIK 2011 (P3B JAWA BALI)

2.5.2 Facility Management of P3B JB

The facilities under P3B JB’s management are increasing each year. Table 2.9 shows that the total length of the transmission line in 2011 increased more than 1,000km compared to 2007. Table 2.10 also shows that the total capacity of the transformers in 2011 increased to about 10,000 MVA compared to 2007. The reason is that the facilities have been developed in proportion to the growth of electricity demand shown in Table 2.11.

Table 2.9 Total Length of Transmission Line (2007-2011)

Transmission Line (km)	2007	2008	2009	2010	2011
500 kV	5,048	5,092	5,111	5,052	5,052
150 kV	11,669	11,844	11,973	12,371	12,906
70 kV	3,603	3,612	3,506	3,608	3,474
Total	20,320	20,548	20,590	21,031	21,432

Source: STATISTIK 2011 (P3B JAWA BALI)

Table 2.10 Total Capacity of Transformers (2007-2011)

	2007		2008		2009		2010		2011	
	Unit	MVA	Unit	MVA	Unit	MVA	Unit	MVA	Unit	MVA
500/150	35	17,000	35	17,000	38	18,500	40	19,500	47	23,000
150/70	60	3,579	59	3,569	61	3,579	61	3,819	60	3,719
150/TM	548	26,070	555	26,481	561	47,075	5780	28,434	601	30,001
70/TM	135	2,802	135	2,748	138	2,741	127	2,751	128	2,727
Total	778	49,451	784	49,798	798	52,135	808	54,504	836	59,447

Source: STATISTIK 2011 (P3B JAWA BALI)

Table 2.11 Increase of Electricity Demand and Facilities

Of the year 2006					Increase (%)	Against the previous year				
2007	2008	2009	2010	2011		2007	2008	2009	2010	2011
5.55	5.89	11.79	17.56	28.21	Peak Demand	5.55	0.31	5.58	5.17	9.06
6.26	10.53	15.25	23.91	32.33	Energy Products	6.26	4.02	4.27	7.52	6.79
-1.22	1.45	5.96	5.04	16.08	DMN	-1.22	2.70	4.44	-0.86	10.51
2.09	2.80	7.63	12.52	22.72	Transformer/MVA	2.09	0.70	4.69	4.54	9.07
0.63	1.76	1.97	4.16	6.14	Transmission/km	0.63	1.12	0.20	2.14	1.91

Source: STATISTIK 2011 (P3B JAWA BALI)

2.5.3 Operation and Maintenance of P3B JB

The numbers in the case of disturbances is shown in the below tables. The number of interruptions has declined or remained after peaking in 2009.

Table 2.12 Disturbance of the Power Supply (2007-2011)

	TR	TL	Busbar	
				Total
2007	96 (83)	236 (64)	15 (12)	347 (159)
2008	134 (115)	277 (80)	0 (0)	411 (195)
2009	131 (124)	289 (74)	6 (5)	426 (203)
2010	115 (106)	244 (62)	8 (6)	367 (174)
2011	134 (101)	258 (65)	4 (2)	396 (168)

*1 TR = Transformer
*2 TL = Transmission Line
*3 Figures in parentheses show the number of the disturbance led to power failure

Source: STATISTIK 2011 (P3B JAWA BALI)

Table 2.13 Disturbance of Transformers (2007-2011)

	500kV/150kV TR	150kV/70kV TR	150kV TL	70kV TL	150kV/20kV TR including 20kV TL	70kV/20kV TR including 20kV TL
2007	15 (4)	7 (5)	66 (66)	8 (8)	8 (8)	0 (0)
2008	22 (10)	9 (6)	80 (77)	0 (0)	23 (22)	0 (0)
2009	11 (8)	7 (4)	98 (98)	0 (0)	15 (14)	0 (0)
2010	15 (13)	12 (6)	45 (44)	14 (14)	22 (22)	7 (7)
2011	20 (5)	6 (5)	58 (53)	16 (13)	33 (25)	1 (0)

*1 TR = Transformer
*2 TL = Transmission Line
*3 Figures in parentheses show the number of the disturbance led to power failure

Source: STATISTIK 2011 (P3B JAWA BALI)

Table 2.14 Disturbance of Transmission Lines and Busbars (2007-2011)

	Transmission Line			Busbar		
	500kV	150kV	70kV	500kV	150kV	70kV
2007	16 (0)	128 (33)	92 (31)	1 (1)	10 (8)	4 (3)
2008	16 (0)	133 (33)	128 (47)	0 (0)	0 (0)	0 (0)
2009	32 (3)	145 (37)	100 (34)	0 (0)	3 (3)	3 (2)
2010	34 (1)	138 (34)	139 (27)	0 (0)	5 (3)	3 (3)
2011	28 (2)	143 (47)	87 (16)	1 (0)	3 (2)	0 (0)

* Figures in parentheses show the number of the disturbance led to power failure

Source: STATISTIK 2011 (P3B JAWA BALI)

2.5.4 Conclusion

According to the human resource data, it is expected that P3B JB has tried to decrease total staff numbers and increase the number of well-educated staff to develop expertise. The facilities under P3B JB's management are increasing each year while the number of malfunctioning facilities have declined or remained. This result implies that the number of disturbances per facilities is on a declining trend.

Chapter 3 Current Voltage Control in the Jakarta System

In this chapter, the current situations of PLN's power system operation for the Jakarta power system are described. The network system in the Jakarta Metropolitan Area, which includes its surrounding area called Region 1, is a part of Java Bali system.

3.1 Main Specifications of Power System Facilities

3.1.1 500kV Transmission Line

ACSR "Dove" and "Gannet" are applied to existing 500kV transmission lines in the Java-Bali system. One circuit per one tower, two circuits per two towers, two circuits per one tower and four circuits per one tower are used as a tower configuration for "Dove" and two circuits per two towers and two circuits per one tower are used as a tower configuration for "Gannet". ACSR "Zebra" will be applied to the transmission lines when a higher transmission capacity is necessary for the future system.

Table 3.1 500kV Transmission Lines in Java-Bali System

Conductor type	Capacity [MVA]	Tower	No. of transmission lines
ACSR/AS 4×DOVE	1984.9	1 cct 1 tower	1 cct (Cilegon – Cibinong)
ACSR/AS 4×DOVE	1984.9	2 cct 2 tower	10 ccts (eg. Suralaya – Balaraja)
ACSR/AS 4×DOVE	1984.9	2 cct 1 tower	19 ccts (eg. Bekasi-Cibinong）
ACSR/AS 4×GANNET	2209.2	2 cct 2 tower	4 ccts (eg. Bandung Selatan – Saguling)
ACSR/AS 4×GANNET	2209.2	2 cct 1 tower	22 ccts (eg. Cilegon-Suralaya）
ACSR/AS 4×ZEBRA	2611.9	2 cct 1 tower	New transmission lines

3.1.2 500/150kV Transformers in Java-Bali System

Table 3.2 shows capacities and impedances of 500/150kV transformers in the Java-Bali system.

Table 3.2 Capacities and Impedances of 500/150kV Transformers in Java-Bali System

Substation	ID	Capacity [MVA]	Impedance(per unit winding base)	No. of transformers
Suralaya	IBT-1	250	0.1427	1
Suralaya	IBT-2	250	0.1310	1
The other substations	-	500	0.1301-0.1427	49

3.1.3 Shunt Reactors/Capacitors

Table 3.3 to Table 3.6 shows the rated voltages and capacities of existing, on-going and planned shunt reactors and capacitors in the Java-Bali system. The shunt reactors are mainly connected to the 500kV system and the shunt capacitors are connected to the 150kV, 70kV and 20kV systems. Each piece of data in the tables is based on P3B:”Program Peningkatan Kuakitas Tegangan” and analysis data (DIgSILENT data) received from the P3B operation system division.

Table 3.3 Shunt Reactors in Java-Bali System (always-on)

Area	Voltage [kV]	Unit size [MVar]	No. of units	Capacity [MVar]
Region 1	500	100	1	100
Region 2	500	100	2	200
Region 3	500	100	2	200
Region 4	500	100	2	200
		50	2	100
Total				800

Table 3.4 Shunt Capacitors in Java-Bali System (Existing)

Area	Voltage [kV]	Unit size [MVar]	No. of units	Capacity [MVar]
Region 1	150	25	10	250
	70	10	1	20
Region 2	150	25	2	50
	70	10	2	20
Region 3	150	25	3	75
Region 4	150	25	10	250
		10	5	50
	70	20	1	20
		10	5	50
Region 5	150	25	7	175
Total				950

Table 3.5 Shunt Capacitors in Java-Bali System (On-going)

Area	Voltage [kV]	Unit size [MVar]	No. of units	Capacity [MVar]
Region 1	150	50	7	350
		25	5	125
Total				475

Table 3.6 Shunt Capacitors in Java-Bali System (Planned)

Area	Voltage [kV]	Unit size [MVar]	No. of units	Capacity [MVar]
Region 1	150	50	15	750
	20	20	11	220
Region 2	150	50	2	100
Total				1,070

3.2 Capacity and Location of Reactive Power Control Equipment

3.2.1 PLN's Emergency Capacitor Bank Installation Plan

PLN has developed their plan for emergency capacitor bank installation as a countermeasure against the network voltage drop caused by increasing electricity demand. The plan's total budget has been already approved internally, and PLN's engineering departments are now studying the availability of the candidate substations' yards for the capacitor banks, and developing construction plans for individual substations.

In PLN's installation plan, Capacitor banks of 1,070 MVAR will be installed in the near future succeeded by the completion of on-going 475MVAR capacitor bank installation. Currently, PLN has 260MVAR capacitor banks installed for the sake of socially important customers in the Jakarta Power grid. The actual plan consists of nineteen 50MVAR capacitor bank installations on 150kV substations' busbars, and a remaining 25/10MVAR capacitor banks on the 22kV busbars as shown in Table 3.7 - Table 3.10.

The locations of the capacitor banks are selected for the 150kV busbars that are electrically the farthest from the supply-side of the 500kV bulk power buses while considering the actual power system operation during a heavy load period, but does not guarantee the space availability of the selected substations for 50MVAR capacitor bank equipment. Although the target completion year of the capacitor bank installation is not clearly stated in the plan, PLN expects the completion year of the 450MVAR on-going installation to be 2013, and the one of additional banks to be 2015. To achieve these urgent installations, corresponding engineering departments are now developing a detailed plan and design of these capacitor bank installations.

Table 3.7 Capacitor Bank Installed in PLN Grid

Subsystem	Substaton	Capacity (MVAR)
Cibinong	Pelabuhan Ratu	10
Gandul 1,2	Teluk Naga	25
Gandul 1,2	Durikosanbi	25
Gandul 1,2	Petukangan	25
Gandul 1,2	Cengkareng	25
Kembangan	Tangerang Lama	25
Bekasi 1,2	Pulogadung	25
Bekasi 1,2	Plumpang	25
Bekasi 1,2	Kemayoran	25
Bekasi 1,2	Angke	25
Bekasi 3,4	Bekasi	25
Total		260

(Source: P3B document：Program Peningkatan Kualitas Tegangan)

Table 3.8 Capacitor Bank under Construction

Subsystem	Substation	Capacity (MVAR)※	Commissioning Yea (Replacement)
Cibinong	Cibinong	25	2012
Kembangan	Tangerang Lama	25	2012
Kembangan	Jatake	25	2011
Bekasi 3,4	Bekasi	50	2011
Bekasi 3,4	Bekasi	−25	2011,Relocation (to Legok)
Gandul 1,2	Durikosanbi	50	2011
Gandul 1,2	Durikosanbi	−25	2011,Relocation (to Angke)
Depok	Cawang Lama	25	2011
Depok	Cawang Lama	50	2012
Depok	Cawang Lama	50	2012
Balaraja	Lengkong	50	2012
Balaraja	Lengkong	25	2011,Relocation (from Plogadung)
Balaraja	Legok	50	2012
Balaraja	Legok	25	2011,Relocation (from Bekasi)
Bekasi 1,2	Pulogadung	50	2011
Bekasi 1,2	Pulogadung	−25	2011
Bekasi 1,2	Kemayoran	25	2012
Bekasi 1,2	Angke	25	2011,Relocation (from Durikosanbi)
Total		475	

※ Minus (−) indicates the removal of capacitors for replacement

(Source: P3B document：Program Peningkatan Kualitas Tegangan)

Table 3.9 Capacitor Bank for Future Expansion (1/2)

Subsystem	Substation	Capacity (MVAR)※	Commissioning Yea (Replacement)
Cibinong	Cibadak Baru	50	150kV, 1 Unit
Cibinong	ITP	50	150kV, 1 Unit
Bekasi 3,4	Jatirangon	50	150kV, 1 Unit
Bekasi 3,4	Jatirangon	50	150kV, 1 Unit
Bekasi 3,4	Bekasi	50	150kV, 1 Unit
Bekasi 3,4	Miniatur	20	20kV, 2 Units
Bekasi 1,2	Pegangsaan	10	20kV, 1 Unit
Bekasi 1,2	Kandang Sapi	10	20kV, 1 Unit
Bekasi 1,2	Gambir Baru	10	20kV, 1 Unit
Kembangan	Cikupa	50	150kV, 1 Unit
Kembangan	Maximangando	50	150kV, 1 Unit
Kembangan	Ciledug	50	150kV, 1 Unit
Kembangan	Curug	10	20kV, 1 Unit
Kembangan	New Senayan	10	20kV, 1 Unit
Depok	Depok	50	150kV, 1 Unit
Cawang	Karet Lama	50	150kV, 1 Unit
Cawang	Karet Lama	50	150kV, 1 Unit
Cawang	Pulomas	25	20kV, 2 Units
Cawang	Gambir Lama	20	20kV, 2 Units
Balaraja	Tigaraksa	50	150kV, 1 Unit
Balaraja	Balaraja Lama	50	150kV, 1 Unit
Balaraja	Serpong	50	150kV, 1 Unit
Gandul 1,2	Serpong	50	150kV, 1 Unit
Gandul 3	Gandul	50	150kV, 1 Unit
Cilegon 1,2	Cikande	50	150kV, 1 Unit
Cibatu 1,2	Tambun	50	150kV, 1 Unit
Cibatu 1,2	Poncol	50	150kV, 1 Unit
Total		1065	

※ PLN specified 1065 MVAR capacitor banks out of 1070 MVAR in total

(Source: P3B document：Program Peningkatan Kualitas Tegangan)

Table 3.10 Capacitor Bank for Future Expansion (2/2)

Subsystem	Substation	Capacity (MVAR)※	Commissioning Yea（Replacement）
Cibinong	Cibadak Baru	50	150kV, 1 Unit
Cibinong	ITP	50	150kV, 1 Unit
Bekasi 3,4	Jatirangon	50	150kV, 1 Unit
Bekasi 3,4	Jatirangon	50	150kV, 1 Unit
Bekasi 3,4	Bekasi	50	150kV, 1 Unit
Bekasi 3,4	Miniatur	20	20kV, 2 Units
Bekasi 1,2	Pegangsaan	10	20kV, 1 Unit
Bekasi 1,2	Kandang Sapi	10	20kV, 1 Unit
Bekasi 1,2	Gambir Baru	10	20kV, 1 Unit
Kembangan	Cikupa	50	150kV, 1 Unit
Kembangan	Maximangando	50	150kV, 1 Unit
Kembangan	Ciledug	50	150kV, 1 Unit
Kembangan	Curug	10	20kV, 1 Unit
Kembangan	New Senayan	10	20kV, 1 Unit
Depok	Depok	50	150kV, 1 Unit
Cawang	Karet Lama	50	150kV, 1 Unit
Cawang	Karet Lama	50	150kV, 1 Unit
Cawang	Pulomas	25	20kV, 2 Units
Cawang	Gambir Lama	20	20kV, 2 Units
Balaraja	Tigaraksa	50	150kV, 1 Unit
Balaraja	Balaraja Lama	50	150kV, 1 Unit
Balaraja	Serpong	50	150kV, 1 Unit
Gandul 1,2	Serpong	50	150kV, 1 Unit
Gandul 3	Gandul	50	150kV, 1 Unit
Cilegon 1,2	Cikande	50	150kV, 1 Unit
Cibatu 1,2	Tambun	50	150kV, 1 Unit
Cibatu 1,2	Poncol	50	150kV, 1 Unit
Total		1065	

※ PLN specified 1065 MVAR capacitor banks out of 1070 MVAR in total

(Source: P3B document：Program Peningkatan Kualitas Tegangan)

(Source: P3B document：Program Peningkatan Kualitas Tegangan)

Figure 3.1 Surveyed Substations in the Study

The PLN’s emergency capacitor installation plan has evaluated the system voltage improvement effects of the total amount of the 1550 MVAR capacitor bank through the power flow analysis of 2012. It concludes that the on-going 475 MVAR installation does not meet the required amount of reactive power sources, but additional 1070 MVAR installation to the on-going 475 MVAR could maintain the majority of busbar voltages in Jakarta subsystems within -5 % of the nominal voltage, at which PLN’s operation code specifies the allowable voltage drop threshold. The study team accordingly decided to verify PLN’s evaluation and evaluate the necessary reactive power sources in the future considering increased demand in the system, which will be reported in Chapter 5.

The study team also visited the substations where PLN’s report selected the candidate locations for capacitor bank installation, and confirmed that in the Plogadung Substation, the existing capacitor banks had been removed as specified in the plan, and the plinth modification for the 50MVAR new capacitor bank was ongoing. Similarly, in the Bekasi substation, a 25MVAR capacitor bank had been dismantled for transportation while circuit breakers remain to be connected to the new capacitor banks, and the plinth modification was ongoing as shown in Figure 3.3. Since the PLN’s capacitor installation plan shows both the dismantling work scheduled for completion in 2011, evaluations of the proceedings of the on-going construction work show that there will be an approximate one-year delay from the original schedule.

(After dismantling the existing capacitor banks, the plinths’ width are increased to fit the new equipment weight and base dimensions)

(The condenser element dismantled and to be transported to the other substation with the nameplate of Cooper of U.S.A. and McGraw-Edison Capacitors, which we believe may be the manufacturer of the element.)

Figure 3.2 Removed Capacitor Bank in Plogadung

(The fences and plinths will be modified to fit the new capacitor banks as Plogadung case. Circuit breakers will be re-used for the new capacitor banks)

Figure 3.3 Site for Capacitor Bank in Bekasi

3.2.2 PLN’s Specifications for Capacitor Bank Installation

The study team investigated PLN’s design standards and specifications for the new capacitor bank installation. Basically, the electrical equipment configuration of the new capacitor bank mainly depends on the availability of a new 150kV feeder necessary for a new capacitor bank connection, and as a result, three connection configurations has been developed to minimize the initial cost for a new capacitor bank as shown below. Furthermore, PLN is concerned that such an early manifestation of circuit breaker troubles with regard to their equipment lifetime expectation: 30years from its commission.

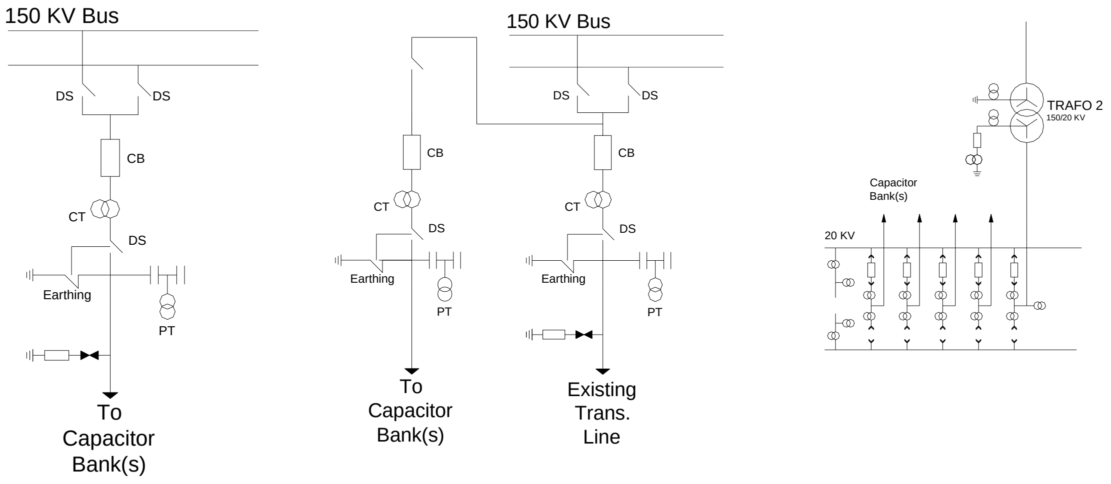
(1st priority) If an existing 150kV air-insulated feeder is available or a new feeder can be built in the target substation, new capacitor banks will be connected to that feeder.

(2nd priority) If an individual 150kV air-insulated feeder is not available, new capacitor banks will be accommodated to an existing feeder with a T-shape circuit connection.

(3rd priority) If 150kV feeders are not air-insulated, a new capacitor bank with a smaller (25/10MVAR) is connected to 22kV feeder.

Also, PLN's criteria generally avoids land acquisition for the new capacitor bank, since it is quite expensive to purchase new land in and around the vicinity of the Jakarta Metropolitan Area.

PLN's seismic design criterion for power equipment installation requires 0.2 G horizontal seismic strength for the new capacitors, and any special countermeasures against flooding and inundation are provided. Also, the criteria specifies the capacitor bank as a dry-type. The total weight of the new capacitor banks is lighter than other oil-immersed power equipment.



(1st Priority) >> (2nd Priority) >> (3rd Priority)

Figure 3.4 Priority among Capacitor Bank Connections

Table 3.11 shows the specifications for the major equipment for the capacitor banks. PLN’s equipment specifications accommodate typical countermeasures against the switching surge voltage of capacitor banks, such as the employment of the +M2 class circuit breakers, which guarantees a 10,000-time circuit breaker operation, and Switching controllers that minimize the switching surge with synchronized switching operations to match the bus voltage phase angles.

Table 3.11 Specifications for Capacitor Bank Equipment

150kV Shunt Capacitors

Specification	
Standards	IEC 60871
Type	Outdoor, three-phase, open rack
Ratings	150kV 50MVAR 50Hz
Insulation Level	LIWV 750kVp, SIWV 325kV
Seisamic Withstand Capability	Corresponding to 0.2G
Minimum nominal specific creepage distance	25 mm/kV
Capacitor unit’s dielectric material	All-film
Inrush Current Limiting Reactor	IEC 60289
Reactor Type	Outdoor, 3 single phase, air core, dry

150kV 40kA 1 pole Circuit Breaker	
Standard	IEC 62271-100:2001-05
Type of Circuit Breaker	SF6
Ratings	150kV 1250A, 40kA 1sec. 50Hz
Switching Insulation Level	750kVp to Ground, 860kVp to phases
Power Frequency Withstand Voltage	325kVrms to Ground, 375 to phases
Minimum nominal specific creepage distance	25 mm/kV
Operating Duty	O-0.3s-CO-180s-CO

The Study team indicated the future needs for the technical confirmation of the frequent operation capability of the capacitor bank circuit breakers when PLN introduces an automatic voltage control scheme, in which capacitor banks should be energized/de-energized on a daily basis by frequently operating corresponding circuit breaker(s). PLN acknowledged the future necessity of the equipment’s frequent operation capacity, and gave an example of switching operation trouble in a frequently-operated capacitor bank circuit breaker at a Bali substation, which results in the electrical breakdown of the circuit breaker’s main circuit due to the incomplete operation of its motor drive. The broken-down circuit breaker had been energized/de-energized three times a day, and broke down six years after its commission. The root cause is the breakage of the pin of the mechanical drive, and the breakage resulted in the imperfect contact of the main circuit breaker contacts and partial overheating. Since the circuit breaker is specified to be a M2 class, which must be capable of 10,000 time operations, PLN could confirm the necessity of the actual operation test as a type test of such frequently operated circuit breakers rather than by simply purchasing M2-spec circuit breakers from manufacturers.

The protection scheme for the capacitor bank consists of three types of relays: Over Current, Under Voltage, and Unbalance. Also for the remote control of the bank, PLN decided to employ an SAS (Substation Automation System) for all of the substation equipment including the capacitor banks and its 150kV feeders, although the energizing/de-energizing of capacitor banks are now operated only manually. Given the advance introduction of SAS, the remote operation of the capacitor banks are relatively easy to achieve by connecting signals from the operation center to the substation sites. PLN is now installing SASs at every opportunity, such as ones in Bukit Semaray Baru Sumaran, but there's no active SAS that are remotely operated.

PLN has already shown their concern concerning the remote control of the massive introduction of capacitor banks at PLN's emergency plan, and PLN showed an interest in achieving efficient and effective remote control of the reactive power sources. To achieve the remote control of the massive capacitor banks, an optical telecommunication infrastructure among the substations and control centers is necessary. Currently, PLN doesn't own their optical cable assets, and is utilizing a third company's optical fiber infrastructure for telecommunication and signal transmission among the control system of substations and control centers instead.

3.3 Voltage Control Method in Power Station

3.3.1 Voltage Control Mode of Generators

An automatic voltage regulator (AVR) which regulates its own terminal voltage is applied to generators as the voltage control mode at Suralaya thermal power station and Priok thermal power station. An automatic reactive power regulator (AQR) which regulates the generator's reactive power output is applied to generators at Cirata hydro power station.

3.3.2 Tap Position of the Generator Step-up Transformers

Generally transformers with an off-load tap changer are applied to generator step-up transformers at power stations. The generator step-up transformers for Piton power station unit 3 and Muara Tawar power station units 3&4 are equipped with an on-load tap changer.

The tap position of the step-up transformer with an off-load tap changer in Suralaya thermal power station was changed to a higher tap position by one tap in order to raise the system voltage based on a request from P3B. In addition, P3B has a plan to raise the tap position by one position.

The tap position of the step-up transformer with an off-load tap changer in Muara Tawar thermal power station will be changed to a higher tap position by one position based on a request from P3B and negotiation between P3B and Muara Tawar power station will be an ongoing process.

Typically, a nominal tap position is selected for the step-up transformer of new and additional generators.

3.3.3 Voltage Control Practice in Power Station

Table 3.12 shows the instruction and operation practices for voltage control at the power station.

If the system voltage drops significantly due to a demand increase, JCC and ACC request power stations connected to 500kV system and 150kV system, respectively based on their own operating areas to increase the generator reactive power output by telephone. Requests from JCC and ACC are made once or twice per day.

As for generators with AVR, the reactive power outputs of generators are increased by manually regulating the terminal voltage at higher voltage. As for generators with AQR, those are increased by manually raising the setting value for reactive power output.

In order to increase the generator reactive power outputs up to the limit of the facilities, the over excitation limitation (OEL) often operates at the Suralaya thermal power station

The lower and upper limit of the terminal voltage of the generators are 95% and 105 % of the nominal voltage 15.75kV at Priok thermal power station. The upper limit of the terminal voltage is set to 16.0kV (101.6% of nominal voltage) since some trouble occurred when the terminal voltage was raised higher than 16.0kV in the past.

The upper limit of the reactive power output is approximately 61MVar based on the capability curve at Cirata hydro power station. The reference reactive power output for AQR is set between -40MVA and +40MVar to maintain the safety margin.

Table 3.12 Instruction and Operation Practices for Voltage Control in Power Stations

Voltage Control Operation	Voltage Level	Order by Whom	Operation by Whom	Tool of Order
Change in reactive power output of generator	500kV	JCC	Operators in power stations	Telephone
	150-70kV	ACC	Operators in power substations	Telephone

3.4 Voltage Control Method in Substation

3.4.1 Operation Practice of Transformer Tap Changer

Table 3.13 shows instruction and operation practices for voltage control in substations.

Generally, the tap positions of the 500/150kV transformers are fixed to reasonable positions throughout the day. As for the four substations consisting of Cirata, Mandirancan, Ungaran and Pedan, the tap positions are changed by 4 positions gradually in order to raise the secondary side voltage according to the demand increase in the morning and tap positions are changed by 4 positions gradually in order to lower the secondary side voltage after the peak demand.

The tap positions of the 500/150kV transformers are changed by the operators at the substations manually based on the instructions received from JCC by telephone. The tap positions of the 150/70kV transformers are manually changed by the operators at the substations based on the instructions received from ACC by telephone. The tap positions of the 150/20kV transformers are adjusted automatically to maintain the secondary side voltage.

Table 3.13 Instruction and Operation Practices for Voltage Control in Substations

Voltage Control Operation	Voltage Level	Order by Whom	Operation by Whom	Tool of Order
On/off switching of shunt reactor/capacitor in substations	500kV	JCC		Manually via SCADA
	150-70kV	ACC		
Changing tap position of transformers	500/150kV	JCC	Operators in substations	Telephone
	150/70kV	ACC	Operators in substations	Telephone
	150/20kV	Automatically		

3.4.2 Operational Method for Shunt Capacitors

The shunt capacitors are always-on minus the on/off switching throughout the day on weekdays and those are always-off throughout the day on holidays in order to suppress system voltage rises during low loads.

The shunt capacitors connected to the system within the ACC operating area can be manually switched on and off by directly via EMS in ACC.

3.4.3 Operational Method for Shunt Reactors

The shunt reactors connected to the long 500kV transmission lines are always-on in order to suppress overvoltage during the line reclosing. Other shunt reactors are always-off on weekdays and those are always-on only on special days such as holidays.

The shunt reactors connected to the 500kV transmission lines can be manually switched on and off directly via EMS in JCC.

3.5 System Monitoring and Control

3.5.1 SCADA System

The Study Team interviewed JCC (Java Bali Control Center), ACC 1 (Area Control Center 1) and ACC 2 (Area Control Center 2) members about the monitoring of the electric system. SCADA or

EMS of JCC and ACC 2 were updated with the systems that have State Estimators and Optimal Power Flow Algorithms work every five minutes. SCADA of ACC 2 is now under renewal. It was said that those functions could not work well due to insufficient data maintenance.

3.5.2 Supervisory and Data Acquisition

JCC enables the supervision of the voltages, active/ reactive power flows and taps of transformers of substations and terminal voltage and active/ reactive power flows of power stations. ACC also enables the supervision of the voltage, active and reactive power flow, taps of transformer and terminal voltage and active/ reactive power flows under the authority of the ACC.

On the Grid Code, it is mentioned which data is to be collected. That is, the proper procedures to determine the values and statuses that should be supervised. And proper data is selected. Furthermore, systematizing the accuracy requirements for tele-metering, correction of tele-metering, integrating the constants of electric facilities and the data maintenance of SCADA enables the utilization of the state estimator and the reliability analysis algorithm.

3.5.3 Operating Limitation of Machines

During the investigation, the Study Team confirmed that the alarms went off several times due to the over excitation. It is usual that OEL alarm causes. If the generator’s reactive power reaches its limit, the generator cannot stabilize the fluctuation of the voltage. That is an undesirable condition.

According to the survey of Suralaya Power Station, after the excitation current reached the OEL or 105%, the current would be controlled to 100%. Unless the current is manually regulated to 95%, the limitation could not be cancelled. Thus, it is important to control the reactive power so as not to cause OEL limitations. The knowledge of the OEL level is to be shared among the operators to keep an appropriate reserve of reactive power. To protect over excitation of generator, a V/Hz relay is installed. If the terminal voltage reached 118% of the nominal voltage and continued for 4 seconds, the generator would trip.

3.6 Operational Record of the Jakarta System

This section reviews the operational record of the Jakarta system in year 2012 based on P3B’s operational record material[1].

3.6.1 Facility Overview

Table 3.14 to Table 3.16 summarize the facilities of Java Bali power system. The Java Bali system is

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[1] “Evaluation of System Operation: Java Bali, Annual Report, Jan. – Dec. 2012,” Management Committee rules tissue, Jan. 15 2013

composed of a large load center of Jakarta in the western part of the island and the large-scale power plants for the base load which are located at the eastern and western ends of the island. The load center and those power plants are connected by two 500 kV backbone transmission lines stretching around 900 km from east to west. The transmission system voltage ranges from 70kV to 150 kV and 500 kV. The two backbone transmission lines contribute to the stability the network. The power flows from the east where power generation surpasses the consumption to the west which is the largest load center.

Table 3.14 Composition of Demand and Supply by Region

	Region	Demand	Supply
1	Jakarta and Banten Province	41 %	35 %
2	West Java	20 %	20 %
3	Central Java	15 %	17 %
4	East Java	21 %	27 %
5	Bali	3 %	2 %

Note: The data are as of Jakarta peak time on October 17, 2012.

(SOURCE: Evaluasi Operasi Sistem Jawa Bali 2011)

Table 3.15 Overview of Transformers

Voltage [kV]	Units	MVA
500/ 150	**47**	**23,000**
150/ 70	**60**	**3,719**
150/ 20	**601**	**30,001**
70/ 20	**128**	**2,727**
Total	**836**	**59,447**

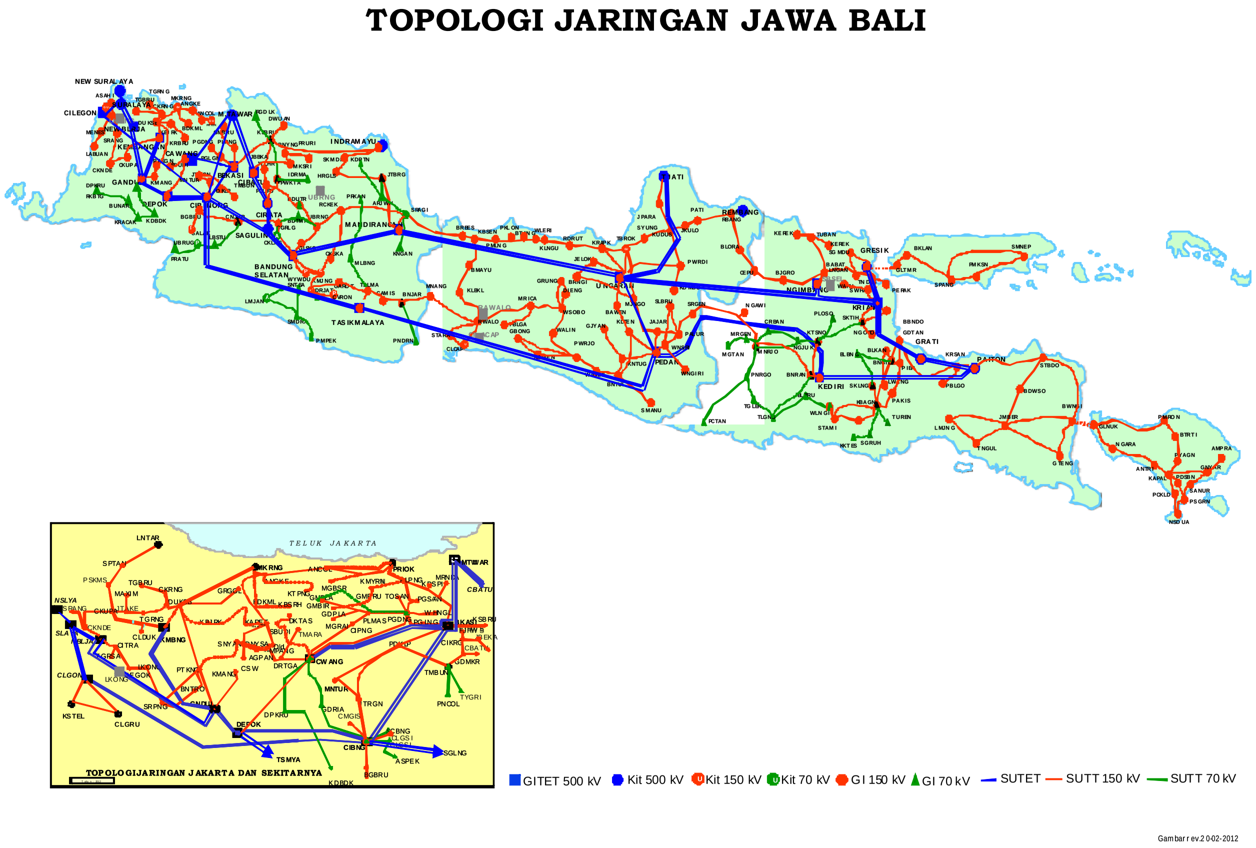
(SOURCE: P3B Jawa Bali, Statistik 2011)

Table 3.16 Overview of Transmission Lines

Voltage [kV]	km
500	**5,052**
150	**12,906**
70	**3,474**
Total	**21,432**

(SOURCE: P3B Jawa Bali, Statistik 2011)

Figure 3.5 shows the current Java Bali system.



(SOURCE: Presentation material provided by APB Jawa Barat)

Figure 3.5 Current Java Bali System

3.6.2 Overview of the Power System

(1) Demand

Figure 3.6 shows the typical daily load curve of the Java Bali System. As seen, there are three times when the load rises, namely in the early morning, around noon, and the evening. Figure 3.7 shows the curve by region. The peak load appears around noon in Region 1 which embraces Jakarta while the peak load appears in the evening in the rest of the system.

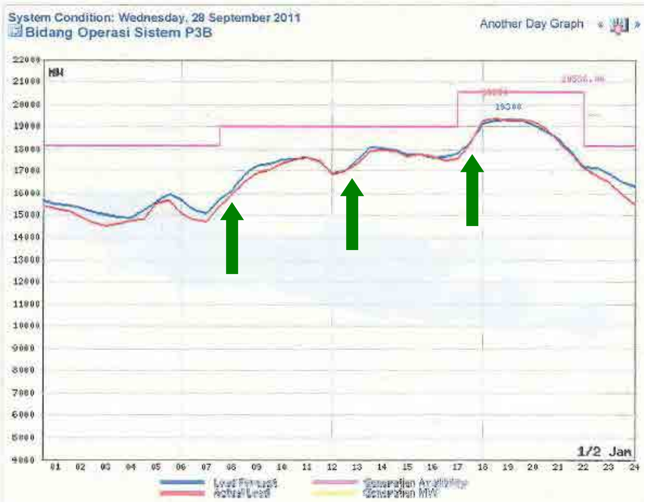
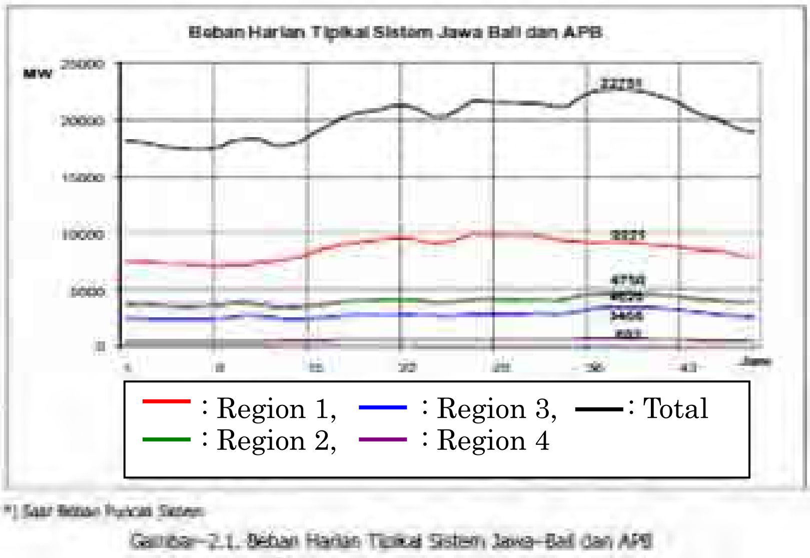


Figure 3.6 Daily Load Curve (September 28, 2011)

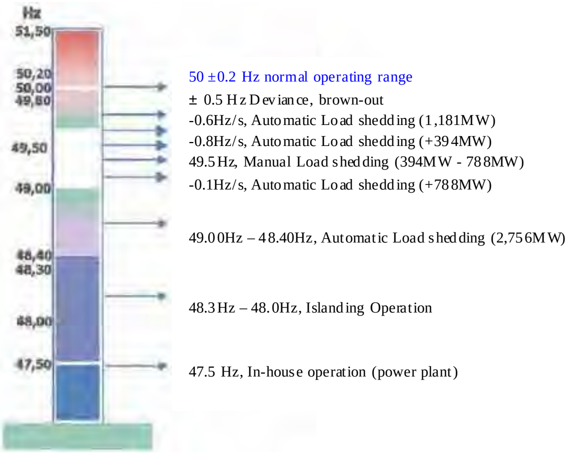


Source:Rencana Operasi Sistem Tenaga Listrik Jawa Bali Tahun 2013

Figure 3.7 Typical Daily Load Curve by Region

(2) Frequency Overview

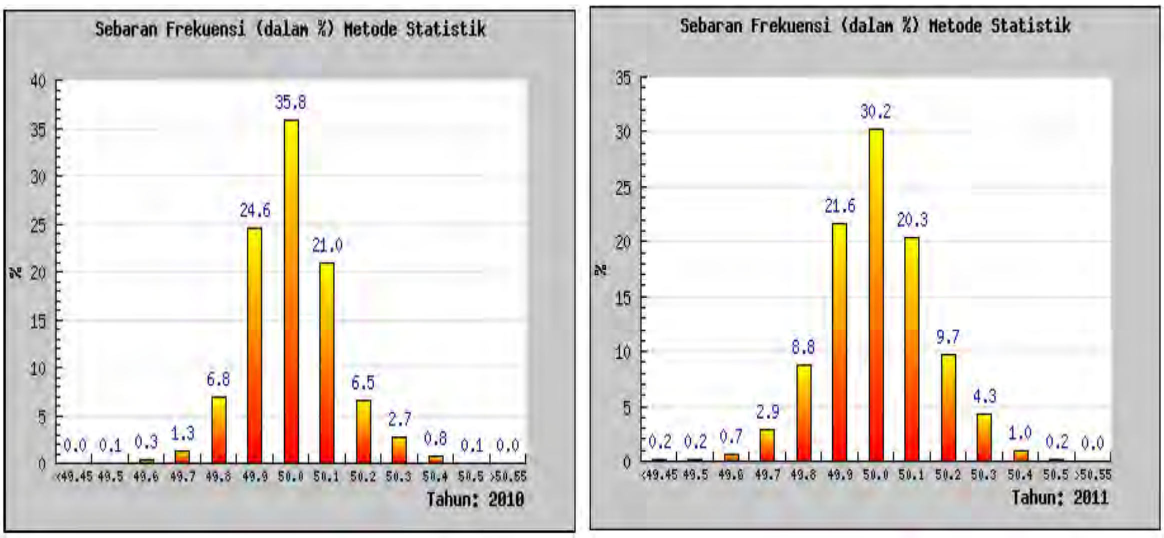
The system frequency is managed to be limited within the normal operating range limit (50 ± 0.2 Hz). According to P3B JB's "RENCANA OPERASI SISTEM TENAGA LISTRIK JAWA BALI TAHUN 2013 (Operation Plan of Java Bali system in 2013)," the frequency control guideline is set as shown in Figure 3.8. In accordance with the level of frequency and/ or the speed of the frequency fall (Hz/ s), the load shedding will be implemented automatically or manually.



(SOURCE: Rencana Operasi Sistem Tenaga Listrik Jawa Bali Tahun 2013)

Figure 3.8 Frequency Control Guideline

Figure 3.9 shows the frequency distribution of Java Bali system for year 2010 and year 2011. As the duration of deviation from the normal operation range increased in year 2011 compared with the one in year 2010, the control of the system frequency has been the issue of the Java Bali system these days.



(SOURCE: Evaluasi Operasi Sistem Jawa Bali 2011)

Figure 3.9 Frequency Distribution of Java Bali System

Table 3.17 summarized the frequency deviation from the normal operation range of year 2012 in accordance with 4 causes. According to the nation's grid code ("ATURAN JARINGAN SISTEM TENAGA LISTRIK JAWA-MADURA-BALI," DEPARTEMEN ENERGI DAN SUMBER DAYA MINERAL, 2007), the system frequency deviation is defined as a case where the system operation is out of its normal operation range between 49.5 Hz and 50.5 Hz. The code also defines the range of the allowable maximum instantaneous deviation as the one from 47.5 Hz to 52.0 Hz.

Table 3.17 The Classification of System Frequency Deviation from the Normal Operation Range by Cause of Frequency Fluctuation (2012)

Cause of fluctuation	Description		Sub total
	Outage	Without outage	
Power station failure	17	72	89
System failure	9	5	14
Demand fluctuation	0	94	94
Lack of supply	2	1	3
Total	28	172	200

(SOURCE: Evaluasi Report 2012)

As seen above, the demand fluctuation – the case where the pace of demand fluctuation was faster than that of the supply response - is the major cause of frequency deviation in the Java Bali system, though the case did not lead to an outage. The following cause is the tripping of the power station mainly due to some failure. The possible causes attributed to the supply side is the lack of supply capacity whose output response speed is fast enough to the demand fluctuation and/or simply the lack of total reserve supply margin. Given that the further development of coal-fired power plants, whose output response speed is not fast, is ongoing/ planned in Java Bali System, it is expected that the large-scale hydropower plants whose output response speed is fast enough like the Upper Cisokan pumped storage power plant will be developed in a timely manner.

(3) System Voltage Overview

The country's grid code stipulates that the lower limit of the system operation voltage for the 500 kV system as the 475 kV (Table 3.18), though 20 out of the total 26 500 kV substations in Java Bali system experienced a voltage lower than 475 kV (**Table 3.19**).

Table 3.18 Normal Operation Range of System Voltage

Standard voltage [kV]	Normal Condition
500	+5%, -5%
150	+5%, -10%
70	+5%, -10%
20	+5%, -10%

(SOURCE: Grid Code, 2007)

Table 3.19 The Number of Substations with Voltage below the Normal Operation Range (2012)

Voltage [kV]	Number of substations/ total
500	20/ 26
150	163/ 322
70	48/ 100

(SORUCE: Evaluasi Operasi Sistem Jawa Bali 2012)

Table 3.20 shows the list of 500 kV substations in west Java which severely suffered voltage drops in year 2011. Table 3.21 shows that out of 150 kV substations.

Table 3.20 500 kV Substations with voltage drops (2011)

No.	Region	500kVSS	The lowest voltage [kV]
1	Region 1	Bekasi	439
2		Cibinong	444
3		Gandul	447
4		Kembangan	447
5		Depok	451
6		Cawang	446
7		Balaraja	444
8	Region 2	Mandirancan	441
9		Saguling	442
10		Bandung Selatan	449
11		Cirata	449

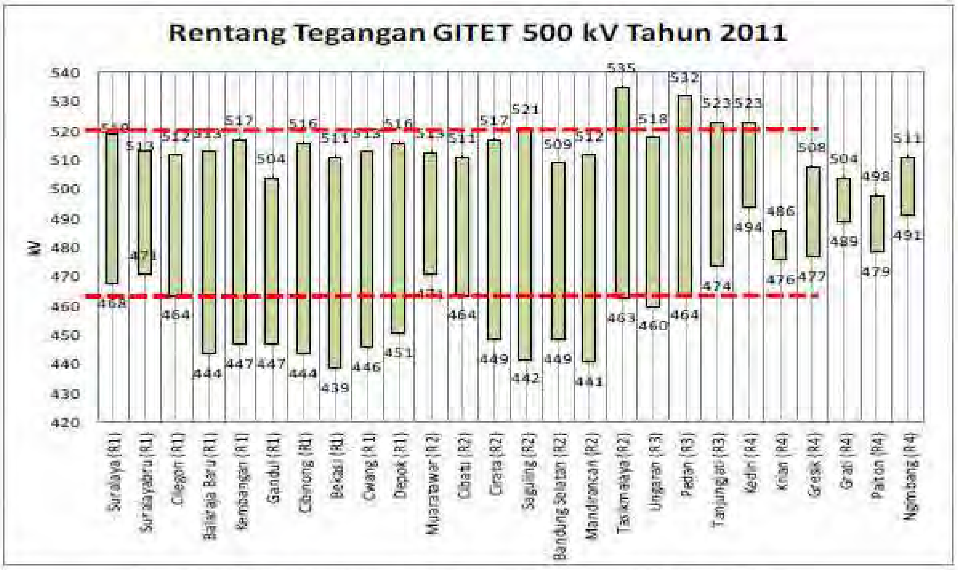
(SOURCE: Evaluasi Operasi Sistem Jawa Bali 2011)

Table 3.21 150 kV Substations in Region 1 with voltage drops (2011)

No.	150kVSS	The lowest voltage[kV]
1	Bogor Baru	110
2	Kebon Jeruk	120
3	Pendo	120
4	Gedung Pola	120
5	Gambir Baru	120
6	Plumpang	120
7	Bintaro	122
8	Danayasa	123
9	Legok	124
10	Serpong	124

(SOURCE: Evaluasi Operasi Sistem Jawa Bali 2011)

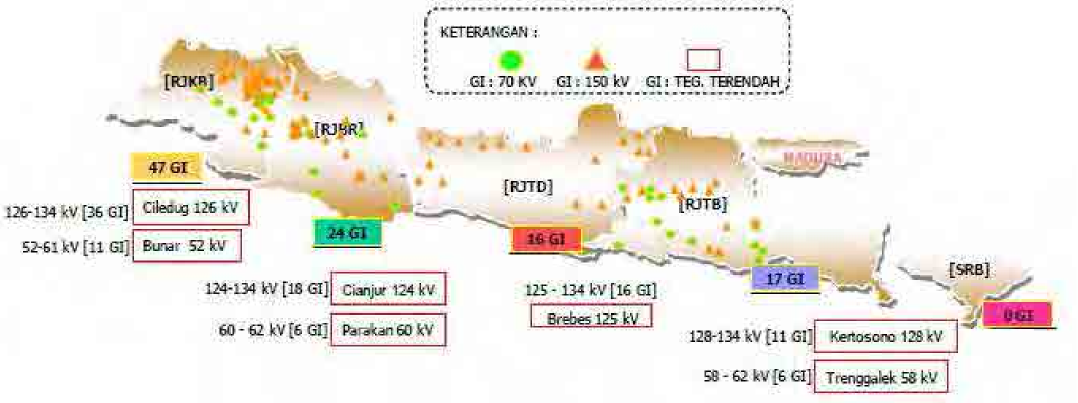
The 150 kV substation which suffered from the lowest operation voltage (110kV. 27% lower than standard voltage) in year 2012 was Bogorbaru substation, while the 70 kV substations with the lowest voltage (51 kV. 26% lower than the standard voltage) were Cilungsi substation and Cigereleng substation. Figure 3.10 shows the voltage operation record of 500 kV substations of the Java Bali system in 2011, while Figure 3.11 shows the geographical distribution of 150 kV and 70 kV substations which suffered from an operational voltage lower than the normal range. As seen, the low-voltage phenomenon (the phenomenon where the operation voltage falls below the lower limit of normal operation range) has been seen mainly in the western half of the Java Bali system.



Gambar 5.6.1. Rentang tegangan GITET 500 kV tahun 2011

(SOURCE: Evaluasi Operasi Sistem Jawa Bali 2011)

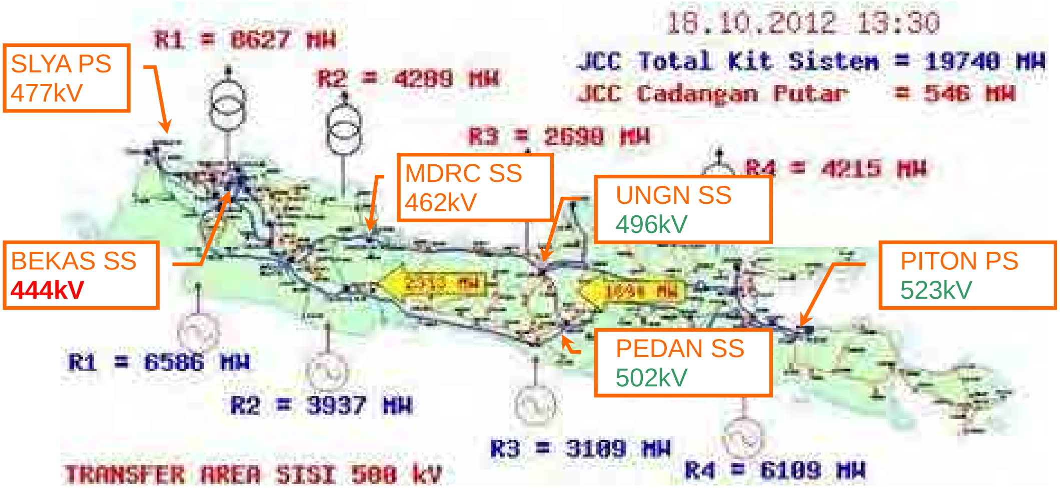
Figure 3.10 Overview of Voltage Operation at 500 kV Substations



Gambar 5.6.2. GI 150 kV & 70 kV November 2011 bertegangan < 90% tegangan nominal

(SOURCE: Evaluasi Operasi Sistem Jawa Bali 2011)

Figure 3.11 Distribution of 150kV and 70 kV Substations suffered from Voltage lower than Normal Operational Range



(SOURCE: SCADA Data provided by P3B JB)

Figure 3.12 Actual Record of Voltage and Power Flow (October 18, 2012)

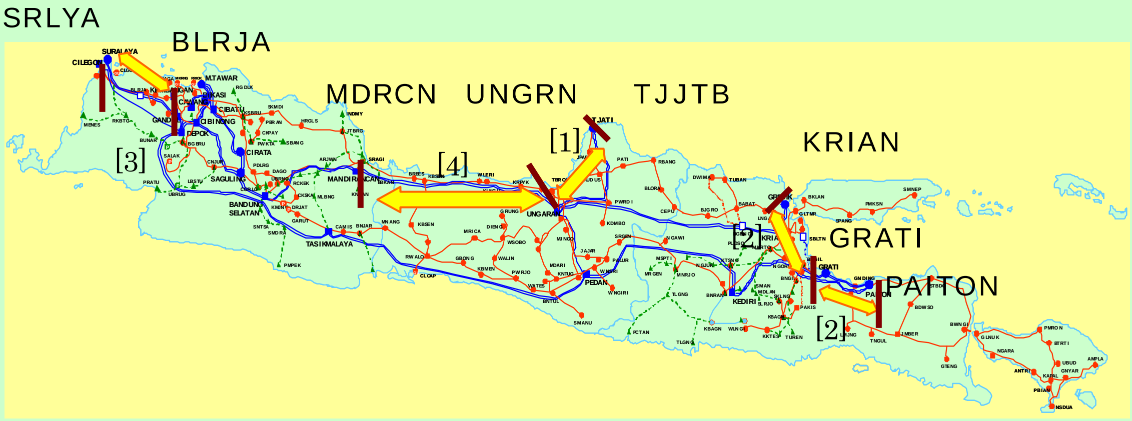
P3B JB has analyzed the root cause of the recent low-voltage issue (Box 3.6.1). For the countermeasure, P3B JB plans to relocate existing shunt capacitors to those substations which are currently suffering from voltage drops. Their operations record report (“Evaluasi Operasi Sistem Jawa Bali 2011”) reveals that the major countermeasures are to optimize the supply of reactive power from the power plants and to relocate the existing shunt capacitors (from the substations which solved the low-voltage issue to those which suffer from this issue). For the latter, shunt capacitors placed in the Eastern, Central and Western Java regions are planned to be relocated to Region 1 (Jakarta and Banten Province).

Box 3.6.1 Root cause analysis on the voltage drops by P3BJB

P3BJB’s operation performance report of 2011 (“Evaluasi Operasi Sistem JawaBali 2011”) analyzed the cause of low voltage issues as follows:

1. Insufficient reactive power supply from power plants in the western side of the Java Bali system.
2. The conditions of the system (”have many deficits and incidents of idleness”).
3. Heavy power flow from east to west.
4. Limitation of transmission capacity and/ or SIL (Surges Impedance Loading) at the sections below (Figure B3.6-1): [1] Tanjung Jati B power station – Ungaran Substation, [2] Paiton power station - Grati power station, [3] Suralaya power station – Balaraja substation, [4] Ungaran substation (Region 3) - Mandirancan substation(Region 2).

The report analyzed that the low-voltage issue at the Central Java’s 500 kV substations of Ungran and Pedan since October 2011 has resulted from the increase of power flow whose amount surpassed the relevant SIL level at the transmission section below based on the fact that the issue arose after the commissioning of Units 3 and 4 of Tanjung-Jati B power station and Paiton 3 and 9 power stations: [a] 500 kv Tanjung Jati B power station – Ungaran substation, [b] 500 kv Paiton power station - Grati power station – Krian substation. The report suggested that limiting the output of Tanjung Jati B power station Units 1 to 4 as well as power stations at Paiton would be an effective countermeasure against the low-voltage issues at the substations at Ungaran and Pedan.



Java Bali system

Other countermeasures such as the relocation of existing shunt capacitors are also ongoing.

In general, the possible causes to lower the system voltage include the following: [1] Heavy power flow over transmission lines and transformers, [2] lack of a reactive power supplier, [3] load with low power factor, [4] insufficient voltage operation. The following subsections (4) and (5) review these possible causes which might appear in the Java Bali system.

(4) Review of transmission and transformer's performance

Table 3.22 reviewed the performance of the transmission and transformers of the Java Bali system which is one of the possible causes of the low-voltage issue. The nation set the preferable normal loading level of transmission lines and 500 kV transformers as 80 % of the capacity[2], though the loading of most transformers in Java Bali system are over 80%. Such heavy loading of transformers could increase reactive power losses, decreasing the system voltage. The more apparent power passes through a transformer, the more reactive power loss is consumed.

Table 3.22 Performance of Transformers of Java Bali System (2012)

Loading during peak time	70/ 20kV		150/ 20kV		150/70 kV		500/ 150 kV	
	Unit	MVA	Unit	MVA	Unit	MVA	Unit	MVA
0%<<20%	3	80	14	666	1	60	1	500
20%=<<40%	5	100	44	2,430	5	290	1	250
40%=<<60%	18	338	117	5,839	12	632	7	3,500
60%=<<80%	36	766	197	9,727	18	1,224	12	6,000
80%=<<100%	57	1436	229	11,894	21	1,461	30	14,500
100%=<	0	0	6	320	0	0	2	1,000
Total	119	2720	607	308,876	57	3,667	53	25,750

(SOURCE: Evaluasi Operasi Sistem Jawa –Bali 2012)

Table 3.23 shows the loading of transformers in Region 1.

Table 3.23 Loading of Transformers in Region 1 (2012. 500 kV Substations)

	Substation	Transformer	Capacity [MVA]	Apparent power [MVA]	Loading [%]
1	Cibinong	#1	500	570	114
2	Balaraja	#1	500	360	72
3	Cawang	#1	500	356	71
4	Kembangan	#2	500	355	71
5	Balaraja	#2	500	353	71
6	Cawang	#2	500	346	69
7	Kembangan	#1	500	342	68
8	Depok	#1	500	281	56
9	Gandul	#1	500	258	52
10	Gandul	#2	500	256	51

Note 1: Loading shows the ratio of Apparent power against the transformer's capacity
Note 2: The data are as of 14:30 on October 17, 2012

(SOURCE: SCADA data provided by P3B JB)

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[2] RUPTL2012-2021, P.41

As seen in Table 3.23, the loading values exceed or almost reach 80% for the top 5 transformers. In terms of geographical trends, the loading at western and southern Jakarta tend to be high. The next table shows the loading of transmission lines (Table 3.24 for 500 kV lines. Table 3.25 for 150 kV lines.).

Table 3.24 Loading of 500 kV Transmission Lines (2012)

	From	To	Rated Capacity [MVA]	Distance [km]	Apparent power [MVA]	Loading [%]	Region
1	SRLY	BLRJ	1,984.9	64.3	1,125	57	REGION-1
2	BEKS	CBING	1,984.9	37.9	913	46	REGION-1
3	CWANG	MRTWA	1,984.9	42.7	747	38	REGION-1=>-2
4	GNDUL	BLRJ	1,984.9	46.2	741	37	REGION-1
5	CLGON	CIBING	2,209.2	130.1	776	35	REGION-1
6	CLGON	SRLYA2	2,209.2	12.9	509	23	REGION-1
7	DEPK	TASIK	2,209.2	280.4	430	19	REGION-1=>-2
8	KBGN	GNDUL	2,209.2	30.1	364	16	REGION-1
9	CBING	SGLNG	2,209.2	80.4	227	10	REGION-1=>-2
10	DEPOK	CBING	1,984.9	21.3	118	6	REGION-1

Note1: Loading shows the ratio of Apparent power against the transmission line’s rated capacity
Note2: The data are as of 14:30 on October 17, 2012

(SOURCE: SCADA data provided by P3B JB)

Table 3.25 Loading of 150 kV Transmission Lines (2012)

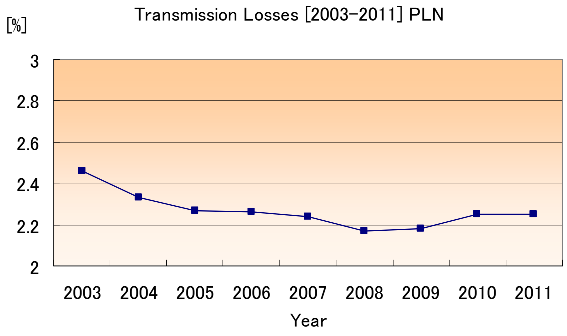
	From (subsystem)	To (subsystem)	Rated capacity [MVA]	Distance [km]	Apparent power [MVA]	Active power [MW]	Reactive power [MVar]	Loading [%]
1	TRSNA(Cawang)	DRNTG(Cawang)	239	5.3	514	-540	-540	(*)215
2	PSKMS(Cilegon)	SPTAN(Cilegon)	392	10.3	764	513	-26	(*)195
3	TGRSA(Balaraja)	CITRA(Balaraja)	392	5.7	459	264	375	(*)117
4	GNDU(Gandul)	PGKGN(Gandul)	376	18.8	331	324	-69	88
5	CLGBR(Cilegon)	SRANG(Suralaya)	331	21.8	279	247	130	84
6	DUKSB(Gandul)	MKRBR(Gandul)	376	12.2	299	-255	-156	79
7	PDKLP(Bekasi)	JTNGN(Cibinong)	392	10.4	296	285	80	76
8	PDKLP(Bekasi)	BKASI(Bekasi)	376	6.6	284	-264	-105	76
9	CWGBR(Cawang)	CNANG(Cawang)	392	3.5	237	226	72	61
10	PRBRU(Bekasi)	KMYRN(Bekasi)	392	4.5	233	219	80	60

Note1: Loading shows the ratio of Apparent power against the transmission line’s rated capacity
Note2: The data are as of 14:30 on October 17, 2012

*: The reason of the fact that the loading of top 3 sections are over 100 % might attribute to the calibration problem of SCADA meters.

(SOURCE: Developed by JICA Study Team based on SCADA data and PSS/E data provided by P3B JB)

As seen above, while the loading of the 500 kV transmission lines are low (the values at most sections are below 50 %), the loading of 150 kV transmission lines are relatively high (the values of the top 5 sections are almost equal to or over 80%).



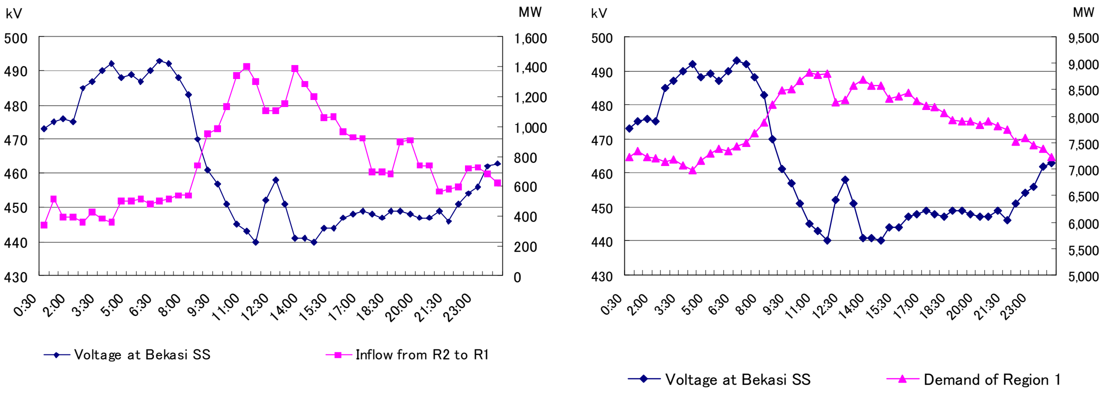
(SOURCE: PLN Statistiks 2011)

Figure 3.13 Trend of Transmission Loss

Figure 3.13 traces the change of transmission losses of the nation's power grid over the past 10 years. The transmission losses of the nation's power system as a whole at the end of 2011 was 2.25 %. The losses have remained at a similar level over the past 10 years.

(5) Load Overview

There is a hypothesis that the low-voltage issue in Jakarta has been mainly caused by the heavy load via long transmission from Region 2 to Region 1. As shown in Figure 3.14, this hypothesis seems true to some extent. That is, the system voltage at Jakarta decreases following the increase of power flow from Region 2 to Region 1 in the morning. This hypothesis, however, does not seem true in the afternoon because the system voltage remains low even when the inter-region power flow decreases in the afternoon. Therefore, it is not necessarily true that there is a strong correlation between the voltage drop and inter-regional power flow. Rather, the demand of Region 1 seems to affect the voltage drops.



(SOURCE: SCADA data provided by P3B JB)

Figure 3.14 Correlation between Voltage Drop at Bekasi 500kV Substation and Power Inflow from Region 2 to Region 1 (left), Demand of Region 1 (right)

Next, another possible cause of the low-voltage issue – power factor of load was reviewed. Table 3.26 summarized the load characteristic by region during Jakarta peak hours. Likewise, Table 3.27 is for Region 1 and Table 3.28 is for Region 2, both of which suffered severe voltage drops.

Table 3.26 Load by Region

Region	P [MW]	Q [MVar]	p.f [%]
Region 1	8,178	1,996	97
Region 2	3,686	1,247	95
Region 3	2,463	1,037	92
Region 4	3,081	1,135	94
Region 5	468	168	94
Total	17,877	5,583	95

(SOURCE: SCADA data provided by P3B JB)

Table 3.27 Load in Region 1

	Sub System	P [MW]	Q [MVar]	p.f [%].	Bus-bar Voltage	
					500 kV [p.u.]	150 kV [p.u.]
1	Suralaya	99	99	71	0.95 0.95 0.94 0.94	0.93
2	Cilegon	1,002	119	99	0.95 0.94	0.95 0.94
3	Balaraja	803	303	94	0.91 0.88	0.83 0.81
4	Kembangan	352	110	95	0.89 0.89	0.85 0.85
5	Gandul	1,605	212	99	0.89 0.89	0.87 0.89 0.93
6	Depok	403	55	99	0.90 0.90	0.87 0.87
7	Bekasi	1,601	275	99	0.88 0.88	0.87 0.87 0.92 0.93
8	Cawang	885	341	93	0.88 0.88	0.91 0.91
9	Cibinong	1,429	483	95	0.90 0.90	0.88
	Total	8,178	1,996	97		

(SOURCE: SCADA data provided by P3B JB)

Table 3.28 Load in Region 2

	Sub System	P [MW]	Q [MVar]	p.f [%]	Bus-bar Voltage	
					500 kV [p.u.]	150 kV [p.u.]
1	Cibatu	1,408	431	96	0.88 0.88	0.93 0.95 0.93
2	Cirata	435	118	97	0.90 0.89	1.00 0.99
3	Bandung Seltan	1,309	500	93	0.91 0.91	0.99 1.01 1.01
4	Mandirancan	363	124	95	0.93 0.92	0.97 0.95
5	Tasikbaru	136	61	91	0.96 0.96	0.97 0.97
	Total	3,651	1,234	95		

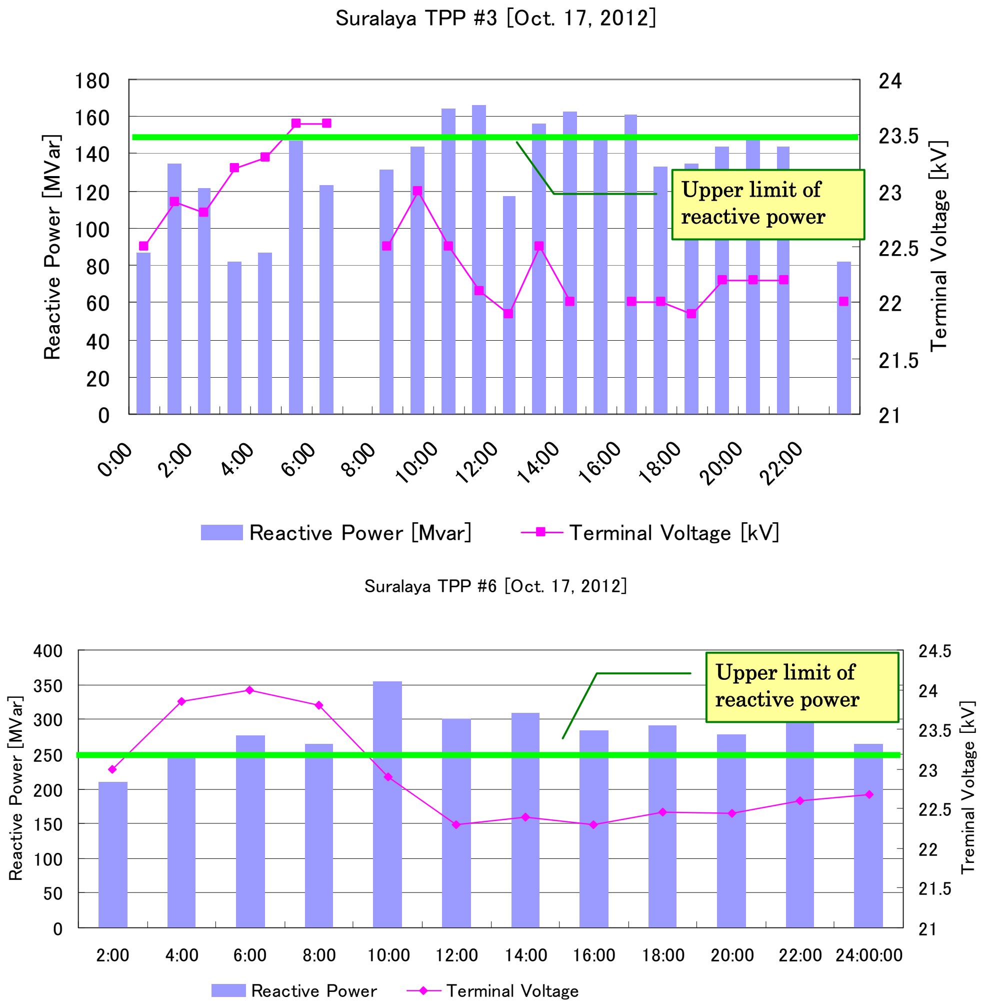
(Secondary side of transformer)

(SOURCE: SCADA data provided by P3B JB)

As obvious from Table 3.26, the average power factors of Region 1, 2's load which suffered severe voltage drops are not necessarily lower than those of the other regions. Likewise inside Region 1, the average power factor of loads in Bekasi subsystem is good (*), i.e. 99%, while the voltage of the substation is observed under the lower limit of the normal voltage operation range (*: the figure is the same as that of the loads under Cilegon substation which does not suffer from severe voltage drops.). For those reasons, the Study Team does not see an obvious strong correlation between the average power factor of the loads and the degree of voltage drop at the substations in the Java Bali System.

(6) Overview of Voltage Operation

Finally, the Study Team reviewed the current voltage operation to mitigate the degree of voltage drops implemented by P3B JB's dispatching center (JCC/ ACC), assessing the power plants' operational record and SCADA data. First, the Team reviewed the voltage operations conducted by the power stations. Figure 3.15 summarized the daily behavior of the terminal voltage and supplied reactive power at Suralaya coal-fired power station, which is the representative of the large-scale power station in Region 1 (the plant's terminal voltage is 23.0 kV. Unit 3 and 6 are chosen.). The record is from October 17, 2012 when the maximum demand was monitored in Region 1. As seen, although it would be preferable for the plant generators to contribute to keeping the grid voltage within normal range by supplying more reactive power through raising their terminal voltage, their terminal voltage were to be lowered because the supplied reactive power has already exceeded the units' capable upper limit (around 150 Mvar for Unit3 and around 250 Mvar for Unit 6).



(SOURCE: Data provided by Suralaya TPP)

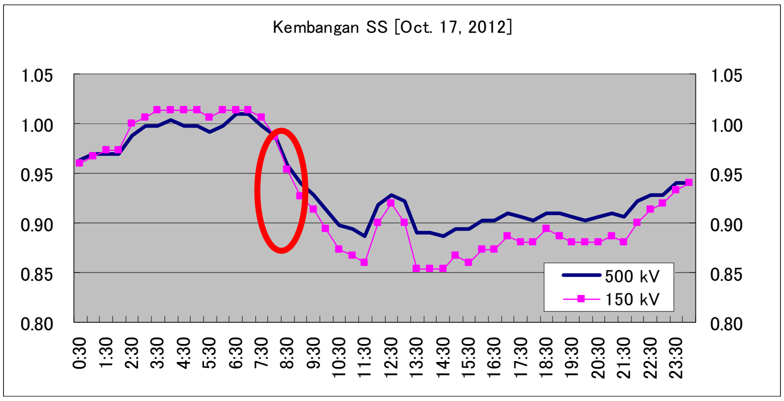
Figure 3.15 Daily Operation Behavior of Terminal Voltage and supplied Reactive Power of Suralaya Coal-fired Power Station (Upper: Unit 3, lower: Unit 6)

Table 3.29 Range of Reactive Power supplied by Suralaya Coal-fired Power Station

Unit	Qmax [MVar]	Qmin [MVar]
#1	150.0	-150.0
#2	150.0	-150.0
#3	150.0	-150.0
#4	150.0	-150.0
#5	250.0	-50.0
#6	250.0	-220.4
#7	250.0	-50.0
#8	286.1	-149.9

(SOURCE: Developed by JICA Study Team based on data of Suralaya TPP and PSS/E data of P3B JB)

Secondly, the Team reviewed the voltage operation conducted at the substations. For this proposal, Bekasi 500 kV substation is selected as the substation has suffered from a severe voltage drops. Figure 3.16 shows the daily behavior of the primary and secondary voltage of the substation on October 17, 2012.



(SOURCE: SCADA Data provided by P3B JB)

Figure 3.16 Daily Voltage Behavior of 500 kV Bekasi Substation

The figure above shows that the secondary voltage (150 kV) fell more than the primary voltage (500 kV) around 8 am, though this does not seem to have resulted from the change of the transformer’s tap position but seems to have resulted from the increase of the bank down power flow of the transformer. According to the interview with P3B JB, they rarely change the tap’s position for 500 kV substations in Region 1.

3.7 Power Supply Balance Perspective

“RUPTL 2012-2021” that is the latest report of the power system plan was published by PLN in February 2013. This section describes the record of power supply, demand, power development plan, and the power demand forecast based on this RUPTL 2012-2021.

Table 3.30 shows the energy sales record of Java - Bali system over the past 5 years. Its annual growing ratios were scattered in the range of 3 to 9%. The sales energy in 2009 was increased only by 3.3% because of the global financial crisis in 2008 that lasted until 2009.

Table 3.30 Energy Sales Record of Java Bali System

	Unit	2007	2008	2009	2010	2011
Energy Sales Record of Java - Bali System	TWh	95.6	100.8	104.1	113.4	120.8
Increase Ratio	%	7.4	5.4	3.3	8.9	6.5
House hold electrification ratio	%	66.3	68	69.8	71.4	72.325

(Source: RUPTL2012-2021 Chapter 3)

Table 3.31 shows the record of the maximum power demand and power generation in the Java-Bali system. The growing ratio of the maximum power demand in 2011 was relatively high at 9.05%. The generation installed capacity means the generator nominal capacity (written in the generator name plates) and the generation capable capacity means the available generation capacity. The reason why the generation capable capacity becomes smaller than the generator nominal capacity can be attributed mainly to the deterioration of the generators and a decline in the calorific power of the coal fuels. The generation installed capacity was 23,306 MW in 2010 and 23,206 MW in 2011 and it was increased by 3,458 MW during this period.

Table 3.31 Records of Maximum Power Demand and Power Generation

	Unit	2007	2008	2009	2010	2011
Maximum Power Demand (Generation Terminal)	MW	16,840	16,892	17,835	18,756	20,439
Maximum Power Demand (Transmission Terminal)	MW	16,251	16,301	17,211	18,100	19,739
Growing Ratio	%	5.6	0.3	5.6	5.2	9.05
Load Factor	%	76	78.7	77.7	79.5	77.76
Generation Installed Capacity	MW	22,236	22,296	22,906	23,206	26,664
Generation Capable capacity	MW	20,309	20,369	21,784	21,596	23,865

(Source: RUPTL2012-2021 Chapter 3)

On the other hand, according to the previous RUPTL 2011-2020, the generation capacity was to be completely installed at 4,474 MW in 2011 as shown in Table 3.32, however, the commissioning year of the Cirebon thermal power plant was delayed by one-year to 2012. The actual incremental capacity was decreased in 2011 in comparison with the previous RUPTL 2011-2020.

Table 3.32 Expected Generation Capacity of 2011 by the Previous RUPTL2011-2020

Name	Type	Capacity (MW)
Muara Karang Rep Blok 2	Combined Cycle	210
Muara Tawar Blok 5	Combined Cycle	234
Suralaya #8	Steam Turbine	625
Teluk Naga/Lontar	Steam Turbine	315
Indramayu	Steam Turbine	990
Rembang	Steam Turbine	630
Tanjung Jati B#3-4	Steam Turbine	660
Cikarang Listrindo	Combined Cycle	150
Cirebon	Steam Turbine	660
Total		4,474

(Source: RUPTL2012-2021 Appendix C.1)

Table 3.33 shows the ratio of the generation capacity to the maximum power demand at the generation terminals. The ratio of the generation capacity to the maximum power demand was 120% to 130%. The margin of the generation capacity to the maximum power demand was secured by 20 to 30%.

Table 3.33 Ratio of the Generation Capacity to the Maximum Power Demand at Generation Terminals

	Unit	2007	2008	2009	2010	2011
Maximum Power Demand (Generation Terminals)	MW	16,840	16,892	17,835	18,756	20,439
Generation Installed Capacity	MW	22,236	22,296	22,906	23,206	26,664
Margin of Generation installed Capacity to Maximum Power Demand	%	32%	32%	28%	24%	30%

(Source: RUPTL2012-2021 Chapter 3)

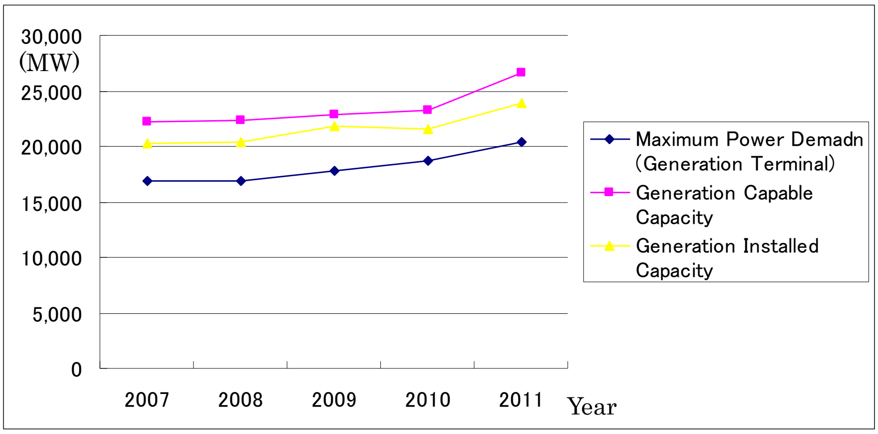
On the other hand, the reserve margin of the generation capable capacity was not much enough because it was less than 20% in 2010 and 2011 as shown in Table 3.34.

Table 3.34 Record of Ratio of Reserve Margin of Generation Capable Capacity to Maximum Power Demand

	Unit	2007	2008	2009	2010	2011
Generation Capable Capacity	MW	20.309	20.369	21.784	21.596	23.865
Maximum Power Demand (Generation Terminal)	MW	16.84	16.892	17.835	18.756	20.439
Margin of Generation Capable Capacity to Maximum Power Demand		20.6%	20.6%	22.1%	15.1%	16.8%

(Source: RUPTL2012-2021 Chapter 3)

According to RUPTL2012-2021, the power generation plan has to be made so as to secure the reliability and economy at a certain degree. Regarding the reliability, the indication of the loss of the load probability (LOLP) should be less than 0.274% (It means that the probability of exceeding maximum power demand to the power supply should be less than 0.274%.) , namely, it should be less than one day. According to the results of the calculation, the reserve margin of the capable capacity should be more than 25 to 30% in the Java Bali System, more than around 35%[3] of the installed capacity. Figure 3.17 shows the record of the maximum power demand and the generation capacity.



(Source: Made from RUPTL2012-2021 by TA Team)

Figure 3.17 Record of Maximum Power Demand and Generation Capacity

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[3] The required reserve margin of generation capable capacity is calculated as around 22 % on the condition that a load curve is assumed with load factor of 70%, the number of the units in the system is 100, their periodical inspections take 10 % of the year, unit failure probability is 3%, and allowable LOLP during a year is one day. (Its calculation procedure is shown in Appendix). The more generation capacities should be secured for the installed capacities than this value

Table 3.35 shows the composition of the power generation capacity of the Java Bali System in 2011. The installed capacity of the steam turbine power station shares are around 50%. Especially for the IPP, its ratio reaches over 70%.

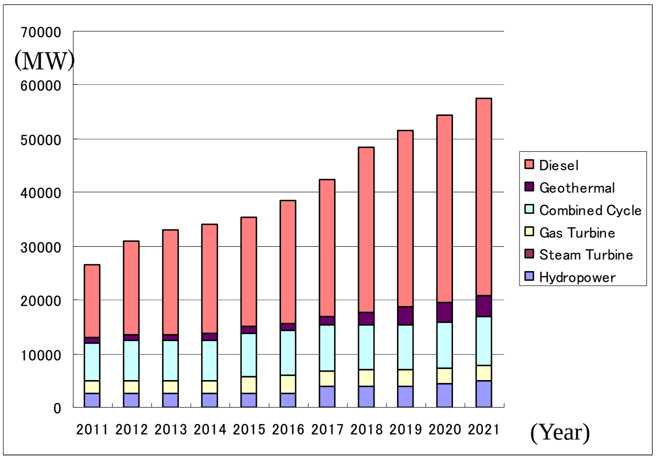
Table 3.35 Installed Capacity of Power Plants in Java Bali (2011)

		PLN	IPP	Total	Share
	Unit	MW	MW	MW	%
Hydropower	PLTA	2,392	150	2,542	10%
Steam Turbine	PLTU	10,694	3,012	13,706	51%
Gas Turbine	PLTG	2,035	300	2,335	9%
Combined Cycle	PLTGU	6,916	0	6,916	26%
Geothermal	PLTP	375	685	1,060	4%
Diesel	PLTD	105	0	105	0%
Total		22,517	4,147	26,664	－

(Source: RUPTL2012-2021 Chapter 3)

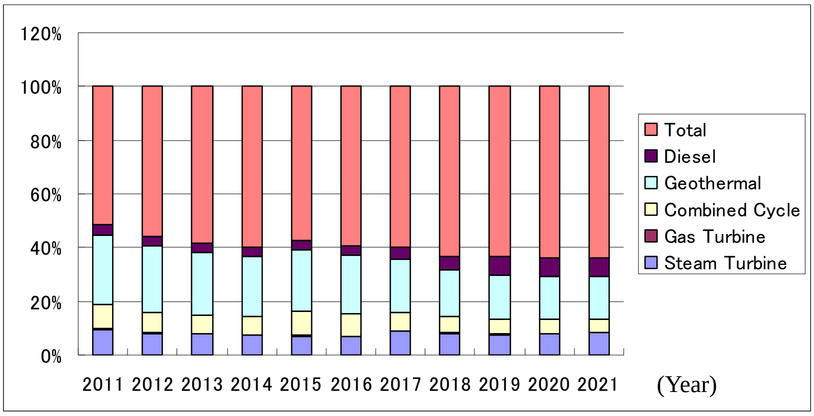
Figure 3.18 illustrates the expected changes in the installed capacity by fuel types and Figure 3.19 shows the shares of the power generation types. The plan increases the share of steam turbine year by year.

Table 3.36 shows the power demand forecast of the Java Bali system from 2012 to 2021. The electrification ratio of the households would reach around 90% in 2021. The peak demand was expected at 42,461 MW and would be increased by 90% from the record of 22,207 MW in 2011. The initial growing ratio of the peak demand is around 8%, however, it would be less than 7% after 2017.



(Source: Made from RUPTL2012-2021 by TA Team)

Figure 3.18 Expected Changes in the Installed Capacity by Fuel Types



(Source: Made from RUPTL2012-2021 by TA Team)

Figure 3.19 Shares of Power Generation Types

Table 3.36 Power Demand Forecast

	Unit	2012	2013	2014	2015	2016
Total Population	10^3	144,078.50	145,913.30	147,779.80	149,678.60	151,610.50
Electrification Ratio of Households	%	75.50	77.80	79.90	81.70	83.20
Sales Energy	GWh	132,371.00	143,474.00	156,387.00	170,461.00	185,803.00
Generation Energy	GWh	151,519.30	163,649.30	178,652.10	194,723.20	212,101.90
Peak Load	MW	22,207	23,923	26,050	28,321	30,770
Growing Ratio	%		7.73%	8.89%	8.72%	8.65%
		2017	2018	2019	2020	2021
Total Population	10^3	153,575.90	155,575.70	157,610.50	159,681.00	161,788.00
Electrification Ratio of Households	%	84.70	86.20	87.60	89.10	90.40
Sales Energy	GWh	198,747.00	212,568.00	227,381.00	242,878.00	259,431.20
Generation Energy	GWh	226,655.80	242,780.80	259,710.30	277,393.40	296,407.90
Peak Load	MW	32,798	35,043	37,392	39,837	42,461
Growing Ratio	%	6.59%	6.84%	6.70%	6.54%	6.59%

(Source: RUPTL2012-2021 Appendix C.1)

Table 3.37 and Table 3.38 show the power generation plan and Figure 4.4 illustrates the maximum power demand forecast and installed generation capacity. The ratio of installed generation capacity to the maximum power demand would be minimized in 2015. The margin of installed generation capacity would be low from 2014 to 2017. The ratio of installed generation capacity to the maximum power demand would become lower than 135% as show in Table 3.38. The margin of installed generation capacity would become lower than around 35%, that is the target mentioned in the RUPTL. Thus, the target of RUPTL, one day of LOLP, may not be achieved during this period.

Table 3.37 Power Generation Plan in 2012-2021(1/2)

(Unit: MW)

	Types	2012	2013	2014	2015	2016	2017	2018	2019	2020	2,021
PLN On-going and Committed											
Priok Ext Blok 3	CCT	740									
Lontar	Steam T	630									
Pelabuhan Ratu	Steam T		1,050								
Pacitan	Steam T	315	315								
Paiton Baru	Steam T	660									
Tj. Awar-awar	Steam T		700								
Adipala	Steam T			660							
Tanjung Jati B #4	Steam T	660									
Indramayu #4 (FTP2)	Steam T							1,000			
Peaker Semarang	Gas T				150						
Upper Cisokan PS (FTP2)	Hydro						1,040				
IPP On-going and Committed											
Cirebon	Steam T	660									
Paiton #3	Steam T	815									
Celukan Bawang	Steam T			380							
Banten	Steam T					625					
Sumsel-8 MT	Steam T					600	600				
Sumsel-9 MT (PPP)	Steam T							1,200			
Sumsel-10 MT (PPP)	Steam T							600			
Cilacap exp	Steam T					600					
Madura 2x200 MW (FTP2)	Steam T					400					
Jawa Tengah (PPP)	Steam T						950	950			
Rajamandala (FTP2)	Hydro					47					
PLTP FTP-2	Geothermal			55		295	380	515	750		

CCT: Combined Cycle, ST: Steam Turbine, GasT: Gas Turbine

(Source: RUPTL2012-2021 Appendix C.1)

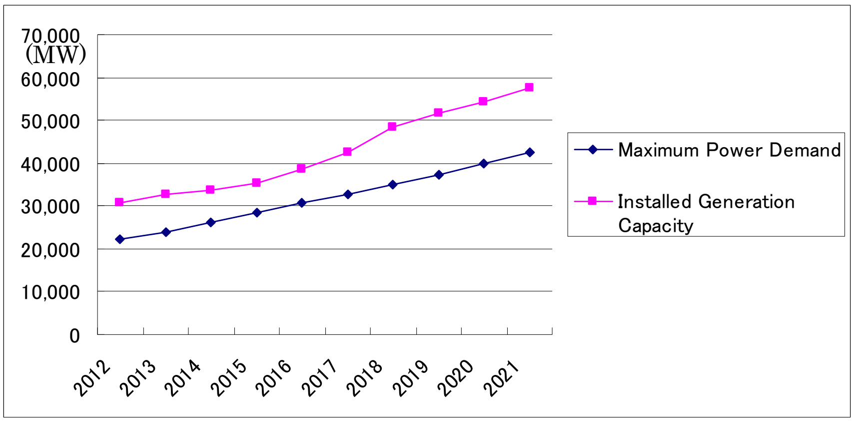
Table 3.38 Power Generation Plan in 2012-2021(2/2)

(Unit: MW)

	Types	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Planed Additional Capacity											
Jawa-1	CCT				500	250					
Jawa-2	CCT										750
Indramayu #5	Steam T									1,000	
Lontar Exp #4	Steam T					315					
Jawa-5	Steam T							1,000	1,000		
Peaker Muara Karang	Gas T				400						
Peaker Grati	Gas T				300						
Peaker Pesanggaran	Gas T				150						
Karangkates #4-5 (Jatim)	Hydro							100			
Kesamben (Jatim)	Hydro						37				
Kalikonto-2 (Jatim)	Hydro						62				
Jatigede (Jabar)	Hydro					110					
Matenggeng PS	Hydro									450	450
Jawa-1	SteamT						1,000				
Jawa-3	SteamT						660	660			
Jawa-4	SteamT								1,000	1,000	
Jawa-6	SteamT										2,000
PLTP Non-FTP2	Geothermal						10	110	305	330	110
Total Planed Additional Capacity		0	0	0	1,350	675	1,769	1,870	2,305	2,780	3,310
Total on-going, committed and planned capacity	MW	4,480	2,065	1,095	1,500	3,242	4,739	6,135	3,055	2,780	3,310
Abolished	MW	-51	-200	-25	0	0	-831	-200	0	0	0
Total Installed Generation Capacity	MW	30,800	32,665	33,736	35,236	38,478	42,385	48,320	51,575	54,155	57,665
Margin of Installed Generation Capacity to Maximum Power Demand		39%	37%	30%	24%	25%	29%	38%	38%	36%	36%

CCT: Combined Cycle, ST: Steam Turbine, GasT: Gas Turbine

(Source: RUPTL2012-2021 Appendix C.1)



(Source: Made from RUPTL2012-2021 by TA Team)

Figure 3.20 Maximum Power Demand Forecast and Installed Generation Capacity

3.8 Plan of Transmission Lines

In response to the steady growth of demand, installation of transmission equipments for supplying load and connecting generations are planned as follows.

Table 3.39 Transmission Lines Planned in the Java Bali System

(Unit km)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
500 kV AC	2	352	224	710.8	852	468	40	20	40	0	2,709
500 kV DC					300						300
150 kV	614	2,683	1,795	1,141	963	404	632	402	106	60	8,800
70 kV		110		100							241

(Authority:RUPTL2012-2021)

Table 3.40 Transformers and Substations Planned in the Java Bali System

(MVA)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
500/150 kV	6,336	4,836	4,503	4,000	7,000	3,500	1,500	1,000	1,000	0	33,675
150/70 kV	6,996	7,630	3,420	2,700	5,820	3,330	3,630	3,300	3,510	2880	43,206
70/20 kV	530	110	30	0	0	30	90	150	60	90	1,090

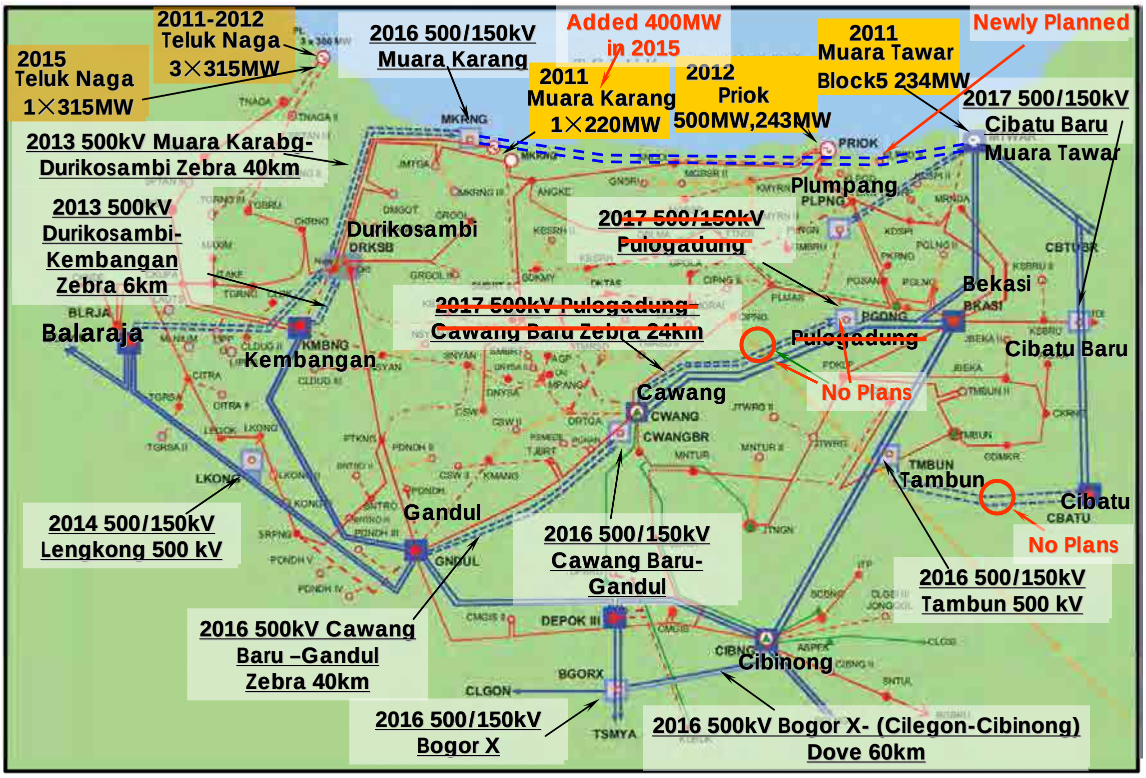
(Authority:RUPTL2012-2021)

RUPTL nominates the following major projects to reinforce the 500kV transmission system.

- Duri Kosambi～Muara Karang line, to be completed in 2013
- Cawang Baru～Muara Karang line, to be completed in 2016
- Paiton～New Kapal (Bali～Java）line, to be completed in 2015 (150 kV)、in 2016 (500 kV)
- Ungaran～Pemalang～Mandirancan～Indramayu line, to be completed in 2016
- Southern Smatela～Java Bali System HVDC 500kV line (3000MW)
- XBogol 500 kV Substation Newly constructed
- XBogol～Tasik、XBogol～Depok、XBogol～Cilegon、XBogol～Cibinon line, to be completed in 2016

Lately RUPTL2011-2020 was changed mainly as follows

- Kembangang～ Balaraja～ Durikosambi and so on delayed by 1 to 2 years
- 500 kV Pulogadung Substation, Pulogadung～Cawang Baru line project is not planned
- Muaratawar～Priok、Muarakarang～Priok line newly planned
- Gresik Thermal is changed to 500 kV, and connected to Tandes 500 kV Substation through the Tandes～Gresik 500kV line.



Red characters and red cancellation lines mean major changed plan in RUPTL2012-2021
(Authority:RUPTL2011-2020 Appendix)

Figure 3.21 Reinforcement Plans of the System around Jakarta [RUPTL2011-2020]

Table 3.41 Installation Plan of EHV Substation in the Java Bali System [RUPTL2011-2020]

Substation	State	Voltage Eqip	Capacity (MVar)	Fiscal Year
New Kapal Antosari	Bali	500/150 2IBT	1,000	2015
Bantul	Jogjakarta	500/150 2IBT	1,000	2015
Ujung Berung	Jawa Barat	500/150 2IBT	500	2011
Muara Tawar	Jawa Barat	500/150 2IBT	1,000	2013
Upper Cisokan PS	Jawa Barat	500/150		2016
Cigereleng II/Cikalong	Jawa Barat	500/150 2IBT	500	2016
Matenggeng	Jawa Barat	500/150		2019
Rawalo/Kesugihan	Jawa Tengah	500/150 1IBT	500	2014
Pemalang 500kV	Jawa Tengah	500/150 2IBT	1,000	2016
Jawatengah	Jawa Tengah	500/150		2016
Bangil 500kV	Jawa Timur	500/150 2IBT	500	2015
Tandes	Jawa Timur	500/150 2IBT	1,000	2017
Grindule	Jawa Timur	500/150		2020

(Authority:RUPTL2011-2020 Appendix)

Table 3.42 Installing the EHV Line in the System around Jakarta [RUPTL2011-2020]

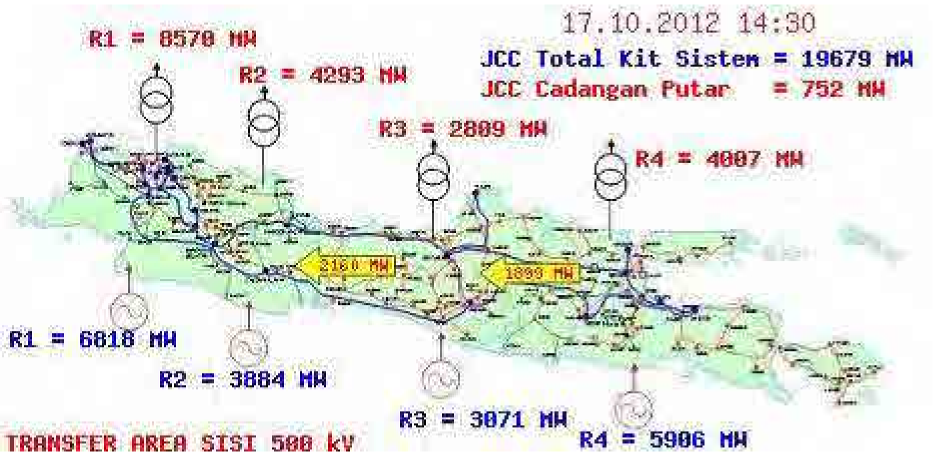
Start	End	Line Type	Year
Balaraja	Suralaya Baru	2cct Dove 80km	2011
Balaraja	Kembangan	2cct zebra 80km	2013
Lengkong 500kV	Inc.(Balaraja – Gandul)	2cct dove 4km	2014
Bogor X & Converter St	Inc.(Cilegon – Cibinong)	2cct dove 60km	2016
Bogor X & Converter St	Inc.(Depok – Tasikmaraya)	4cct dove 6km	2016
Banten PLTU	Inc.(Suralaya – Balaraja)	4cct dove 40km	2016
Bekasi	Tx.(Muara Tawar – Cibinong)	2cct dove 12km	2012
Duri Kosambi	Kembangan	2cct zebra 6km	2013
Cawang Barn	Gandul	2cct zebra 40km	2016
Muara Karang 500kV	Duri Kosambi	2cct zebra 30km	2016
Pulogadung	Cawang Baru	2cct zebra 24km	2017
Bekasi Theramal	Muara Tawar	2cct dove 20km	2018
Tembun 500kV	Inc.(Bekasi – Cibinong)	2cct dove 2km	2016
Cibatu Baru	Inc.(Cibatu – Muara Tawar)	2cct gannet 4km	2017
Indramayu	Cibatu	2cct zebra 270km	2017
Bogor X & Converter St	Tanjun Pucut	500kV HVDC OHI	2016
Tanjun Pucut	Ketapang	500kV HVDC CABLE	2016

(Authority:RUPTL2011-2020 Appendix)

Chapter 4 Current Jakarta System Model and Analysis

The purpose of this chapter is to study the possibility of occurrence of a blackout by evaluating the upper limit of the power demand from the viewpoints of voltage instability in the Jakarta power system by using the system model made that reflects the current situations of the current Java-Bali system. The system analysis model is made based on the data sets received from P3B JB with the revised information obtained by the Study Team.

4.1 Premise of Model Development



(SOURCE: SCADA data provided by P3B JB)

Figure 4.1 Simulated Power Flow Diagram at 14:30 on October 17, 2012

Hereinafter, the system analysis data shown are set/ updated by the Study Team based on the PSS/E model's data set provided by P3B JB. The Study Team selected the phase of October 17, 14:30, 2012 to the simulated power system situation due to the peak load of Jakarta where its maximum record on the day through the year 2012 was observed and because the bus voltage at Bekasi 500 kV substation showed its lowest value at 14:30 on the day (Figure 4.1). Table 4.1 shows each model's component in detail.

Table 4.1 Main Component of Java Bali System Model of 2012

Component	Input data	Number of data
Generator	- Active power - Reactive power - Terminal voltage	250 units
Transformer	- Capacity - Reactance - Winding ratio	371 units
Transmission line	- Line constants - Distance	1,250 sections
Load	- Active power - Reactive power	459 locations
Reactive power supplier	- Capacity	63 locations
Network topology	- Connection points	1,250 sections

4.1.1 Generator

For the data entry of generators, the JICA Study Team cited the values from the SCADA data provided by P3B JB (Table 4.2). The model covered all the generators connected to the 500 kV and 150 kV Java Bali System. Given the referred output of the generators (active power and reactive power) which included the amount consumed by in-house use at the power stations, the input of the model subtracted this portion which is evenly set as 6 % of the output of each generator.

Table 4.2 Input of Generators

Item	Description	SOURCE
Active power (P)	Actual record multiplied by (1 – in-house use rate). 6% is set for in-house use rate covering all the generators.	SCADA data provided by P3B JB
Reactive power (Q)	Same as above.	Same as above.
Terminal voltage (V)	Actual record. Some data has been adjusted.	Same as above.

4.1.2 Transformer

For the model’s input data of reactance and the capacity of the 500/150 kV transformers, the Study team prioritized the data registered in the database (database of DIgSILENT simulation software) maintained by P3B JB’s system operation group based on discussions with the counterpart, and replaced the figures originally set in the PSS/E dataset with those registered in the database. (Table 4.3).

Table 4.3 Capacity and Reactance of 500/150 kV Transformers (Winding MVA Base)

Item	Region	Capacity [MVA]		Reactance X [pu]	
		Before	After	Before	After
500/ 150 kV transformers	All	446	500	0.12	0.131～0.142

4.1.3 Transmission Lines

Similar to the case of transformers, the Study Team prioritized the facility data of Region 1 registered in the P3B's DIgSILENT database, and replaced the figures originally set in the PSS/E dataset with those registered in the database (Table 4.4).

Table 4.4 Lines' Impedance and Distance

Voltage	From	To	Impedance [pu] (showing reactance value as a sample)		Distance [km]		Note
			Before	After	Before	After	
500 kV	MDRCN	UBRNG	0.01595	0.007975	120.0	60.0	
150 kV	MRNDA	BKASI	0.005002	0.010003	4.2	8.5	
	MNTUR	PDKLP	-	0.011855	-	10.5	Network topology also updated.
	MNTUR	JTRGN	0.0195	0.0068	17.2	6.0	
	PKDLP	JTRGN	-	0.0068	-	6.0	Network topology also updated.
	BRLJA	CITRA	0.0190	0.0068	23.2	6.0	
	LEGOK	LKONG	0.00902	0.020399	8.0	18.0	
	LKONG	SPRNG	0.00657	0.020399	5.8	18.0	

Note: The above table uses abbreviated name for the start and the end substations which are also used in the simulation model.

4.1.4 Reactive Power Supplier

Similar to those of the transformers, the values of the model's input data are set to match the data registered in the database of DIgSILENT as well as those that resulted in the P3B's study[4].

Table 4.5 Reactive Power Supplier Data

Item	System Voltage	Reactive Power Capacity [MVar]
Shunt capacitors/ shunt reactor	500 kV	50, 100
	150 kV	10, 25, 50, 100

4.1.5 Load

Similar to the above, all the loads connected to 150 kV and 70 kV Java Bali system are modeled (Table 4.6).

Table 4.6 Load Data

Item	Input	Source
Active power(P)	Actual record	SCADA data provided by P3BJB.
Reactive power (Q)	Same as above	Same as above.

---

[4] Program Peningkatan Kualitas Tegangan, P3B JB, Nov. 2012

4.1.6 Network Topology

The Study team tried emulating the network topology as of October 17, 2012, 14:30, specifically the ones of Region 1 and of Region 2, both of which experienced severe voltage drops. Table 4.7 shows the resource which was referred to for this purpose.

Table 4.7 Network Topology

Region	Coverage	Source
Region 1	Network topology by 150 kV subsystem	- SCADA data provided by P3BJB. - Operation record of October 17, 2012 provided by ACC1.
Region 2	Network topology by 150 kV subsystem	- Operation record of October 17, 2012 provided by ACC2.
Region 3	500 kV system	- SCADA data provided by P3BJB.
Region 4	500 kV system. Part of 150 kV system	- Same as above.

4.2 Validity of the Model (Simulation Result)

This section evaluated the validity of the model which has been developed in the manner shown in 4.1. For this purpose, the Study Team compared the calculation output with the actual record. For this validity check, the voltage at the substation’s bus bar is selected as the benchmark indicator (Table 4.8). For reference, the amount of power flow is also selected as the benchmark indicator.

Table 4.8 Indicator to be Verified (Voltage and Power Flow Amount)

Verified indicators	Coverage	Source
Bus bar voltage	Bus bar voltage of all the 500 kV substations as well as power stations in Java Bali system.	SCADA data provided by P3B JB
Power flow (P, Q)	Power flow of 500 kV and 150 kV transmission lines as well as that of 500/150 kV IBT within Region 1.	Same as above.
	Power flow of 500 kV and 150 kV transmission lines as well as that of 500/150 kV IBT within Region 2.	Same as above.
	500 kV and 150 kV inter-regional power flow between Region 1 and 2, between Region 2 and 3, and between Region 3 and 4.	Same as above.

The result is shown in the following pages.

4.2.1 Verification of the Calculated Voltage Profile

Table 4.9 and Table 4.10 summarized the comparison results between the actually-observed record and the simulated results for the voltage at the bus bar of the substations in Region 1.

Table 4.9 Comparison of Calculation Result of the Voltage at 500 kV Substations

Substation	Voltage [kV]		
	Actual record	Calculation result	Gap
Bekasi	440	445.4	5.4
Balaraja	442	454.6	12.6
Cawang	442	445.3	3.3
Kembangan	443	445.6	2.6
Gandul	447	447.2	0.2
Cibinong	448	446.4	-1.6
Depok	449	447.4	-1.6
Cilegon	470	469.4	0.6
Suralaya	471	469.6	-1.4

Note: The data are as of 14:30, Oct. 17, 2012

(SOURCE: SCADA data provided by P3B JB)

Table 4.10 Comparison of Calculation Result on Voltage at 150 kV Substations in Region 1

	Substation	Voltage [kV]			500 kV Subsystem		Substation	Voltage [kV]			500 kV Subsystem
		Actual record	Calculation Result	Gap				Actual record	Calculation Result	Gap	
1	PGDN	(*)37	129	-	BEKASI	15	JTAKE	122	122	0	BRLJ
2	PLPNG	(*)97	130	-	BEKASI	16	PRIO5	122	131	9	BEKASI
3	MPANG	(*)100	126	-	CAWANG	17	TLKGA	122	120	-2	BRLJ
4	LEGOK	(*)106	123	-	BRLJ	18	MRNDA	123	126	3	BEKASI
5	CITRA	(*)116	124	-	BRLJ	19	CLDUG	124	126	2	KEMBANGAN
6	CMGIS	(*)117	129	-	CIBINONG	20	KMANG	124	136	12	GANDUL
7	SPRNG	120	124	4	BRLJ	21	CNANG	124	126	2	GANDUL
8	BGBRU	120	129	9	CIBINONG	22	DKTAS	125	124	-1	DEPOK
9	LKONG	120	124	4	BRLJ	23	LNTAR	125	127	2	CILEGON
10	MAXIM	120	122	2	BRLJ	24	CWBR5	126	124	-2	CAWANG
11	BLRJ	121	124	3	BLRJ	25	MNTU	126	128	2	BEKASI
12	PSKM	121	122	1	CILEGON	26	CKNDE	127	128	1	CILEGON
13	SPTAN	121	121	1	CILEGON	27	CSW	127	131	4	BEKASI
14	CKUPA	122	123	1	KEMBANGAN	28	JTNGN	127	127	0	CIBINONG

Note: The data are as of 14:30, Oct. 17, 2012

*: Because these figures are far different from the other figures, they may not reflect actual values possibly due to insufficient calibration of SCADA meters.

(SOURCE: SCADA data provided by P3B JB)

As a result, it has been confirmed that the simulation results fall within the range between plus or minus 5 % from the actually observed record. Therefore, the developed model for year 2012 can be regarded as appropriate to evaluate the current voltage conditions of the Java Bali System.

Figure 4.2 shows the comparison result of the 500 kV system in the format of the voltage profile.

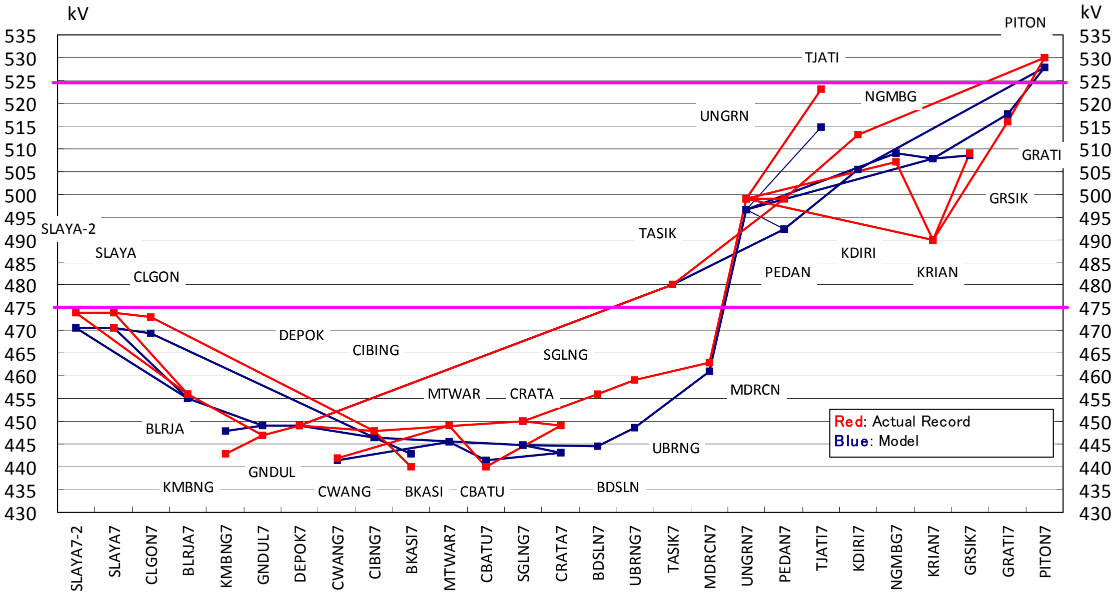


Figure 4.2 Voltage Profile (500 kV Substations in Java Bali System)

As seen, although there are some gaps between the actual record and the calculation results for the substation voltage located in the eastern half of the system, the gap for the substation voltage located in western half of the system, which is the main focus of this study, is small enough to conduct a further assessment of the current voltage situation. Figure 4.3 excerpted the results of those located in Region 1.

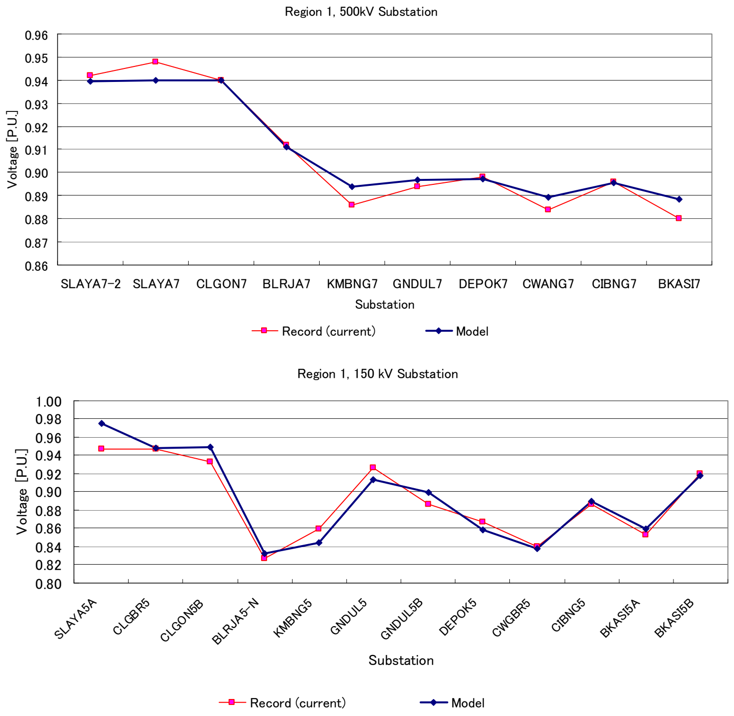


Figure 4.3 Comparison of Calculation Result of Voltages at 500/ 150 kV Substations (Upper: 500 kV bus, lower: 150 kV bus)

As seen in the above figure, both the calculated primary and the secondary voltages of the 500 kV substations located in Region 1 shows a small deviation from their corresponding actual record within the range from minus 5% to plus 5%. Therefore, the developed models are confirmed to be appropriate to be used for further evaluation of the voltage conditions of the current Java Bali power system. For reference, Table 4.11 shows the comparison results between the inter-regional power flow of Java Bali System between the calculation results and the actual record.

Table 4.11 Comparison of Calculation Result on Inter-region Power Flow of Java Bali System

	Region 1	←	Region 2	←	Region 3	←	Region 4	Total
Supply [MW]	6,818 6,998		3,884 3,777		3,071 3,079		5,906 4,789	19,679 18,643
Demand [MW]	8,520 8,127		4,293 3,686		2,809 2,463		4,007 3,549	19,629 17,825
Accommodation [MW]		2,096 1,832		2,229 2,202		1,532 1,693		

Note: Red) Actual record, Black) Calculation result

Figure 4.4 – Figure 4.7 show a detailed comparison result over the 500 kV system by region. The calculated result of the power flow inside each region shows a deviation from the actually-observed record by plus-minus around 10 %.

As a result of the model’s validity evaluation, the following has been confirmed: [1] 500 kV system’s voltage profile shows that the simulation results imitates the actual record with the gap ranging within plus minus 5 kV (within 1%), [2] The value of the intra- and inter-regional power flow also imitates that of the actual record in most cases. For those reasons, the validity of the developed model to be used for the assessment of the voltage conditions of the current Java Bali System has been confirmed. The subsection 4.2.3 analyzes the upper limit of the Jakarta power demand for the current (year 2012) system employing a PV curve analysis approach. Its result can be useful in identifying how much margin is left before leading to a widespread blackout triggered by a voltage collapse, calculating the above-mentioned limit.

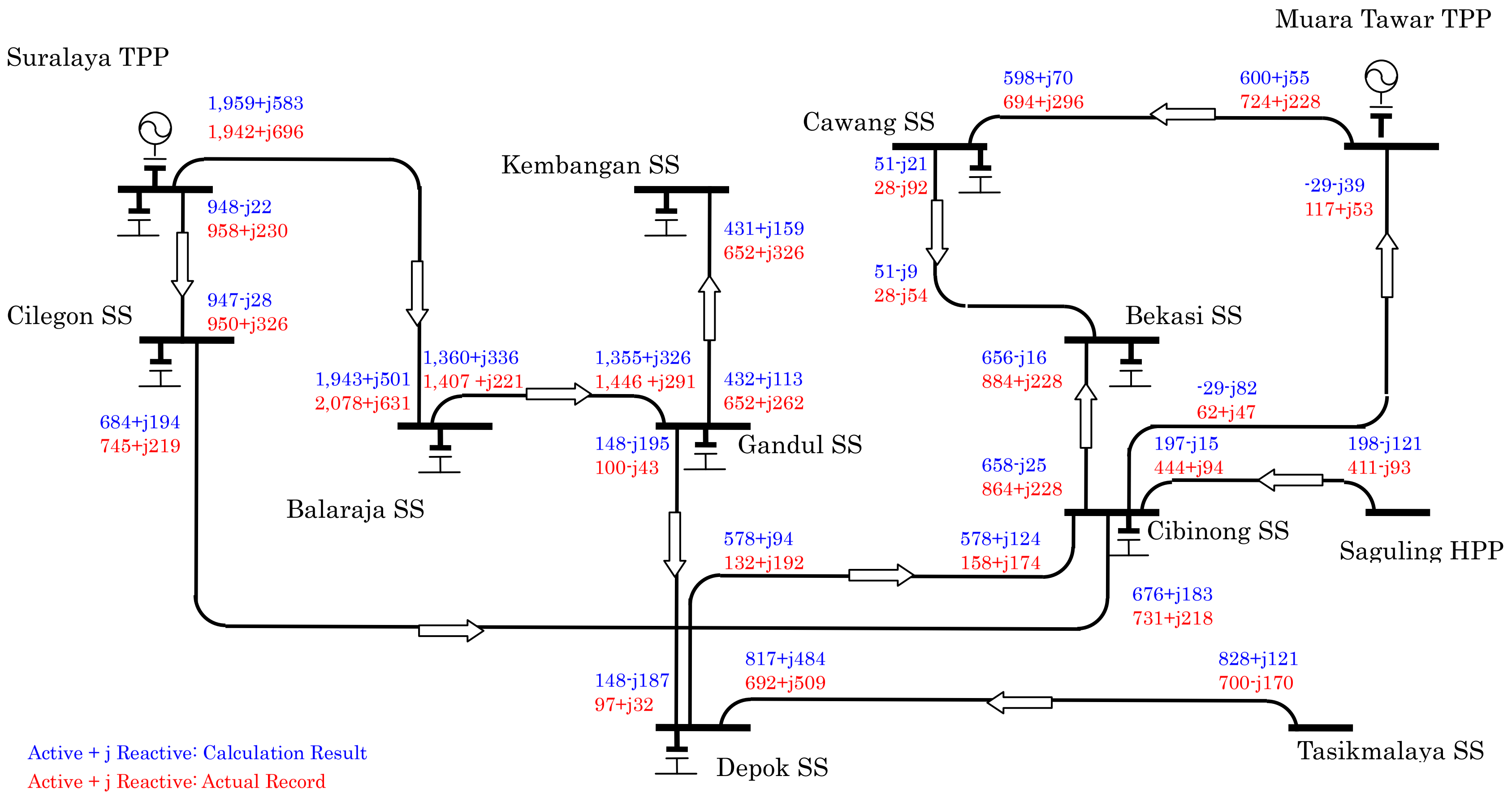
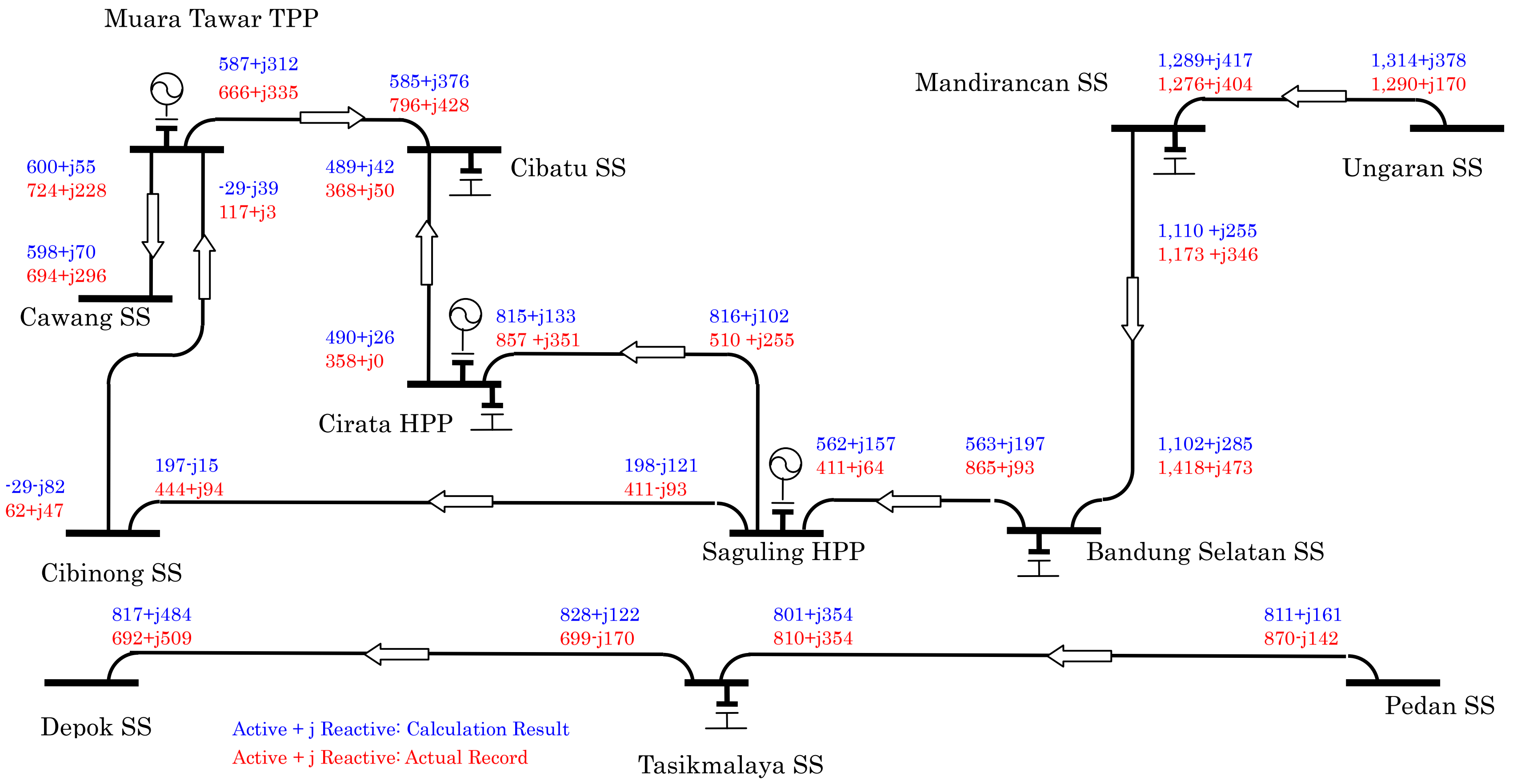


Figure 4.4 500 kV System Power Flow Simulation Result of Jakarta and Banten Area (Region 1)



Note: Although some of actual records do not seem to reflect exact value partly due to insufficient calibration, the above shows the values as provided

Figure 4.5 500 kV System Power Flow Simulation Result of West Java Area (Region 2)

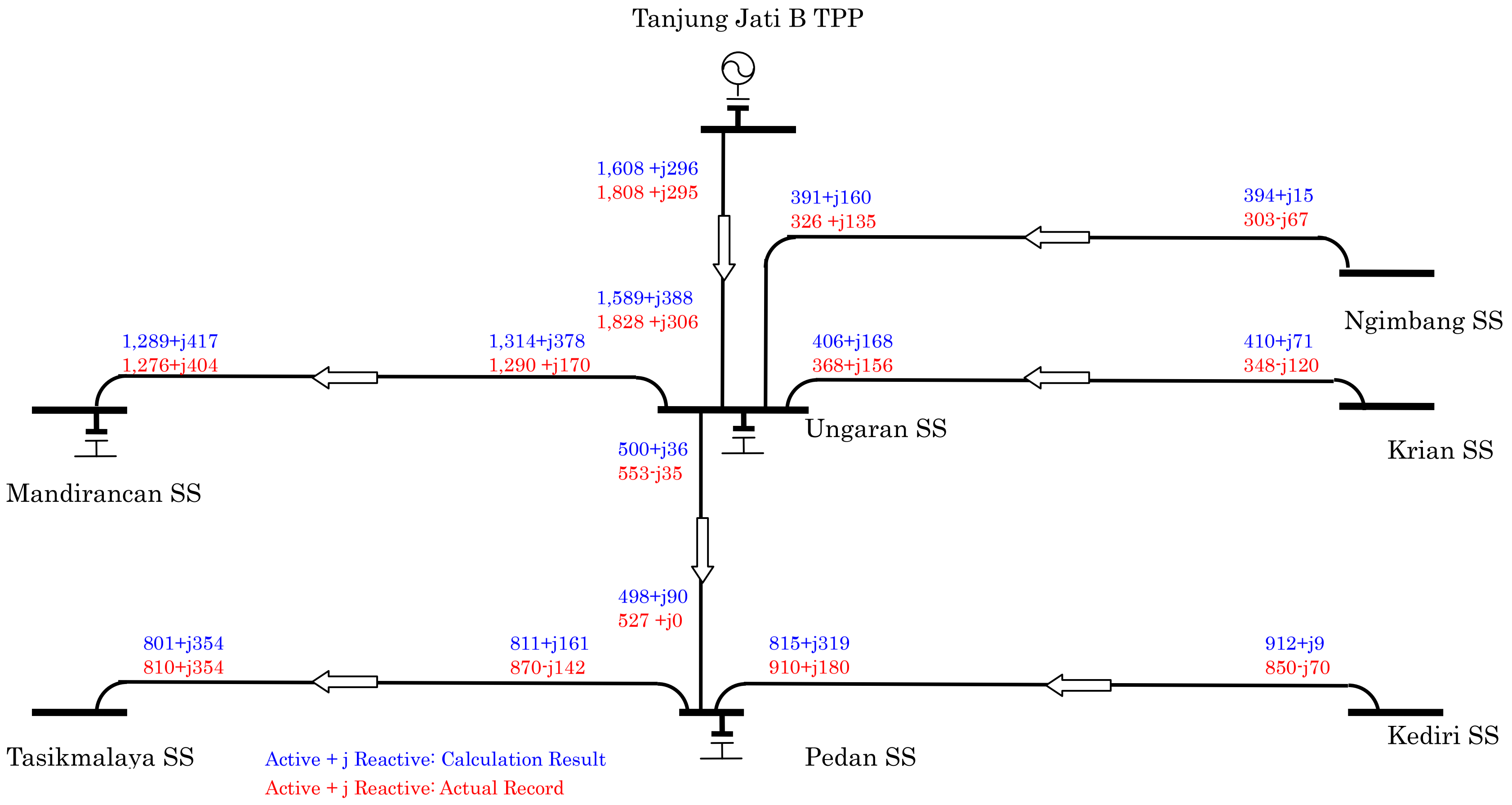
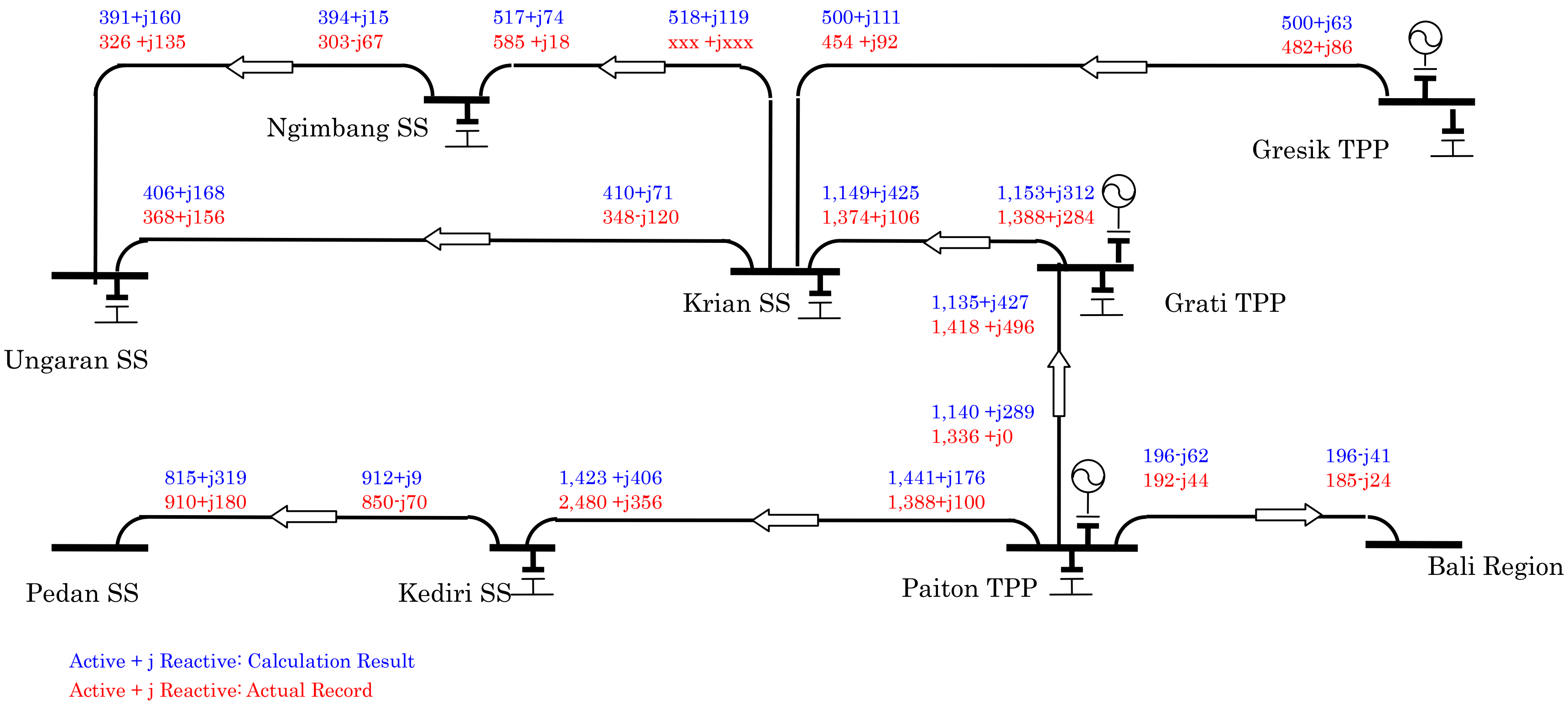


Figure 4.6 500 kV System Power Flow Simulation Result of Central Java Area (Region 3)



Note: The section between Paiton TPP and Bali Region is 150 kV system.

Figure 4.7 500 kV System Power Flow Simulation Result of East Java Area (Region 4)

4.2.2 Reactive Power Balance by Subsystem under 500 kV Substation in Region 1

Table 4.12 shows the reactive power balance per subsystem in Region 1, which is obtained by power flow simulation.

Table 4.12 Reactive Power Balance by Subsystem (zone) within Region 1

Unit: MW

		ZONE 1 SURALAYA	ZONE 2 CILEGON	ZONE 3 BARALAJA	ZONE 4 KEMBANGAN	ZONE 5 GNDUL	ZONE 6 DEPOK	ZONE 7 BEKASI	ZONE 8 CWANG	ZONE 9 CIBINONG	Total
Active power	Supply	3,024	792	0	0	1,203	0	1,222	0	178	6,419
	Demand	99	1,002	803	352	1,605	403	1,693	885	1,427	8,268
	Loss	1	28	27	2	20	19	10	4	27	139
	Balance	2,923	-237	-831	-354	-425	-422	-485	-889	-1,276	-1,996

Unit: MVar

		ZONE 1 SURALAYA	ZONE 2 CILEGON	ZONE 3 BARALAJA	ZONE 4 KEMBANGAN	ZONE 5 GNDUL	ZONE 6 DEPOK	ZONE 7 BEKASI	ZONE 8 CAWANG	ZONE 9 CIBINONG	Total
Reactive power	Supply	1,148	328	0	0	603	0	325	0	72	2,477
	Demand	52	119	303	110	433	55	275	341	373	2,059
	Reactive power supplier	0	0	0	0	-74	106	-112	0	-8	-88
	Charging capacity	5	71	184	26	174	549	214	75	323	1,621
	Loss	376	269	364	56	345	224	255	87	360	2,335
	Balance	726	11	-482	-140	74	164	122	-352	-330	-210
Bus bar voltage (150 kv) [p.u.]		0.98	0.95	0.84	0.84	0.91 0.90	0.86	0.92 0.86	0.84	0.89	

Note: Figures of the Bus bar voltage in red show that the values are below the lower limit of the operation range.

As seen, the secondary bus bar voltage (150 kV) at the 500/ 150 kV substations tends to be low in the subsystems (zone) whose reactive power balance is low. Table 4.13 shows the power accommodation among the subsystems (or “Balance” in Table 4.12) in detail.

Table 4.13 Power Accommodation among the Subsystems in Region 1

		To:										
		ZONE 1 SURALAYA	ZONE 2 CILEGON	ZONE 3 BARALAJA	ZONE 4 KEMBANGAN	ZONE 5 GNDUL	ZONE 6 DEPOK	ZONE 7 BEKASI	ZONE 8 CWANG	ZONE 9 CIBINONG	Region 2	Sub Total
From:	ZONE 1 SURALAYA		936.5 142.5	1,959.3 583.0					2,922.9 725.6			2,922.9 725.5
	ZONE 2 CILEGO	-936.5 -142.5		141.1 25.3	-136.8 15.0	16.5 -67.4				705.9 180.4		-236.9 10.0
	ZONE 3 BARALAJA	-1,959.3 -583.0	-141.1 -25.3		59.3 -33.7	1,210.3 159.6						-830.8 -482.3
	ZONE 4 KEMBANGAN		136.8 -15.0	-59.3 33.7		-431.4 -158.7						-354.0 0140.0
	ZONE 5 GNDUL		-16.5 67.4	-1,210.3 -159.6	431.4 158.7		148.6 -195.1	0 0	221.5 202.1			-425.3 79.5
	ZONE 6 DEPOK					-148.6 195.1			0 0	554.4 89.9	-827.8 -121.4	-422.0 163.5
	ZONE 7 BEKASI								67.6 94.6	-450.0 51.2	-102.2 -23.8	-484.5 127.0
	ZONE 8 CWANG	-2,922.9 -725.6				-221.5 -202.1		-67.6 -94.6		0 0	-600.0 -55.4	-889.0 -352.2
	ZONE 9 CIBINONG		-705.9 -180.4				-554.4 -89.9	450.0 -51.2			-306.2 39.3	1,276.4 -330.3
	Region 2						827.8 121.4	102.2 23.8	600.0 55.4	306.2 -39.3		1,836.2 161.3

Legend: Upper in cell: active power [MW], lower in cell: reactive power [MVar]

4.2.3 Assessment of Margin to Critical Status

This subsection employed the developed 2012 model to evaluate the voltage stability limit which could lead to a widespread blackout. For this purpose, the Study Team utilized a PV (active power – system voltage) Curve analysis approach to calculate the upper limit of Jakarta power demand. In this approach, only the Region 1’s demand is increased starting from the current peak demand, while the output of the generators located in the rest of the system, i.e. Regions 2 to 4, are increased to balance the increased demand. The result is shown in Figure 4.8.

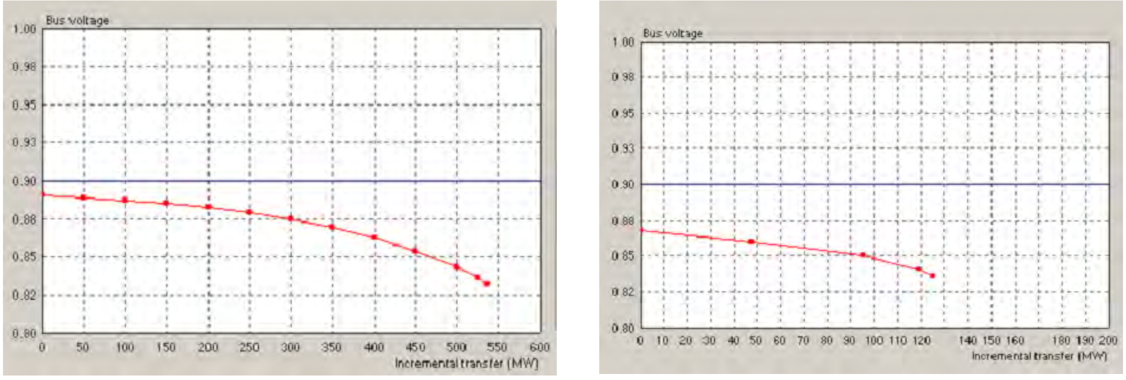


Figure 4.8 Result of PV Curve Analysis (Left: normal condition, right: N-1 condition)

As seen in the normal conditions case above the left, the margin between the upper limit of the Jakarta demand and the peak-time operation point (8,520 MW, Region 1) is 537.50 MW, or 6 % of the Region 1’s operating peak demand of October 17, 2012. The N-1 condition case shows that the current situation seems to need significant attention. In the case where the out-of-service of one circuit of the transmission section bridging Central and West Java e.g. Ungaran 500 kV substation and Mandirancan 500 kV substation would result in a margin of 131.25MW between the upper limit of Jakarta demand and the peak-time operation point (around 1% of the total demand of Region 1). Given that it is possible for the demand to deviate from its forecasted value by such level, it is recommended to implement countermeasures as early as possible.

Figure 4.9 shows the same result of Figure 4.10 in a different manner – adding Region 1’s power demand. As seen, the led results closely match the observed actual record of October 17, 2012.

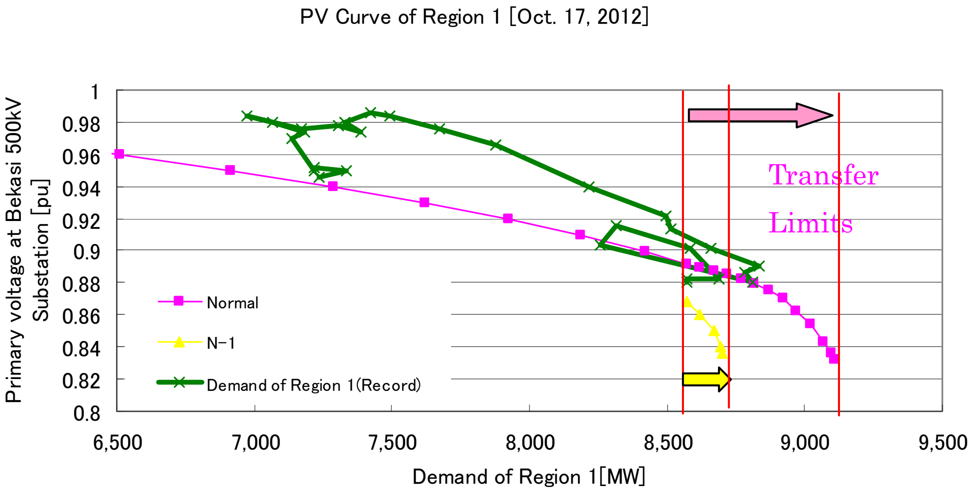


Figure 4.9 Result of PV Curve Analysis

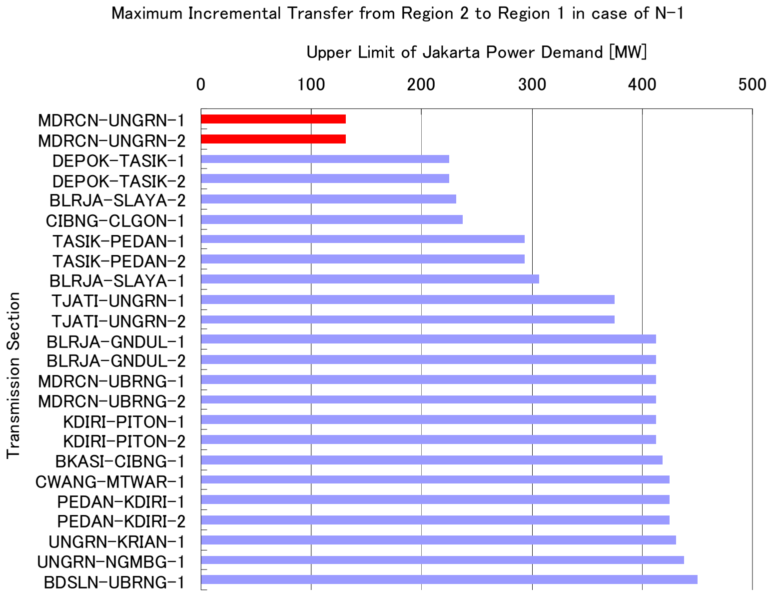


Figure 4.10 Correlation between the N-1 Failure Section and Upper Limit of Jakarta Power Demand

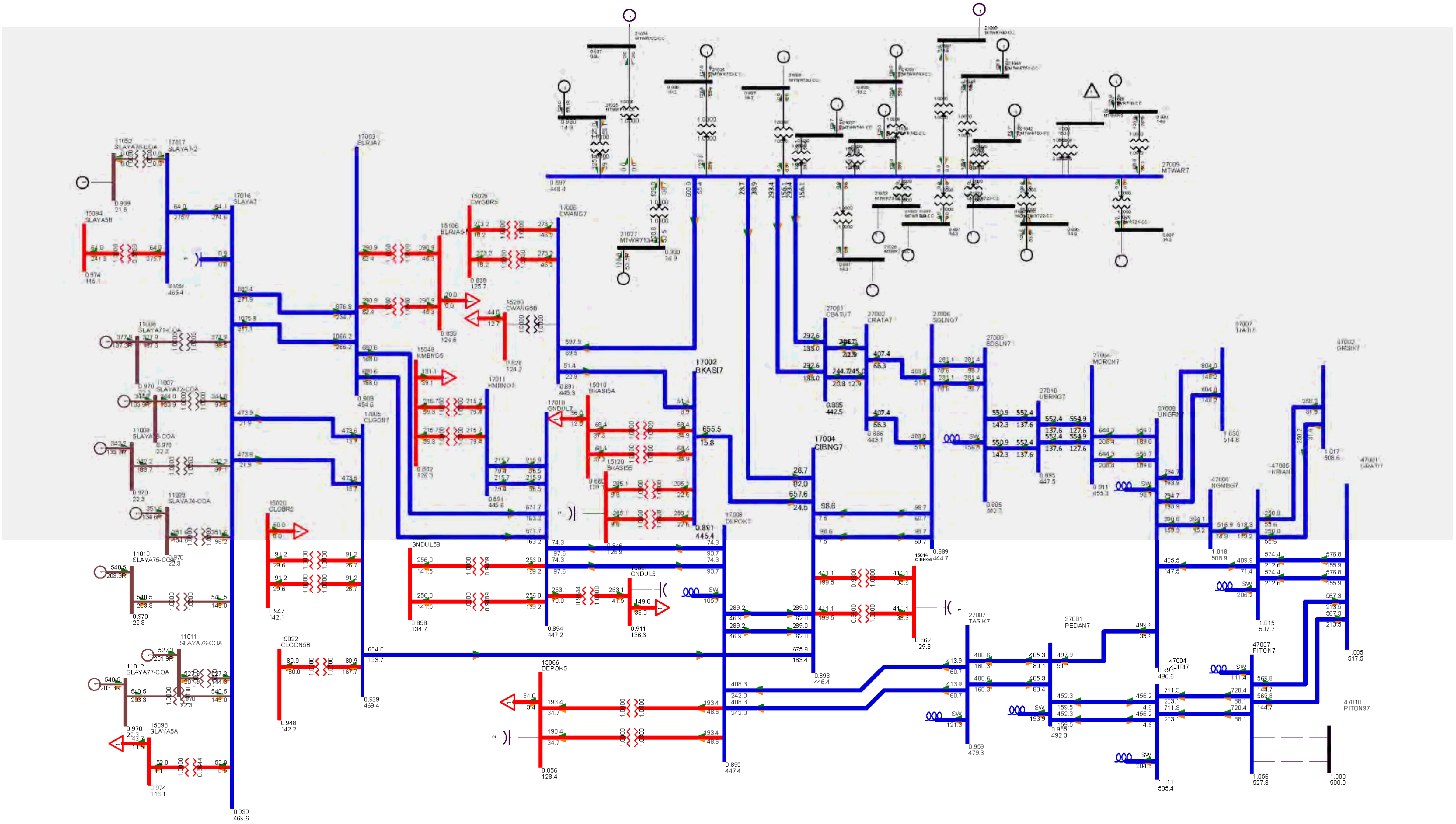


Figure 4.11 500 kV Power Flow Diagram of Java Bali Power System (October 17, 2012, 14:30)

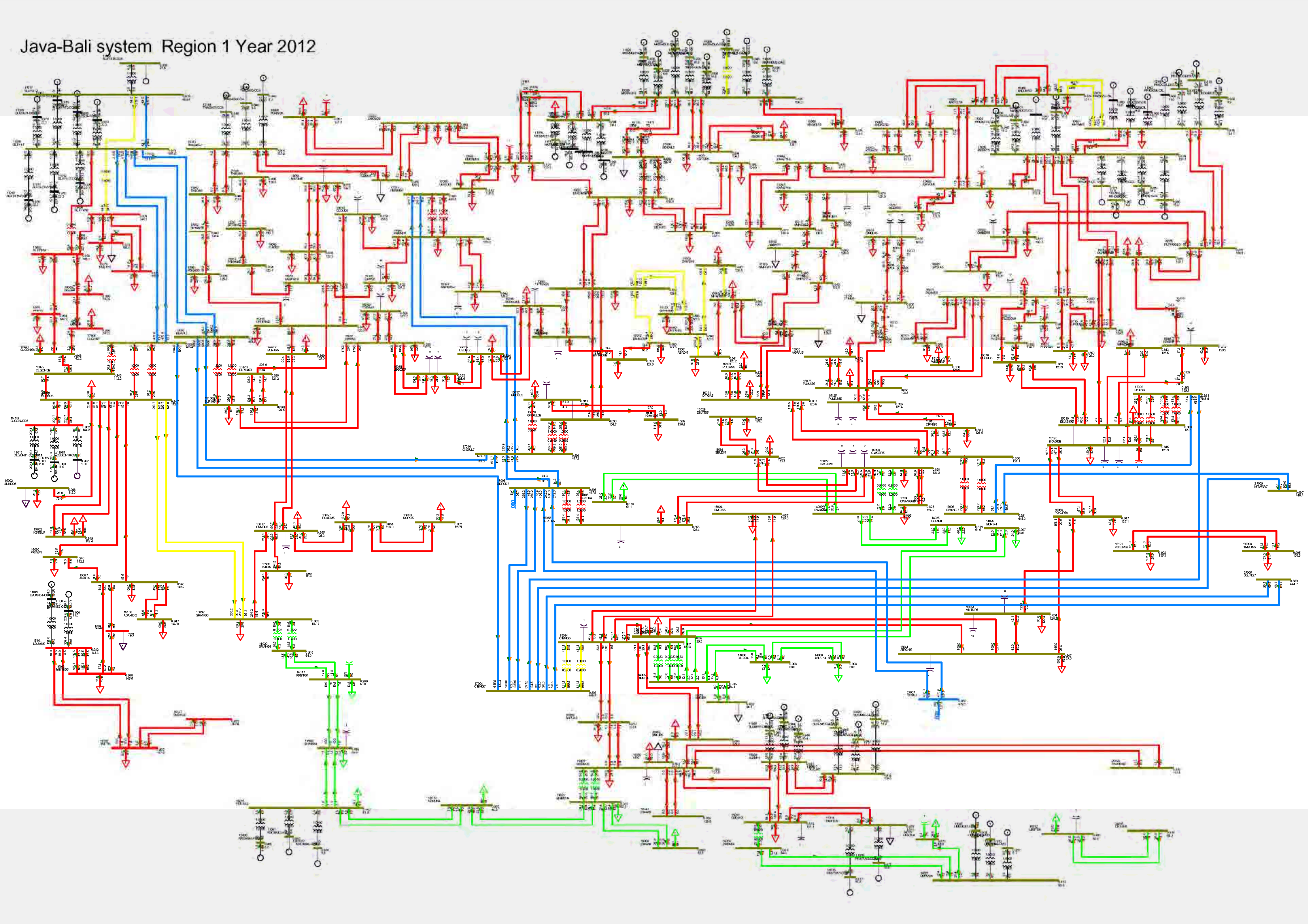


Figure 4.12 500 kV and 150 kV Power Flow Diagram of Region 1 (October 17, 2012, 14:30)

Chapter 5 Modeling and Analysis of the Jakarta system in the Near Future (Year 2015)

In this chapter, the required amount of shunt capacitors and its effects in the near future are analyzed by carrying out a system analysis of the 2015 Jakarta system.

5.1 Study on the Installation of Additional Shunt Capacitors

5.1.1 Amount of Required Additional Shunt Capacitors

(1) Active Power Load

Active power loads derived from PSS/E file for Jakarta peak demand (13:00) in 2015 received from P3B were used for this study. Table 5.1 shows the total load in each region under Jakarta peak demand in 2015.

Table 5.1 Total Load in Each Region under Jakarta Peak Demand in 2015

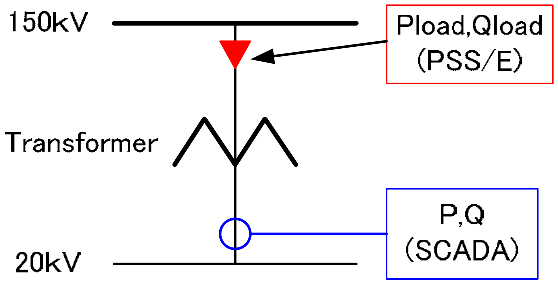
	Total	Region 1	Region 2	Region 3	Region 4	Region 5
Jakarta peak at 13:00	24,653	9,869	6,052	3,143	4,964	625

(2) Reactive Power Load

Reactive power load is composed of the elements which are proportional to the active power and square of the active power. The reactive power load tends to increase in accordance with the active power. Reactive power also includes the fixed component which is generated from the reactive compensator and the charging capacity of the transmission lines and so on. Typically, the method to take the above components in a whole is used to estimate the reactive power load. In this study, a quadratic regression analysis was performed using the P&Q values measured at each substation bus. P-Q correlation equations were calculated in order to precisely predict reactive power loads.

The Study Team calculated the P-Q correlation equations of loads within Region 1 and Region 2 where significant system voltage drops occurred in the Java-Bali system under peak demand. The calculation was performed based on the P&Q values measured on 17th October 2012, when Jakarta peak demand occurred in recent years. The P&Q values measured at the substation bus are corresponding to loads modeled in the PSS/E file.

The measured active and reactive power through the 150/20kV and 70/20kV transformers was used in this study. The P&Q values are measured at the secondary side of the transformer, on the other hand each load is modeled at the primary side of the transformer in the PSS/E file. Consequently, in consideration of reactive power loss through the transformer, reactive power is corrected using the calculation below.



$$P_{load} \cong P$$

$$Q_{load} = Q_{loss} + Q$$

$$Q_{loss} \cong x_t \cdot (p^2 + q^2) \cdot P_0 [MVar]$$

(Assuming that V=1.0 pu)

Figure 5.1 Correction of Reactive Power

Generally, there is a correlation between the active power load and the reactive power load, which is represented by quadratic equation below,

$$Q_i = aP_i^2 + bP_i + c$$

where Pi and Qi are active and the reactive power components of each load, respectively. The subscript i identifies the number of each load.

P-Q correlation equations were calculated using quadratic equations, linear equations or the constant power factor based on a flow chart shown in Figure 5.2 and the calculated constant terms (a and b).

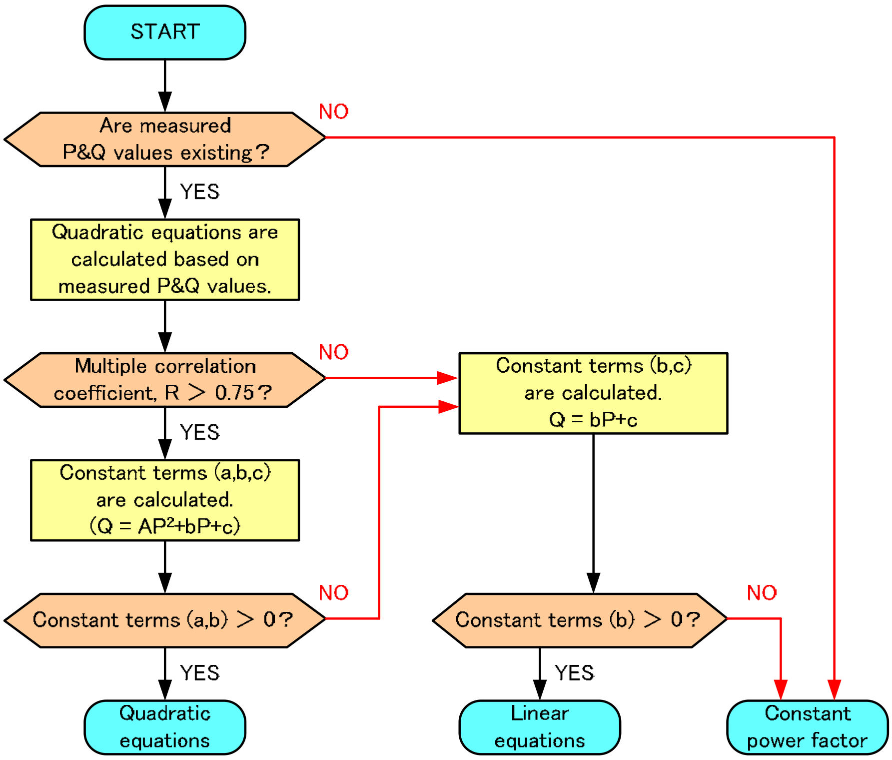


Figure 5.2 Flow Chart for P-Q Correlation Equations

Table 5.2 shows the results of the P-Q correlation equations and the estimated reactive power of the loads in Region 1 and Region 2. Basically, the reactive power of the loads were estimated using P-Q correlation equations calculated based on the measured P&Q values. If the differences between the estimated active power of the loads and measured P values were large, the reactive power of the loads are estimated using the constant power factor.

Table 5.2 Result of P-Q Correlation Equations and Estimated Reactive Power of Load

<Reactive Power Loads Estimated Using Quadratic Equations>

Bus Number	Bus Name	Id	Data received from P3B		Constant terms (a,b and c) $Q=aP^2+bP+c$			Based on PQ-correlation equation
			Pload (MW)	Qload (Mvar)	a	b	c	Qload (Mvar)
15001	ABADI5 150.00	1	41.817	13.939	0.001597	0.354481	−3.8409	13.775
15031	DTIGA5 150.00	1	94.225	30.442	0.001541	0.321707	−2.4301	41.566
15032	DUKSB5A 150.00	1	120.773	24.155	0.000661	0.231560	−2.2196	35.382
15034	GMBLA5 150.00	1	89.137	22.284	0.001570	0.303001	−4.2465	35.239
15045	KBSRH5 150.00	1	90.58	32.35	0.004353	0.077886	3.8822	46.654
15057	MGBSR5 150.00	1	90.58	59.225	0.000569	0.426184	−5.2692	38.000
15063	MPANG5B 150.00	1	90.58	30.475	0.001671	0.157219	−1.5650	26.389
15084	SBUDI5 150.00	1	90.58	21.313	0.000845	0.497627	−4.7024	47.307
15109	PCORN5 150.00	1	65.188	16.338	0.001193	0.589337	−9.6539	33.835
15122	SNYAN5B 150.00	1	90.58	29.772	0.002563	0.182913	1.0364	38.632

<Reactive Power Loads Estimated Using Linear Equations>

Bus Number	Bus Name	Id	Data received from P3B		Constant terms (b and c) Q=bP+c		Based on PQ-correlation equation
			Pload (MW)	Qload (Mvar)	b	c	Qload (Mvar)
14017	RKBTG4 70.000	1	6.97	1.525	0.095625	3.0322	3.699
15004	ANCOL5B 150.00	1	90.58	23.575	0.565973	-21.4197	29.846
15005	ANGKE5A 150.00	1	120.773	23.681	0.645235	-41.3339	36.593
15007	ASAHI5 150.00	1	46.027	15.009	0.717083	-12.2907	20.714
15009	BGBRU5 150.00	1	98.936	23.77	0.308092	-0.6741	29.807
15011	BLRJA5 150.00	1	72.075	14.61	0.566869	-5.8656	34.992
15012	BNTRO5A 150.00	1	90.58	43.87	0.595074	-19.8544	34.047
15015	CIPNG5 150.00	1	71.912	19.519	0.469416	-10.0277	23.729
15017	CKNDE5 150.00	1	39.271	26.18	0.607657	-6.5646	17.299
15019	CLDUG5 150.00	1	79.696	28.128	0.268544	7.8932	29.295
15024	CMGIS5 150.00	1	71.926	24.213	0.357402	5.7454	31.452
15026	CSW5 150.00	1	60.386	23.759	0.405428	-2.2383	22.244
15028	CWGBR5 150.00	1	42.758	8.552	0.538671	-11.3618	11.671
15029	DKATS5 150.00	1	60.386	24.532	0.620475	-9.8837	27.584
15035	GPOLA5 150.00	1	72.42	19.214	0.495668	-7.0387	28.858
15036	GMBRU5 150.00	1	90.58	30.447	0.442476	-0.7519	39.328
15040	JTAKE5 150.00	1	120.773	28.417	0.869802	-48.7572	56.291
15044	KBJRK5 150.00	1	90.58	26.867	0.507608	-20.6515	25.328
15046	KDSPI5 150.00	1	60.386	12.713	0.540138	-6.3209	26.296
15047	KMANG5 150.00	1	90.58	24.417	0.467855	-13.4278	28.950
15049	KMYRN5 150.00	1	89.311	26.049	0.596003	-12.5563	40.673
15050	KOPO5 150.00	1	45.219	15.544	0.681874	-7.6493	23.184
15051	KRTBR5 150.00	1	90.58	33.967	0.519339	-7.6647	39.377
15054	LEGOK5 150.00	1	90.58	11.322	0.427613	-9.3099	29.423
15058	MGRAI5 150.00	1	60.804	39.756	0.537329	2.1589	34.831
15061	MNTUR5 150.00	1	62.776	22.213	0.727686	-22.0390	23.642
15066	DEPOK5 150.00	1	71.248	19.431	0.411410	-2.1853	27.127
15067	PCADM5 150.00	1	101.544	55.388	0.699142	-32.3221	38.672
15071	PGSAN5 150.00	1	90.58	32.938	0.605788	-16.0612	38.811
15075	PLMAS5 150.00	1	90.58	35.799	0.510334	-11.1503	35.076
15077	PLPNG5-40 150.00	1	120.773	39.363	0.602583	-26.2243	46.551
15083	PTKNG5 150.00	1	90.58	17.722	0.450966	-20.1076	20.741
15089	SNTUL5 150.00	1	61.443	22.891	0.726579	-23.6058	21.037
15091	SPTAN5 150.00	1	62.621	13.046	0.261173	2.9456	19.301
15095	SRPNG5A 150.00	1	90.58	55.632	0.584270	13.2473	66.170
15098	TGRNG5 150.00	1	118.405	65.78	0.893295	-19.8715	85.899
15121	PDKLP5B 150.00	1	90.58	23.806	0.385772	2.7991	37.742
24046	PGDRN4 70.000	1	33.443	3.716	0.153666	1.2482	6.387
25002	BDUTR5A 150.00	1	132.669	43.606	0.580578	-23.3628	53.662
25004	BNJAR5 150.00	1	64.405	10.388	0.287545	4.1824	22.702
25008	CBATU5A 150.00	1	46.443	28.783	0.569104	1.8228	28.254
25028	DWUAN5 150.00	1	99.981	37.729	0.681612	-19.3977	48.751
25034	GDMKR5 150.00	1	73.852	15.666	0.750618	-29.4424	25.992
25042	JTBRG5 150.00	1	45.726	5.9	0.220267	8.3363	18.408
25072	PDLRG5 150.00	1	120.576	22.697	0.355575	4.7390	47.613
25074	PNCOL5 150.00	1	130.702	33.886	0.549184	-16.3874	55.392
25076	PNSIA5 150.00	1	31.474	10.853	0.931196	-12.0329	17.276
25080	PRMYA5 150.00	1	54.847	30.166	0.585022	0.6427	32.729
25082	PRURI5 150.00	1	44.838	10.19	0.816346	-18.0100	18.593
25086	RCKEK5 150.00	1	84.735	46.219	0.418029	22.6220	58.044

(3) Voltage dependency of the load characteristics

Typically, a static load model is used to represent the voltage dependency of the loads for static analysis of system voltage characteristics. The active power component P and the reactive power component Q are considered separately. The voltage dependency of the load characteristics is represented by the exponential model below:

$$P = P_0 (V / V_0)^m$$
$$Q = Q_0 (V / V_0)^n$$

where P and Q are active and reactive components of the load when the bus voltage magnitude is V. The subscript 0 identifies the values of the respective variables at the initial operating condition.

The parameters of this model are the exponents m and n. With these exponents equal to 0, 1, or 2, the model represents constant power, constant current, or constant impedance characteristics, respectively.

(a) Constant power characteristics

The constant power type load maintains a constant power draw from the system despite the change in voltage.

(b) Constant current characteristics

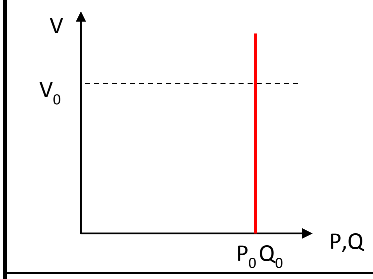
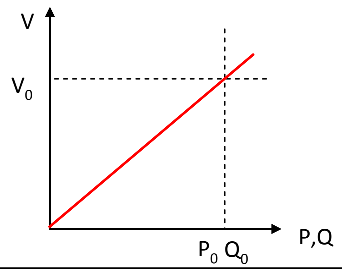
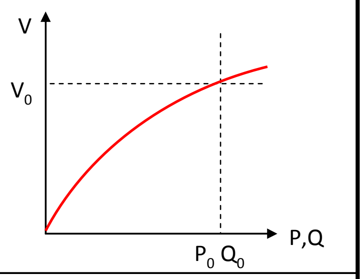
The power drawn by the constant current loads is proportional to the voltage when the voltages change.

(c) Constant impedance characteristics

The power drawn by constant impedance loads is proportional to the square of the voltage when the voltages change.

The above-mentioned three voltage dependencies of the load characteristics are particular cases. For composite system loads, the exponents m and n usually ranges between 0 and 2, those are more than 2 in some cases. Table 5.3 shows the voltage dependency of the load characteristics categorized into constant power, constant current and constant impedance characteristics.

Table 5.3 Voltage Dependency of Load Characteristics

(a) Constant power	(b) Constant current	(c) Constant impedance
m,n = 0 $P = P_0 (V/V_0)^0$ $Q = Q_0 (V/V_0)^0$	m,n = 1 $P = P_0 (V/V_0)^1$ $Q = Q_0 (V/V_0)^1$	m,n = 2 $P = P_0 (V/V_0)^2$ $Q = Q_0 (V/V_0)^2$
		
Constant power type load maintains a constant power draw from the system despite the change in voltage.	The power drawn by constant current loads is proportional to the voltage when the voltages changes.	The power drawn by constant impedance loads is proportional to the square of voltage when the voltages changes.

When the system voltage decreases, the current drawn by constant impedance loads is reduced and the current drawn by constant current loads is maintained. On the other hand, current drawn by constant power loads is increased since consumed power is not changed in case of voltage drop. Since reactive power losses in transmission lines and transformers are increased with increasing current drawn by constant power loads in case of voltage drop, system voltage deteriorated further. Constant power characteristics are a severe condition for maintaining voltage stability.

Since it is preferable that the voltage stability analysis is performed assuming the severe conditions as much as possible in the development of a reactive power compensation plan, constant power characteristics was applied in this study based on a discussion between P3B and the Study Team.

(4) Generator

Table 5.4 shows generation dispatching scenario under Jakarta peak demand in 2015. Generator outputs of each fuel type were allocated in consideration of actual operations. The terminal voltages of the generators were set at 1.0pu.

Table 5.4 Generation Dispatching Scenario under Jakarta Peak Demand in 2015

Fuel type	Setting
Coal	Maximum output
Gas	Output is adjusted for the demand-supply balance
LNG	Output is adjusted for the demand-supply balance

Oil	Minimum output
Hydro	Output is set based on the actual record on 17 Oct 2012. Following reservoir type hydro power plants were set based on information from P3B: Cirata: 2×98 MW Saguling: 2×147 MW Jatiluhur: 2×15 MW
Geothermal	Maximum output

(5) Configuration of the Java-Bali 500kV System

Figure 5.3 shows the system configuration of the Java-Bali 500kV system in 2015.

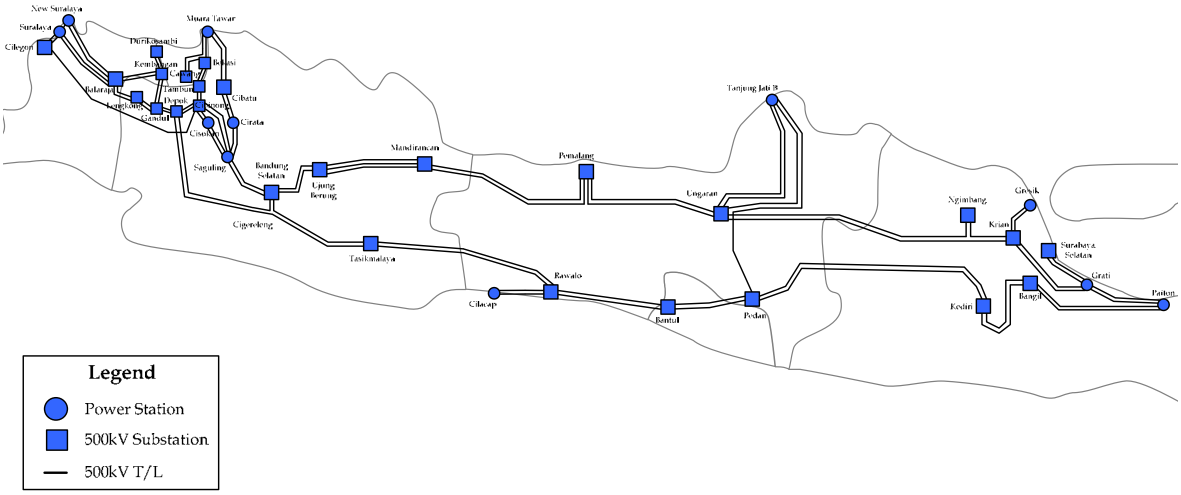


Figure 5.3 Configuration of Java-Bali 500kV System in 2015

(6) Transmission Line

Based on the discussion between P3B and the Study Team, the parameters of the 500kV transmission lines are modified using parameters shown in Table 5.5 and line length derived from the PSS/E file received from P3B. The line length between Mandirancan SS and Ujung Berung SS was revised from 120km to 60km based on the report of the "Preparatory Survey on Central and West Java 500 kV Transmission Line Project".

Table 5.5 Parameters of the 500kV Transmission Lines [ohm/km]

Conductor type	Tower	R+	X+	B	R0	X0	B0
DOVE	1 cct 1 tower	0.025954361	0.332697565	3.412471212	0.113360637	0.753248332	2.297849980
DOVE	2 cct 2 tower	0.026035814	0.332302953	3.415807277	0.091217209	0.700037623	2.317765770

DOVE	4 cct 1 tower	0.026168289	0.273961232	4.140229038	0.113482850	0.728754943	2.122049759
DOVE	2 cct 1 tower	0.026413490	0.274996404	4.312904222	0.267082887	0.961424013	3.158480028
GANNET	2 cct 2 tower	0.021835698	0.330877685	3.430941164	0.087017047	0.698612270	2.324728013
GANNET	2 cct 1 tower	0.021967275	0.272534564	4.162620117	0.109280764	0.727326196	2.128335171
ZEBRA	2 cct 1 tower	0.017540862	0.271232878	4.189264387	0.104852802	0.726022375	2.135777390

(7) Transformer

The capacities and reactances of the 500/150kV transformers were revised based on the analysis data (DIgSILENT data) received from the P3B operation system division. The parameters for the transformers in Nginbang SS were applied to parameters for new and additional 500/150kV transformers in the future system as typical parameters based on a discussion between P3B and the Study Team. The tap positions of the 500/150kV and 150/70kV transformers were adjusted in order to maintain secondary side voltages between 0.90pu and 1.05pu in the initial condition. The tap positions of the transformers were fixed during the process of study on the amount of required shunt capacitors. The winding ratios of the generator step-up transformers at Suralaya thermal power station were set to 1.025pu based on the result of the site surveys and the other winding ratios were set to 1.00pu.

Table 5.6 Capacity and Impedance of New and Additional Transformers in the Future System

Capacity [MW]	Impedance (pu winding base)	Remark
500	0.132	Derived from Ngimbang SS

(8) Shunt Reactor and Shunt Capacitor

The shunt reactors and shunt capacitors shown in Table 5.7 and Table 5.8 were assumed to be in-service in 2015. Table 5.8 was made based on P3B:"Program Peningkatan Kuakitas Tegangan" and analysis data (DIgSILENT data) received from the P3B operation system division, including the shunt capacitors described in Chapter 3.1.3

Table 5.7 In-service Shunt Reactor in 2015

Area	Voltage [kV]	Unit size [MVar]	No. of units	Capacity [MVar]
Region 1	500	100	1	100
Region 2	500	100	2	200
Region 3	500	100	2	200
Region 4	500	100	2	200
		50	2	100

Total	800

Table 5.8 In service Shunt Capacitor in 2015

Area	Voltage [kV]	Unit size [MVar]	No. of units	Capacity [MVar]
Region 1	150	50	22	1,100
	150	25	15	375
	70	10	1	10
	20	20	11	220
Region 2	150	50	2	100
	150	25	2	50
	70	10	2	20
Region 3	150	25	3	75
Region 4	150	25	10	250
	150	10	5	50
	70	10	7	70
Region 5	150	25	7	175
Total				2,495

(9) Results of the Required Amount of Shunt Capacitors

As for Region 1 and Region 2 including the Jakarta area, the required amount of shunt capacitors was studied in order to satisfy the voltage criteria under normal and N-1 contingencies shown in Table 5.9. As for Regions 3, 4 and 5, the required amount of shunt capacitors was studied in order to satisfy the voltage criteria only under normal condition since Regions 3, 4 and 5 are outside the scope of this study.

Table 5.9 Voltage Criteria under Normal and Contingency Condition

Nominal voltage	Normal condition
500 kV	95% - 105%
150 kV	90% - 105%
70 kV	90% - 105%
20 kV	90% - 105%

Source: “PLN PLANNING AND OPERATION CRITERIA”

The unit sizes of the shunt capacitor shown in Table 5.10 were applied based on the unit sizes of the existing shunt capacitors. Basically, the number of units was assumed to be limited to two units in this study. If more than two units were required to satisfy the voltage criteria, further shunt capacitors were added. Further study is necessary to determine the unit sizes of the shunt capacitors in consideration of the calculation results of the voltage deviation with the on/off switching of a shunt capacitor.

Table 5.10 Unit size of Shunt Capacitor

Nominal voltage	Unit size [MVar]
150 kV	25
70 kV	10

Table 5.11 and Table 5.12 show the list of required shunt capacitors for each Region under Jakarta peak demand in 2015.

Table 5.11 List of Required Additional Shunt Capacitor in 2015 (1/2)

Area	Substation	Type of S/S (kV)	Unit size [MVar]	No. of Units	Total [MVar]
Region 1	PCADM	150	25	1	25
	LBSTU	150	25	1	25
	LBSTU	70	10	1	10
	PDKLP	150	25	2	50
	CIAWI	150	25	1	25
	BGBRU5-2	150	25	1	25
	BGBRU	70	10	1	10
	BUNAR	150	25	1	25
	BUNAR	70	10	1	10
	ASPEK	70	10	2	20
	KDBDK	70	10	1	10
	MENES	70	10	1	10
	Subtotal				245
Region 2	BDUTR	150	25	2	50
	BNJAR	150	25	1	25
	CBREM	150	25	2	50
	CNJUR*1	150	25	2	50
	DWUAN	150	25	1	25
	PNCOL*2	150	25	2	50
	SRAGI	150	25	1	25
	TMBUN	150	25	1	25
	CBBAT5-2	150	25	1	25
	DGPKR	150	25	1	25
	CKDNG	150	25	1	25
	KANCI	150	25	1	25
	CKJNG	150	25	1	25
	BBKAN	150	25	1	25
	SORNG	150	25	1	25
	BDSLN	150	25	2	50
	TTJBR	150	25	2	50
	ALIQCKRG	150	25	1	25
	CSHIN	150	25	1	25
	PRTMN	150	25	2	50
	WINTX	150	25	1	25
	ARJWN	70	10	2	20
	CKRNG	70	10	2	20

	IDMYU	70	10	2	20
	JTBRG	70	10	2	20
	PGDRN	70	10	1	10
	PLMNN*3	70	10	4	40
	PMGPK*4	70	10	4	40
	SPFIC	70	10	1	10
	TGENG	70	10	1	10
	SPFVI	70	10	2	20
	Subtotal				910

Table 5.12 List of Required Additional Shunt Capacitor in 2015 (2/2)

Area	Substation	Type of S/S (kV	Unit size [MVar]	No. of Units	Total [MVar]
Region 3	PMLNG	150	25	1	25
	Subtotal				25
Region 4	MNYAR	150	25	1	25
	MNYAR	70	10	1	10
	NGORO	150	25	2	50
	PKMIA	150	25	1	25
	KBAGN	150	25	1	25
	PYJKT	150	25	2	50
	GMPGN	70	10	1	10
	KKTES	70	10	2	20
	SKRJO	70	10	1	10
	TAGNG	70	10	1	10
	TUREN	70	10	1	10
	MSTEL	70	10	2	20
	Subtotal				265
Total					1,445

※ 1 Total shunt capacitors in CNJUR SS are 75MVar (25MVar × 3 units) including the existing 25MVar × 1unit. The Study Team recommends that P3B perform further study to select the unit size, since the voltage deviation with the on/off switching of one 50MVar shunt capacitor is beyond 2% (approximate 2.6%) in this study.

※ 2 Total shunt capacitors in PNCOL SS are 100MVar (50MVar × 1 unit, 25MVar ×2 units) including the planned 50MVar × 1unit. The Study Team recommends that P3B perform a further study to select the unit size, even though the voltage deviation with the on/off switching of one 50MVar shunt capacitors is within 2% (approximate 1.6%) in this study.

※ 3 Additional shunt capacitors in PLMNN SS are 40MVar (10MVar × 4 units). The Study Team recommends that P3B perform a further study to select the unit size, since the voltage deviation with the on/off switching of one 10MVar shunt capacitors is beyond 2% (approximate 3.0%) in this study.

※ 4 Additional shunt capacitors in PMGPK SS are 40MVar (10MVar × 4 units). The Study Team recommends that P3B perform a further study to select the unit size, since the voltage deviation with the on/off switching of one 10MVar shunt capacitors is beyond 2% (approximate 3.3%) in this study.

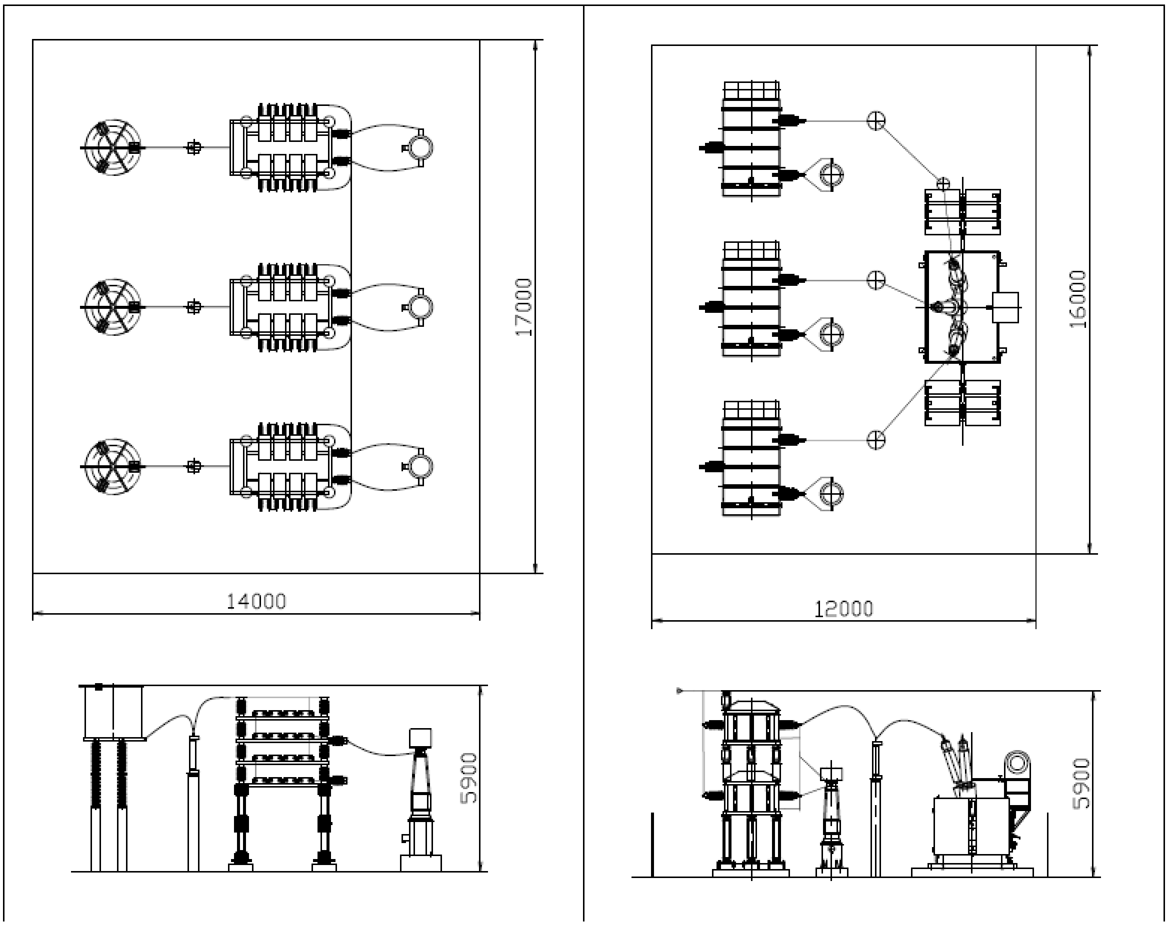
※ 5 The above considerations are based on the condition with the existing minimum unit of 25 MVar. It can be possible to reduce the total cost to bind the required capacity with the unit of 50 MVar, to consider power demand during the installation and confirm the power flows and voltage fluctuation at the time.

5.1.2 Installation Area of the Substation

In case of a condenser is installed in the substation, it is necessary to consider the installation area of the condenser and the CB, DS and CT for the bus-bar connection included the bus-bar expansion.

(1) Installation Area of the Condenser

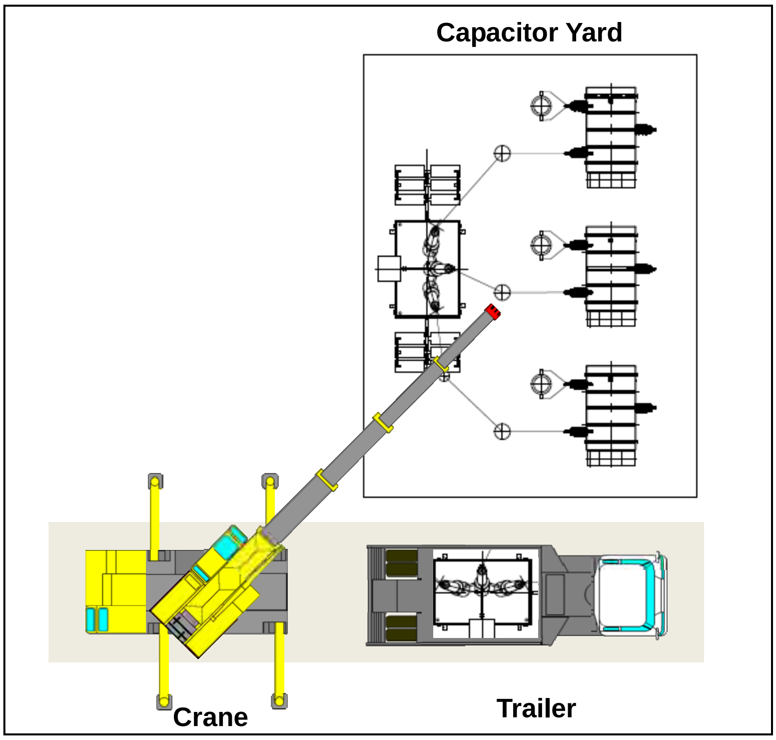
The necessary area for the installation of the condenser is as shown in Figure 5.4. In addition, since it is assumed that the weight for the equipment will be up to 28 tons, we recommend that an access road be installed.



Can Type Condenser(Existing type)	Tank Type Condenser(Compact type)

Source: the Study Team

Figure 5.4 Example of Installation for Condenser



Source: the Study Team

Figure 5.5 Access Road

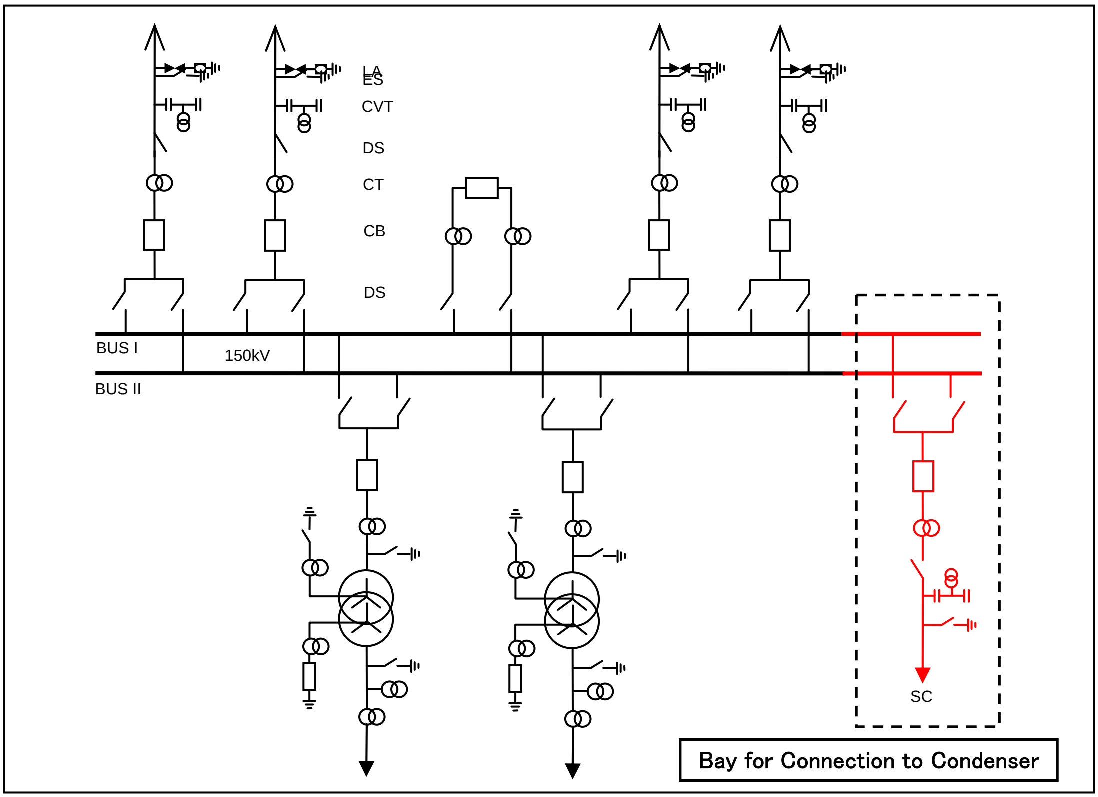
In addition, in case difficult to realize an installation adjacent to the switchyard and the use of gas insulated switchgears (GIS), we recommend that a condenser be installed to the idle land of the substation and connected to the condenser use of the cable.

Source: Tokyo Electric Power Company

Figure 5.6 Connection Method by Cable (66kV 40Mvar)

(2) Extension of Bus-bar and Connection Bay for the Condenser

The connection of the condenser to the bus-bar is preferable. In addition, the existing bus-bar is to be extended and it is necessary to install for CB, DS and CT. The necessary area for the installation of the connection bay is different for the bus-bar type of the existing substation. In case, the substation for the double bus-bar operation, an installation area will be approximately 14m x 28m. In addition, as for the gas insulated substation, a connection feeder will be installed.



Source: the Study Team

Figure 5.7 Single Line Diagram for connection of Condenser

5.1.3 Candidate of Installation for Condensers

Visits to the substation at the 2nd survey are as shown in Table 5.13. Since the installation area is sufficient in the substation, it is unnecessary to downsize for the condenser at the present time.

Table 5.13 Visits Substation at 2nd Survey

No.	Name of Substation	
1	150/20kV	Cikupa Substation
2	150/20kV	Lengkong Substation
3	150/20kV	Karet Lama/Baru Substation
4	500/150/66kV	Bekasi Substation
5	150/20kV, 150/67kV	Pulogadung Substation
6	500/150/20kV	Cawang Substation

Source: the Study Team

In addition, the PLN has a layout plan of the condenser, consequently, we studied the layout plan of the condenser where the installation location has not been decided concretely where there are 150/20kV Cikupa substation and 150/20kV Karet Lama/Baru substation.

Figure 5.8 Visited Substations for Capacitor Bank Installation

(1) 150/20kV Cikupa Substation

The overall view of Cikupa substation is as shown in Figure 5.9. There is an installation area for the condenser in the switchyard. However, it is difficult to extend for the existing bus-bar crosswise direction. Consequently, an access bus-bar is installed in the switchyard so that both existing bus-bars can be connected to the condenser as shown in Figure 5.9. In addition, since it is difficult to connect the existing bus-bars and the new bus-bar used by the overhead wire, the cable head is installed and a connection is used by the cable.

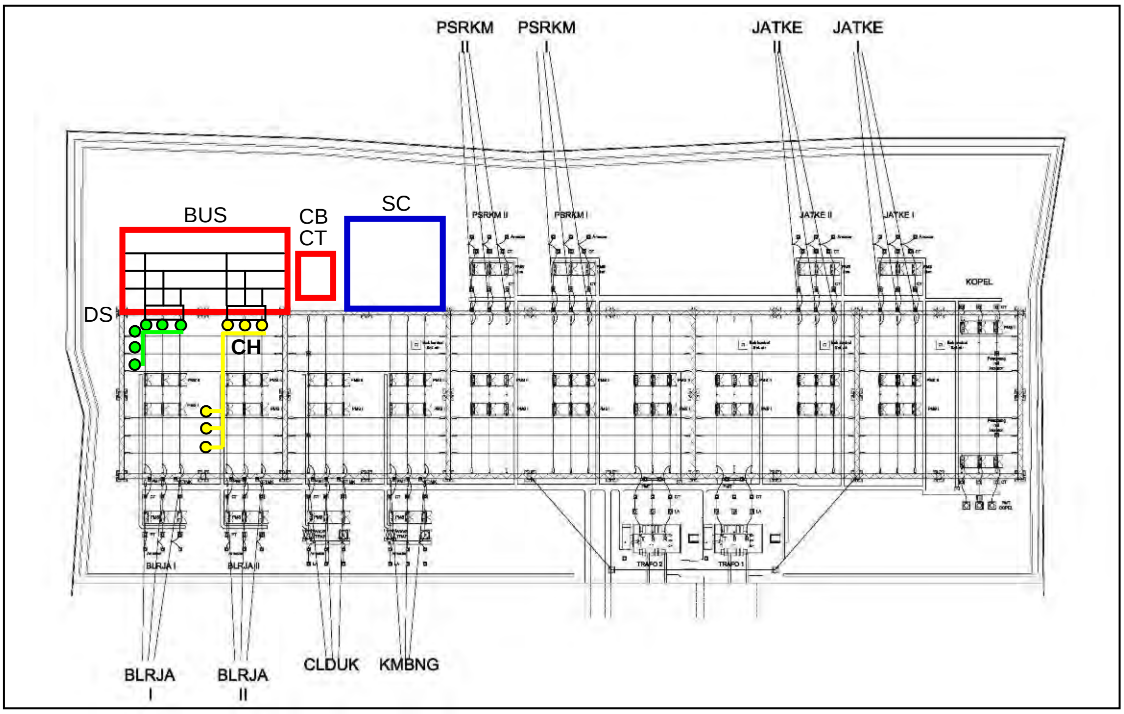
Source: the Study Team

Figure 5.9 Overall View of 150/20kV Cikupa Substation

Photo Switchyard at Cikupa Substation

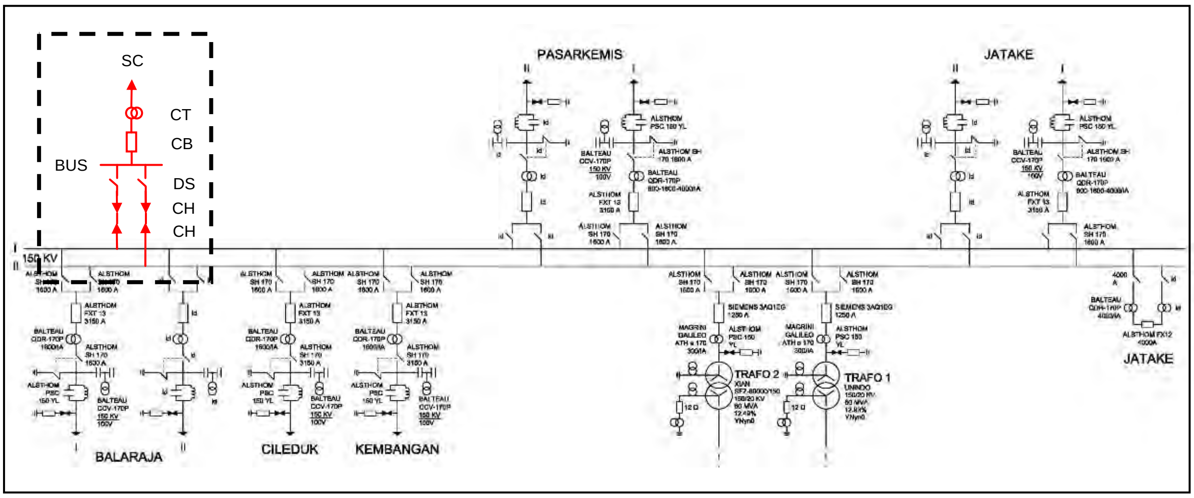
Photo Switchyard at Cikupa Substation

The layout plan of the Condenser and a single line diagram for the connection of the condenser at Cikupa substation is as shown below;



Source: the Study Team

Figure 5.10 Layout Plan of Condenser at 150/20kV Cikupa Substation



Source: the Study Team

Figure 5.11 Single Line Diagram of connection for Condenser at Cikupa Substation

(3) 150/20kV Karet Lama and Karet Baru Substation

150/20kV Karet Lama and Karet Baru substation are in the same site as shown in Figure 5.12. Furthermore. Karet Lama is the air insulated substation and Karet Baru is the gas insulated substation.

Source: the Study Team

Figure 5.12 Overall View of 150/20kV Karet Lama and Karet Baru Substation

(a) Karet Lama Substation

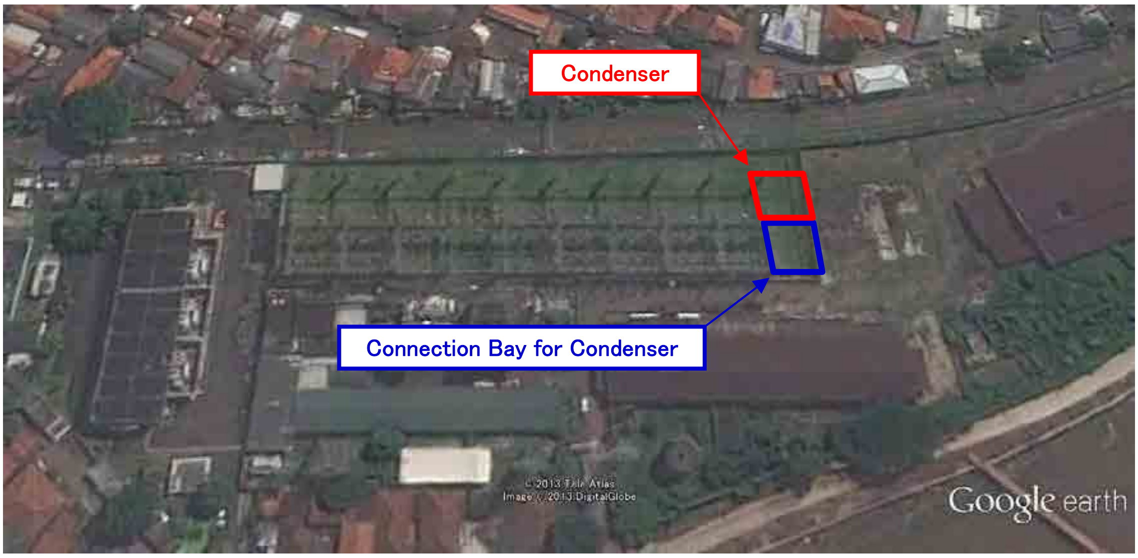
Adjacent to the switchyard of Karet Lama substation is an idle lot. Therefore, since the condenser and connection bay can be installed, the idle lot is used for the installation of the condenser and connection bay.

Idle lot of adjacent to Switchyard

Idle lot of adjacent to Switchyard

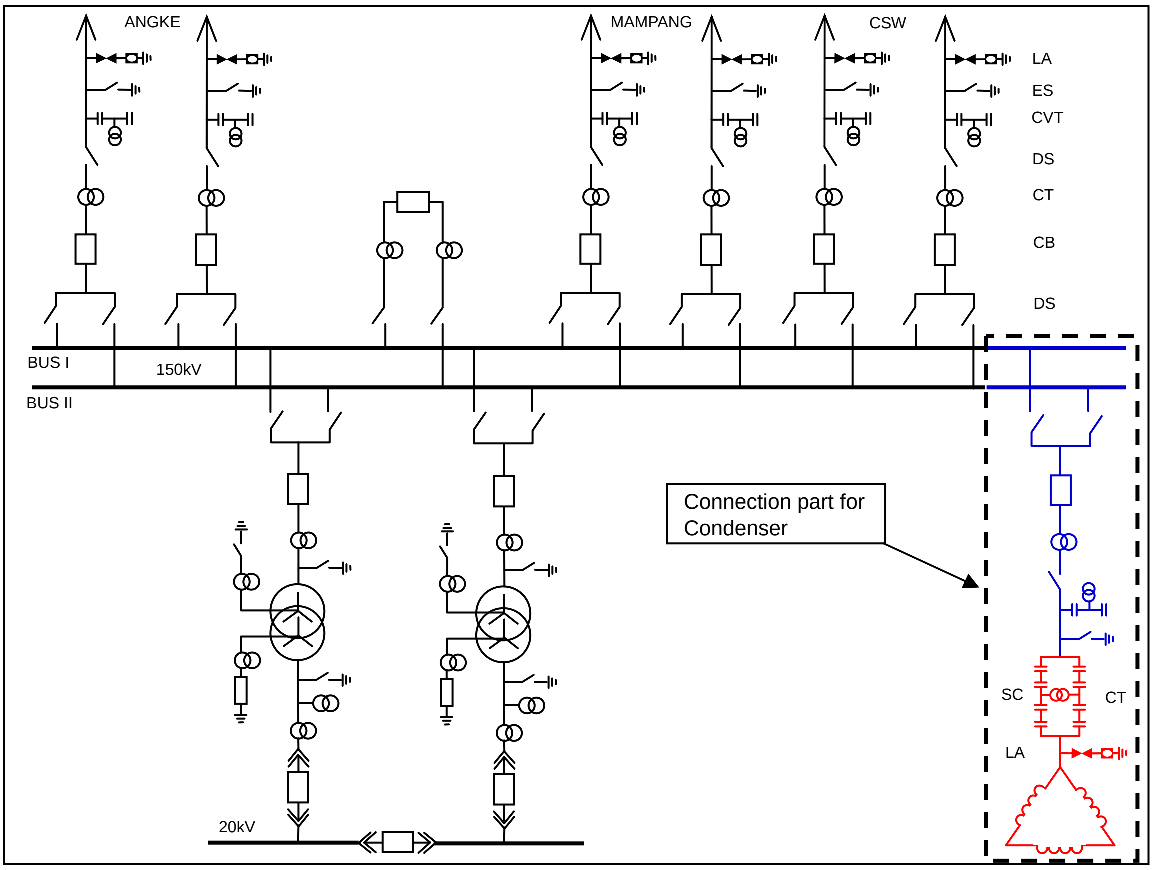
The layout plan of the condenser and the single line diagram of the connection for the condenser at

Karet Lama substation is as shown below;



Source: the Study Team

Figure 5.13 Layout Plan of Condenser at 150/20kV Karet Lama Substation



Source: the Study Team

Figure 5.14 Single Line Diagram at 150/20kV Karet Lama Substation

(b) Karet Baru Substation

Since there is no area for the installation of the condenser at the periphery of Karet Baru substation, it will be installed using the idle lot for the side of Karet Lama substation.

Adjacent to switchyard of Karet Lama substation is an idle lot. It is available for the installation of the condenser part of Karet Baru. However, since the bay expansion will be assumed in the future, it is preferable to secure an idle lot that is adjacent to the switchyard.

Source: the Study Team

Figure 5.15 Idle Land in the Substation

Photo Idle Land of Karet Lama Substation

Photo Idle Land of Karet Lama Substation

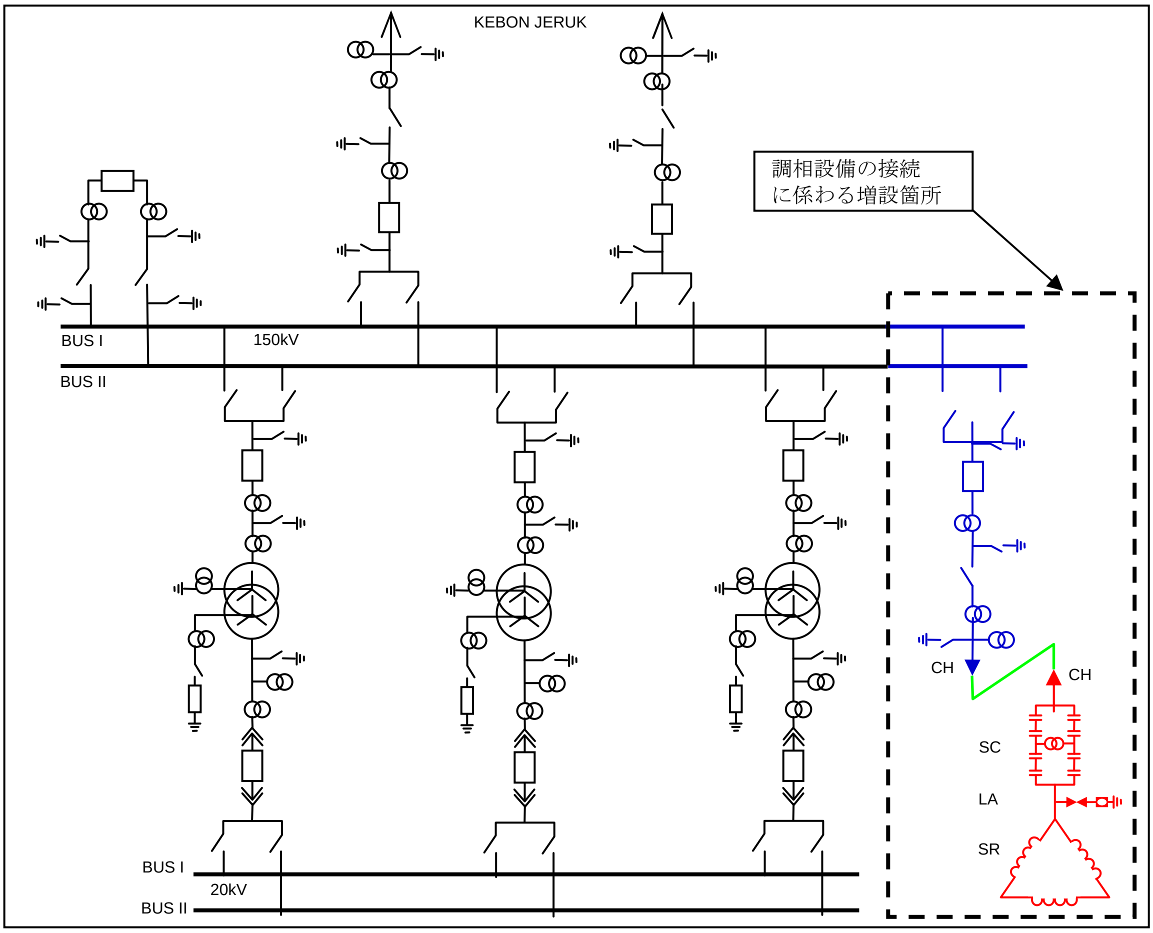
It is desirable that a connection feeder to the condenser be installed to the existing GIS and connect it to the condenser from the viewpoint of reliability.

In addition, Karet Baru and Karet Lama substation is connected and the condenser is commonly used as one of the options.

The layout plan of the condenser and a single line diagram of the connection for the condenser at Karet Baru substation is as shown below;

Source: the Study Team

Figure 5.16 Layout Plan of Condenser at 150/20kV Karet Baru Substation



Source: the Study Team

Figure 5.17 Single Line Diagram at 150/20kV Karet Baru Substation

(3) Equipment Placement Considering Future Expansion of the Substation

Since each piece of substation equipment deteriorates gradually and electricity demand in Jakarta continues to grow, the site usage of existing substations must be carefully planned by considering the substation’s future expansions, modifications and emergency equipment repairs anticipated in 10 to 20 years ahead. Also, the project designers of PLN’s capacitor bank installation should secure the necessary work space for the installation work of the heavy/big equipment components, such as the capacitor elements and the circuit breakers. Examples of the necessary space could be the access roads, nearby equipment yards and workspace for the crane operations near the capacitor bank yard.

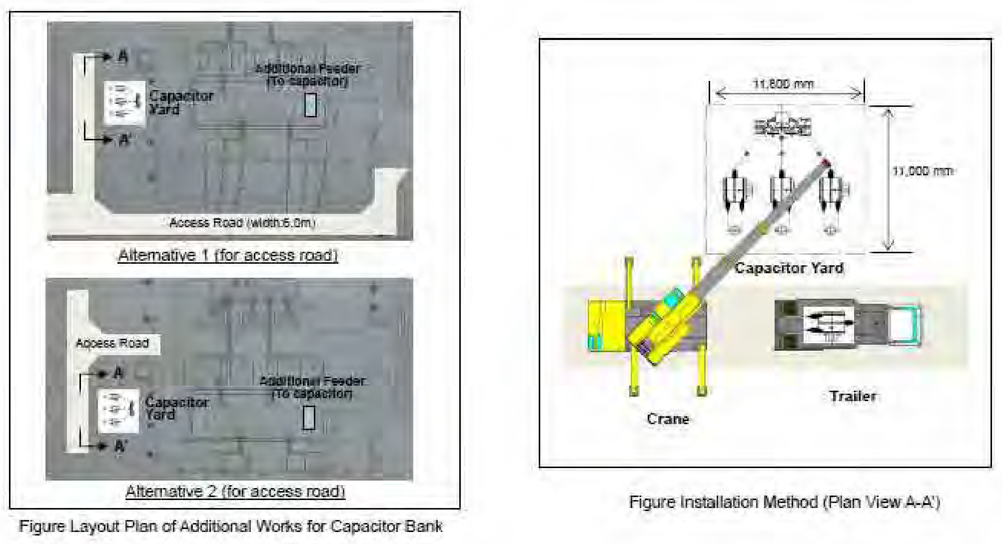


Figure Layout Plan of Additional Works for Capacitor Bank

Figure Installation Method (Plan View A-A')

Figure 5.18 Necessary work spaces for capacitor banks

According to the team’s interviews with P3B engineers, PLN will choose Gas Insulated Switchgear (GIS) as switchgears to minimize the total area of newly built substations in the Jakarta Metropolitan area and its vicinity, where land prices became too expensive to purchase a necessary area for conventional air-insulated switchgears. It could be possible to establish an interconnection between the 150kV transmission line and the neighboring substation instead of installing the capacitor banks in the substation, where only one 150kV transmission feeder expansion is possible due to limited expansion space. Thus, the long-term planning of substation expansion and modifications are quite important when selecting installation locations for future capacitor bank installations.

As an example of the consideration of future expansion, TEPCO’s substation replacement procedures, in which aged air insulated switchgears are replaced with compact gas-insulated switchgears to minimize the footprint of the new substation is shown in Figure 5.19 - Figure 5.23. As shown in this case, the outage of the existing (aged) substation is minimized to achieve reliable electricity supply during the construction period, securing a sufficient amount of space for the new equipment in advance with the existing substation site is quite beneficial for the pursuits of safer construction work, cost reduction, and simplification of construction work. To secure the necessary spaces for future expansion, the location of the capacitor banks planned should be well examined especially in case of substations in high population density area, such as Karet Substations and other substations in the center of the Jakarta Metropolitan area.

(Current Condition: no room for the new 150kV feeder installation without facility outage(s))

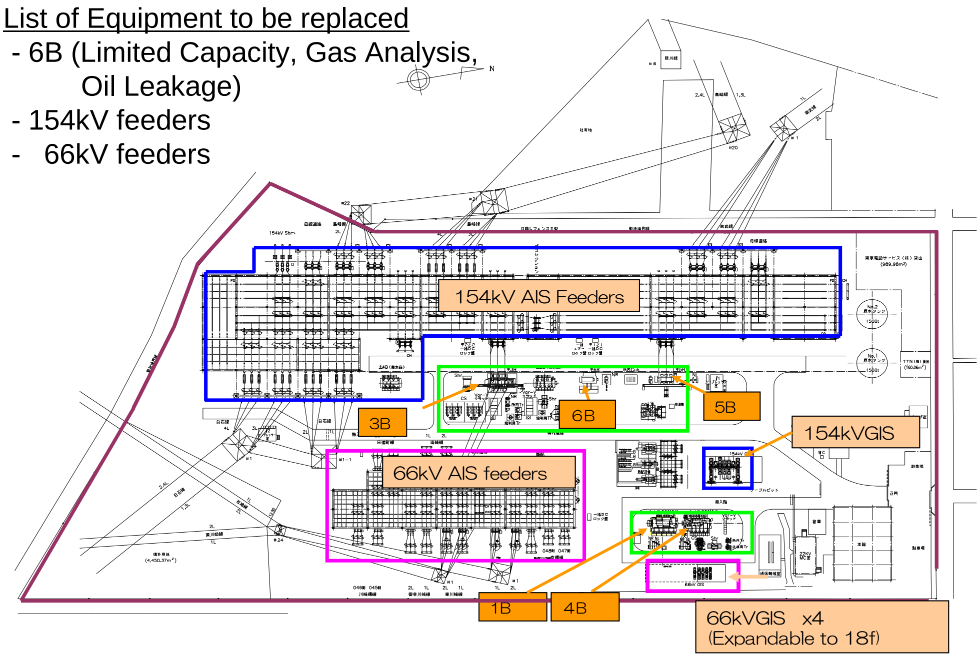


Figure 5.19 The layout of 154/66kV Air-insulated Substation (Existing)

(Construction Step 1: Replacement of 66kV air-insulated switch gears to GIS form.)

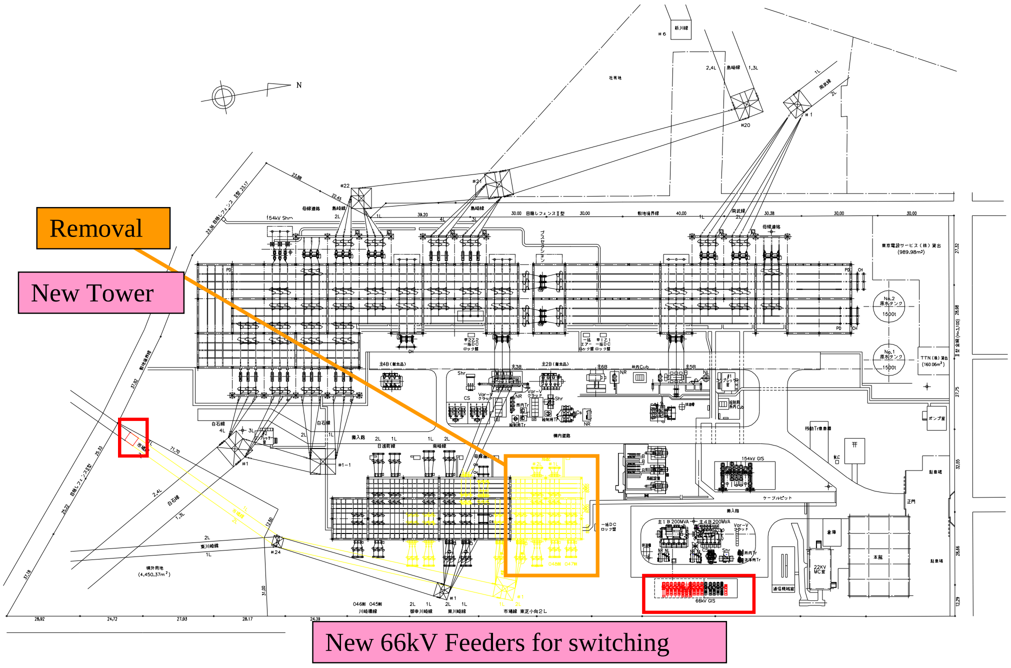


Figure 5.20 The layout of 154/66kV Air-insulated Substation (Existing

(Construction Step 2: 154kV GIS installation on the previous 66kV AIS Switchgear yard.)

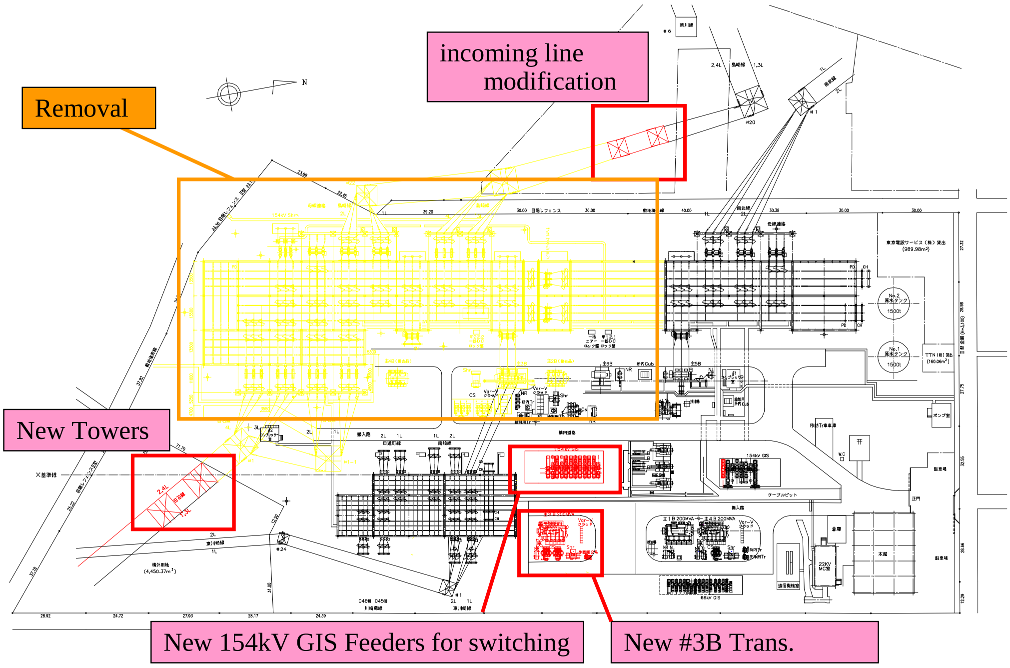


Figure 5.21 Installation of 154kV GIS and Trans. & Removal of 154 AIS feeders

(Demolition of 150kV old air-insulated switchgear yard to create a wide space)

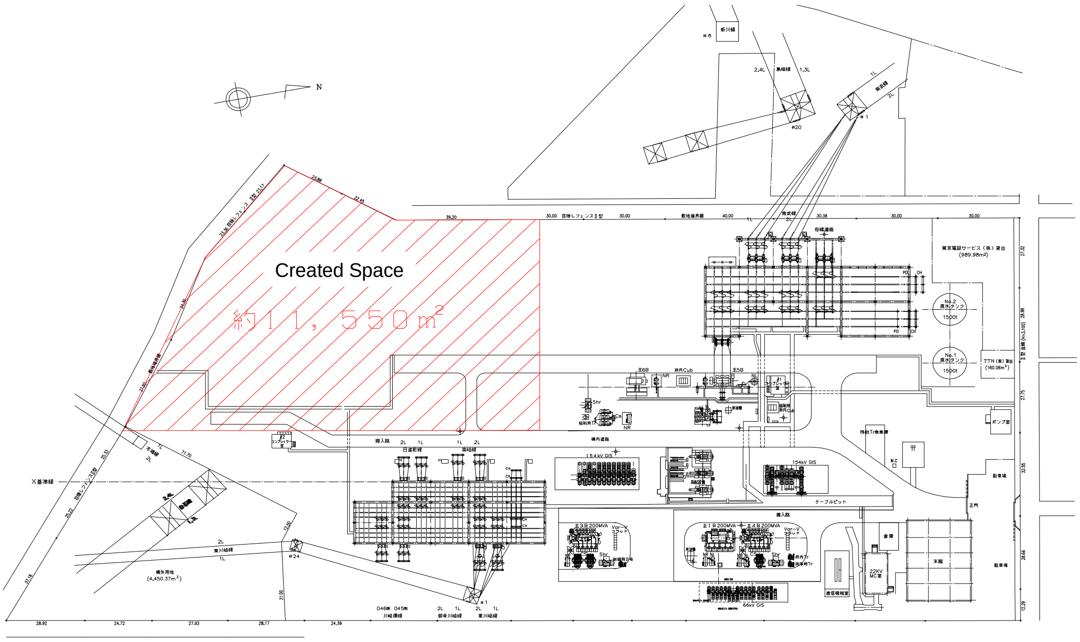


Figure 5.22 New Gas Insulated Switchgears and Transformers

(Final Form of the substation replacement to a GIS form. Available space can be utilized)

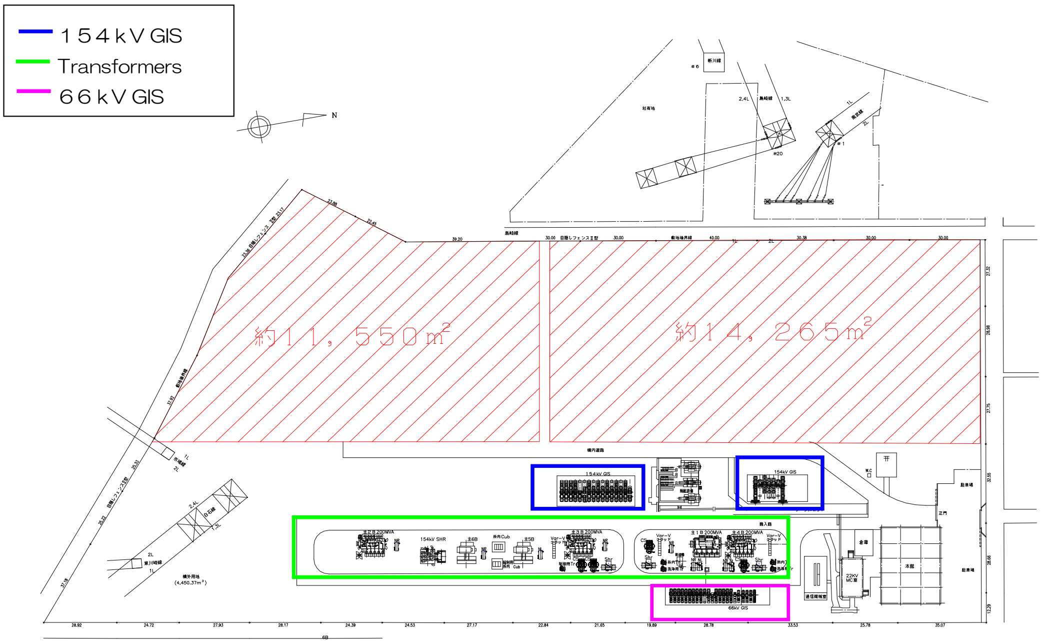
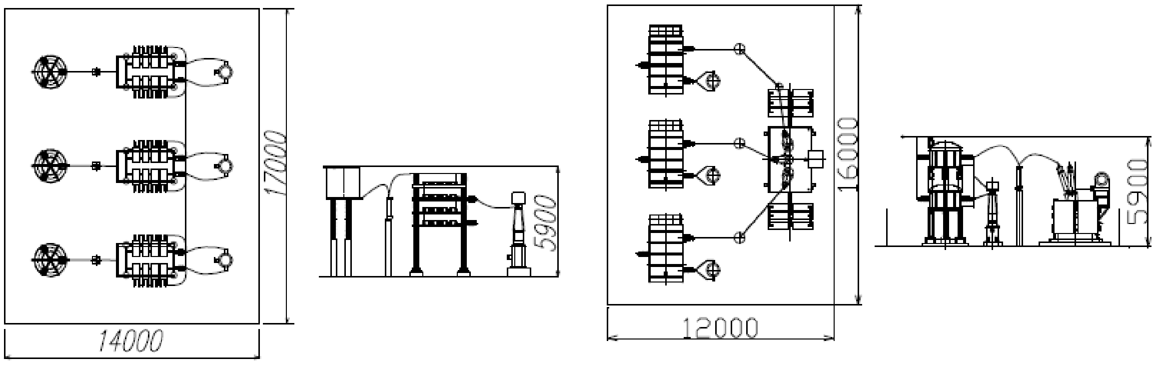


Figure 5.23 Substation’s Final Form

(4) Introduction of Compact Design Equipment for higher reliability and better land usage

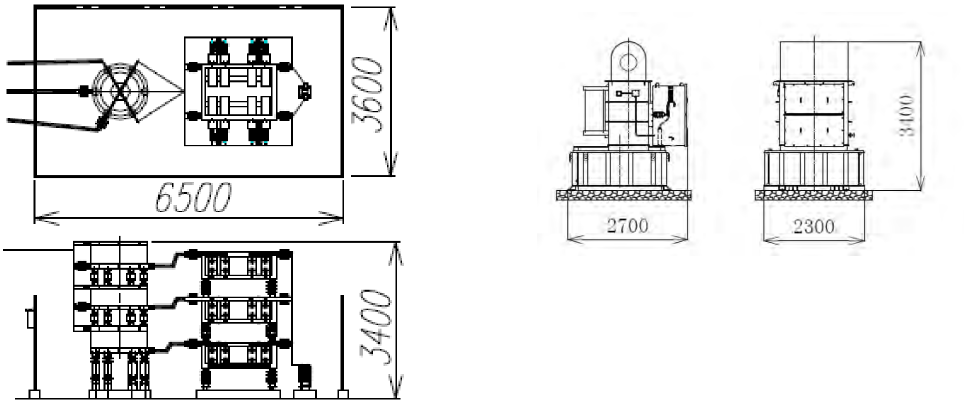
For Tokyo Metropolitan area electricity supply, whose electricity demand density is quite high and similar to the Jakarta area, Tokyo Electric Power Company has been deploying compact design power equipment, which encloses the main power circuit into insulation oil or gas in an air-tightened compact container, to pursue effective land use and a higher supply reliability. Consequently, TEPCO employs compact oil-immersed, all-film capacitors (tank designed) for reactive power sources, and connects them to the tertiary side of transmission transformers, which has a nominal voltage of 66kV or 22kV as a basic form. A quite limited number of TEPCO’s capacitor banks is directly connected to 66kV Busbars. Since the connection scheme of TEPCO is different from PLN’s connection practices, it is impossible to introduce Japanese 66kV compact capacitor banks directly. Thus, the study team consulted a Japanese compact capacitor bank manufacturer, Nissin electric, to nominate candidate compact capacitor banks, and the manufacturer proposed one 154kVcapacitor bank, which immerses the capacitor elements into the insulation oil in the steel tank with improved reactors for operation surge suppression.

The compact capacitor banks may be introduced selectively if the advantages of the compact type match the capacitor bank’s operational requirements, and the expenses can be justified. The price of the suggested compact capacitor bank almost triples to the conventional one because of the high-quality film used in the capacitor elements, oil-immersed design, and the improved surge suppression capability. However, the compact type capacitor banks are inherently immune to environmental conditions, and have a three-times longer lifetime than the capacitor elements, and endures higher operational surges. Thus, it could be beneficial to employ compact type capacitor banks selectively based on the lifecycle cost estimation, and the necessity of special consideration for operational and environmental conditions, such as the frequent operation of circuit breakers caused by the fluctuation of the system voltage, and corrosive atmospheric conditions particularly problematic in the case of facilities near chemical factories.



(Left: conventional、right: tank design)

Figure 5.24 Comparison of 150 kV Conventional and Compact Type Capacitor Bank



(Left: conventional、right: tank design)

Figure 5.25 Comparison of 22 kV Conventional and Compact Type Capacitor Bank

(5) Utilization of Power Cables for utilizing a limited substation site

In order to pursue the substation site utilization to maximize the substation’s future expandability while installing the necessary amount of capacitor banks in the near future, it is beneficial to employ power cables, which requires far less insulation distance and so enables the substation design that is far more flexible, for connections among the 150kV busbar, capacitor banks, and relevant circuit breakers. In PLN’s current design practice, an air-insulated equipment form is selected because of its lower initial installation costs, and a very limited number of power cables have been installed as the interconnection, such as the interconnection cables between 150kV GIS and the transformers at Plogadung substation. However, it could be beneficial to employ power cables if additional land acquisition is necessary to install the new air-insulated feeder, and the land price for the expansion is extremely expensive. Thus, the land usage optimization with the usage of power cables should be examined when the capacitor banks installation project is developed.

Figure 5.26 Cable Interconnection at Plogadung Substation

Figure 5.27 Example of Cable Usage for TEPCO's Capacitor Banks

(6) Frequent Operational Capability of the Circuit Breaker for Capacitor Banks

Considering the voltage regulation effect of the capacitor bank installation and the future growth of electricity demand in the Jakarta Metropolitan area, the voltage fluctuation between the daytime and nighttime will be intensified in the near future, and consequently, the daily operation of some capacitor banks are necessary to maintain the grid's supply voltage within an allowable range. To achieve such frequent operation of circuit breakers, which exceeds the conventional circuit beaker's maximum operation limit, a special purpose circuit breaker that is capable for frequent operations throughout its lifetime is necessary, and such circuit breakers are built with higher reliable operation principles and reliable materials with higher manufacturing quality control. PLN has already specified the technical requirements for these special purpose circuit breakers as IEC's M2 class. However, considering the fact that an M2 class circuit breaker in the Bali system broke down and caused an outage due to the malfunction of its operation mechanism, further actions such as the technical examination of the corresponding specifications, the actual operational testing of the capacitor bank circuit breakers, more frequent inspection and the repair of the circuit breakers would be necessary to ensure the long-term reliability of these newly installed reactive power sources.

As an example of the technical examination of the frequently operated circuit breaker, TEPCO similarly specifies circuit breakers for capacitor banks as an IEC M2 class, and additionally requires manufacturers to confirm a proper 30,000 time interruption operation as a type test after TEPCO's engineers' design review of the circuit breaker components. TEPCO also mandates a consumable parts replacement every fixed number of actual current interruptions to secure the proper current interruption.

The installation of such high-spec circuit breakers for all capacitor banks, which require frequent repairs with circuit breaker planned outage, is difficult for the power company to pay for. Thus, it could be economical to specify frequently operated capacitor banks and selectively install high-quality equipment so as to minimize the total costs while ensuring sufficient system reliability.

5.1.4 Installation Costs

Installation costs are different from each kind of substation and the specification of a condenser. In addition, we estimated the installation costs based on the cost information for a 150kV JATAKE substation received from PLN. The typical costs of four options are as shown below.

1. Air Insulated Substation

(1) Installation of Can Type (Option 1)

Installation cost for a can type condenser of 50MVar for the air insulated substation is as shown in Table 5.14. This cost is included for the connection bay to the condenser.

Table 5.14 Installation Cost of the Can Type Condenser for the Air Insulated Substation

No.	Description	Price (Rp.)
1	Electrical Works	7,647,615,000
	(Capacitor)	(3,373,306,000)
2	Civil Works	1,145,237,000
3	Price Escalation (10%)	879,285,000
4	Physical Contingency (2%)	193,442,000
	Total	**9,865,581,000**

Source: the Study Team

(2) Installation of the Tank Type (Option 2)

The installation cost for the tank type condenser of the 50MVar for an air insulated substation is as shown in Table 5.15. This cost is included for the connection bay to the condenser.

Table 5.15 Installation Cost of Tank Type Condenser for Gas Insulated Substation

No.	Description	Price (Rp.)
1	Electrical Works	15,677,934,000
	(Capacitor)	(9,250,000,000)
2	Civil Works	1,078,703,000
3	Price Escalation (10%)	1,675,663,000
4	Physical Contingency (2%)	368,646,000
	Total	**18,800,947,000**

Source: the Study Team

2. Gas Insulated Substation

(1) Installation of Can Type (Option 3)

Installation cost for a can type condenser of 50MVar for a gas insulated substation is as shown in Table 5.16. This cost includes the feeder of the connection to the condenser. The cost for the connection between the GIS feeder and the condenser is the estimated use of cable.

Table 5.16 Installation Cost of the Can Type Condenser for an Air Insulated Substation

No.	Description	Price (Rp.)
1	Electrical Works	14,686,119,000
	(Capacitor)	(3,373,306,000)
2	Civil Works	845,197,000
3	Price Escalation (10%)	1,553,131,000
4	Physical Contingency (2%)	341,688,000
	Total	**17,426,138,000**

(2) Installation of Tank Type (Option 4)

The installation cost for a can type condenser of the 50MVar for a gas insulated substation is as shown in Table 5.17. This cost includes the feeder of the connection to the condenser. The cost for the connection between the GIS feeder and the condenser is the estimated use of cable.

Table 5.17 Installation Cost of the Tank Type Condenser for the Gas Insulated Substation

No.	Description	Price (Rp.)
1	Electrical Works	22,716,438,000
	(Capacitor)	(9,250,000,000)
2	Civil Works	822,507,000
3	Price Escalation (10%)	2,353,894,000
4	Physical Contingency (2%)	517,856,000
	Total	**26,410,697,000**

3. Comparison of Installation Costs

A comparison of the installation costs in consideration of 30 years operation is as shown in Table 5.18. The initial cost is very different from the can type and the tank type. However, since the design lifetime for the tank type is long and approximately 30 years, when considering the total cost for 30 years operation, difference in the amounts will be small.

Table 5.18 Comparison of Installation Cost in Consideration of 30 Years Operation

Unit : Rp

Description	Air Insulated Substation		Gas Insulated Substation	
	Option 1	Option 2	Option 3	Option 4
Construction Cost (Initial)	9,865,581,014	18,800,947,560	17,426,138,145	26,410,697,098
Replacement of Condenser	4,385,298,450	0	4,385,298,450	0
Total	**14,250,879,464**	**18,800,947,560**	**21,811,436,595**	**26,410,697,098**

Source: the Study Team

Note: Replacement cost is considered the main unit of the condenser only.

5.2 Evaluation of the Effect of Additional Shunt Capacitors

5.2.1 Effects of the Additional Shunt Capacitors on the System Voltage

Figure 5.28 shows the voltage profiles of the 500kV system with and without additional shunt capacitors shown in Table 5.11 and Table 5.12. As can be seen from the figure, the system voltage is improved by additional shunt capacitors. Mainly, the 500kV system voltages without additional shunt capacitors in Region 1 and Region 2 do not satisfy the voltage criteria, all the 500kV system voltage with additional shunt capacitors satisfies the voltage criteria.

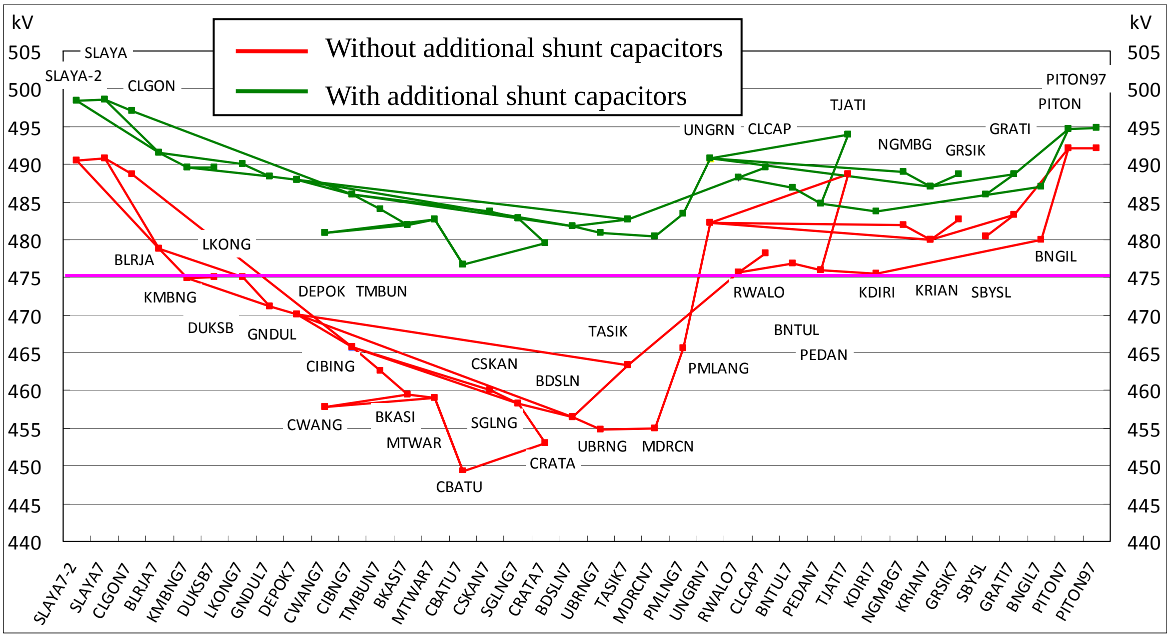


Figure 5.28 Voltage Profiles of the 500kV System with and without Additional Shunt Capacitors

Table 5.19 shows parts of the system voltages in the Cibatu 150kV subsystem with or without additional shunt capacitors. The system voltages without additional shunt capacitors fall below 0.90pu and those with additional shunt capacitors are maintained above 0.90pu.

Table 5.19 Parts of System Voltages in Cibatu 150kV Subsystem with and without Additional Shunt Capacitors

Bus Number	Bus Name	Without additional shunt capacitors		Without additional shunt capacitors	
		Voltage [pu]	Voltage[kV]	Voltage [pu]	Voltage[kV]
25009	CBATU5B	0.8987	134.8	0.9832	147.5
25017	CIKRG5B	0.8697	130.5	0.9738	146.1
25034	GDMKR5	0.8648	129.7	0.9718	145.8
25058	LSTDO5	0.8705	130.6	0.9743	146.1
25074	PNCOL5	0.8557	128.4	0.9735	146.0
25096	TLJMB5	0.8586	128.8	0.9370	140.6
25134	CLIPO5	0.8803	132.0	0.9763	146.4
25903	GNRJP5	0.8656	129.8	0.9712	145.7
25904	ALIQCKRG5	0.8631	129.5	0.9712	145.7
25905	SMTRCKRG5	0.8631	129.5	0.9712	145.7
15121	PDKLP5B	0.8538	128.1	0.9720	145.8

5.2.2 Reactive Power Balance in Each Region

Figure 5.29 and Figure 5.30 show the reactive power balance in each region with and without additional shunt capacitors, respectively. The total reactive power flow from Region 1 to Region 2 and Region 3 to Region 2 is 1,831MVar in the case of no additional shunt capacitors. Reactive power flows between Region 1 and Region 2 and between Region 2 and Region 3 are reduced since the reactive power balance in Region 2 is improved due to additional shunt capacitors.

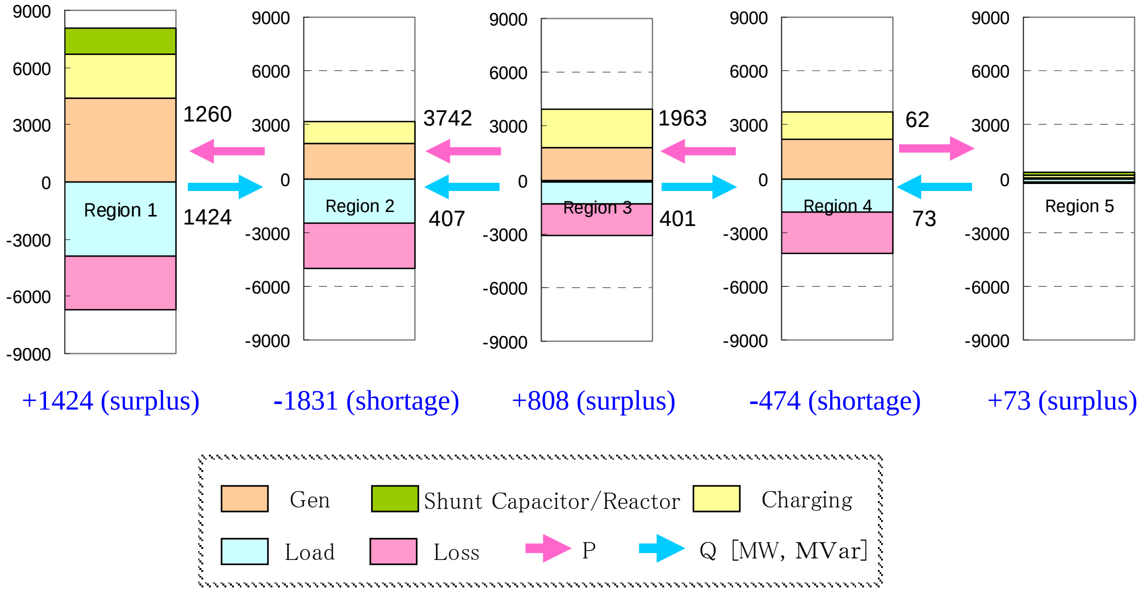


Figure 5.29 Reactive Power Balance in Each Region without Additional Shunt Capacitors

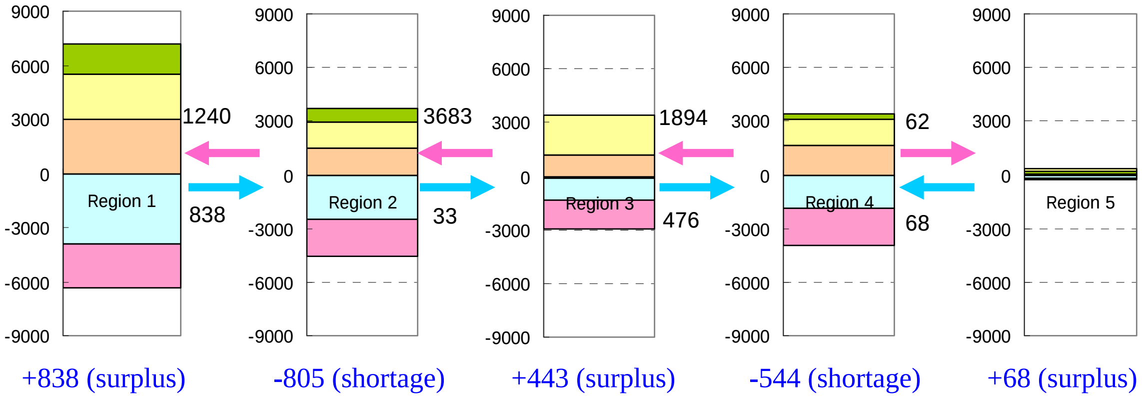


Figure 5.30 Reactive Power Balance in Each Region with Additional Shunt Capacitors

5.2.3 Result of PV Analysis

A PV analysis under Jakarta peak demand in 2015 was performed in order to examine the effects of the installation of additional shunt capacitors for voltage stability and to calculate the upper limit of the power transfer to the Jakarta metropolitan area limited by voltage stability. A PV analysis was performed under two scenarios with an increase in the load of different areas as shown below.

(Scenario 1)

A PV curve was drawn by simulating the increase in the load of Jakarta (load of Region1) from its peak power demand. In this case, the upper limit of the Jakarta power demand was taken as an evaluating value by increasing the power outputs of the generators that are located in a region other than the Jakarta area (Region 2, 3, 4, 5) among the operating generators.

(Scenario 2)

A PV curve was drawn by simulating the increase in the loads of the west Java (loads of Region1 and 2) from its peak power demand. In this case, the upper limit of west Java power demand was taken as the evaluating value by increasing the power outputs of the generators that are located in an area other than Regions 1 and 2 among the operating generators.

(1) Upper Limit of Power Demand under Normal Conditions

Figure 5.31 shows the PV curves with and without the additional shunt capacitors under normal conditions in scenario 1. The horizontal axis of the figure shows the total load in Region 1, a vertical axis shows the 500kV busbar voltage at Bekasi SS, Cawang SS, Kembangan SS and Cibatu SS. As can be seen from the figure, the upper limits of the power demand are increased due to additional shunt capacitors.

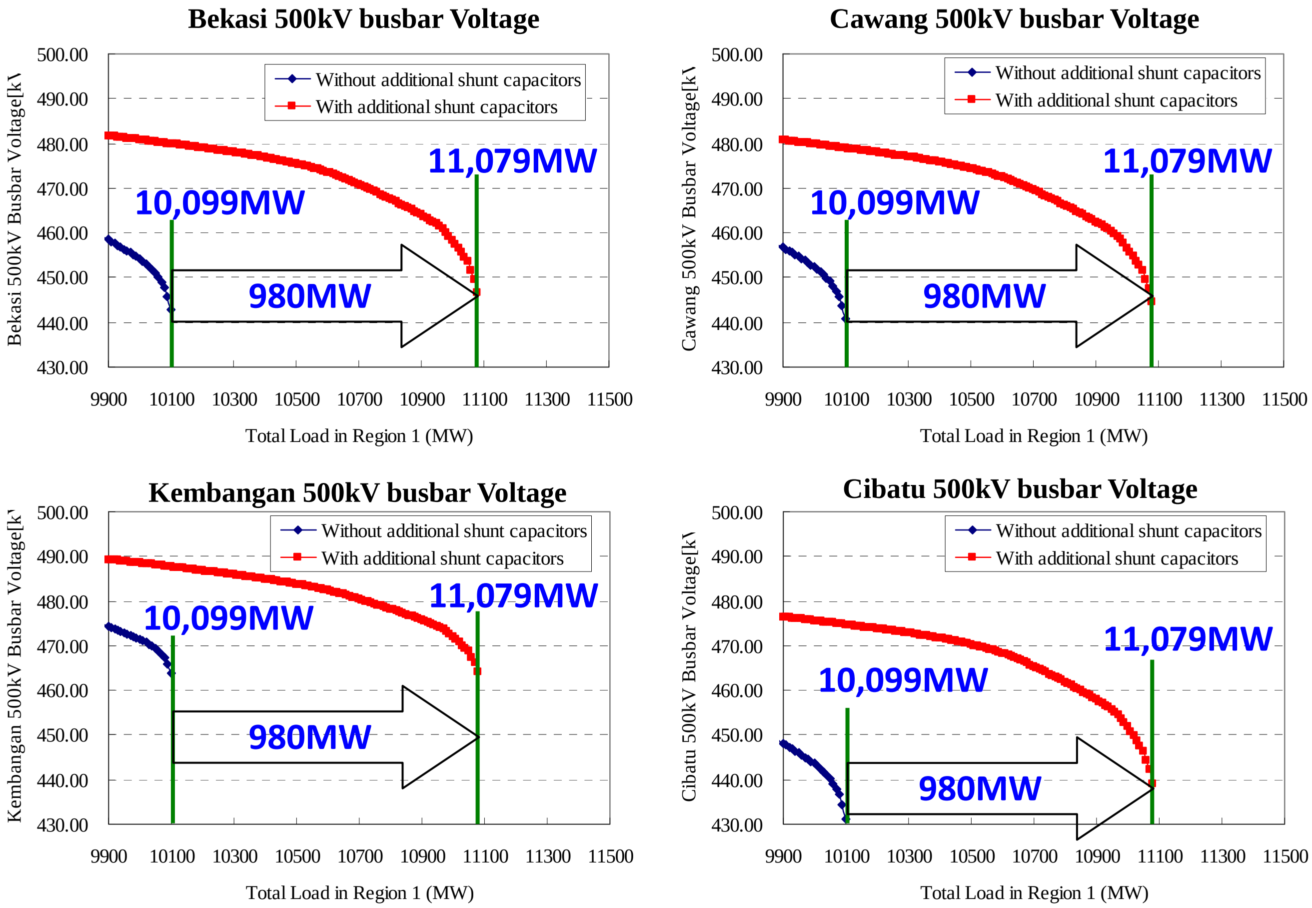


Figure 5.31 PV Curves under Normal Condition in 2015 (Scenario 1)

Figure 5.32 shows the PV curves with and without additional shunt capacitors under normal conditions in scenario 2. The horizontal axis of the figure shows the total load in Region 1 and Region 2. As can be seen from the figure, the upper limit of the power demand are increased due to additional shunt capacitors being the same as in Scenario 1.

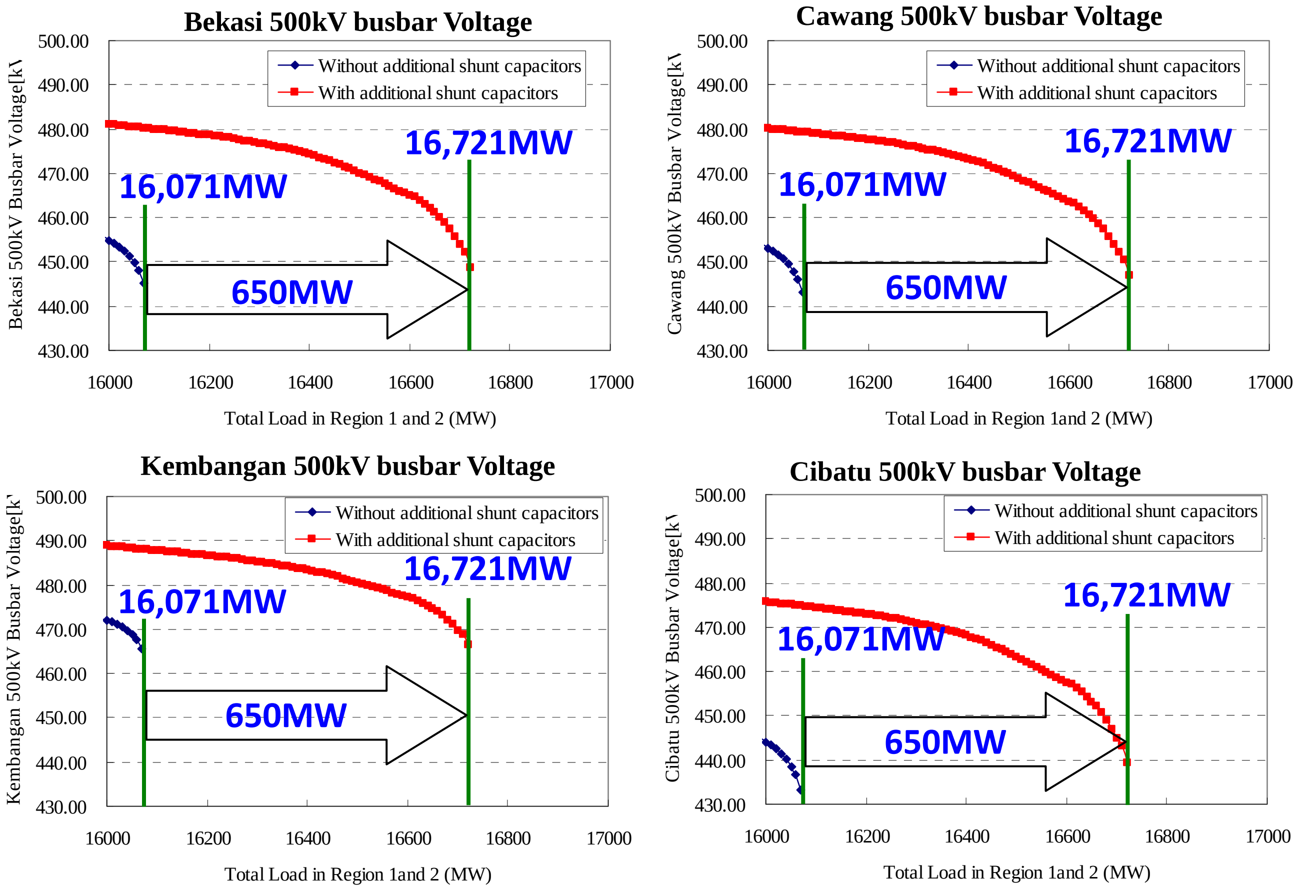


Figure 5.32 PV Curves under Normal Condition in 2015 (Scenario 2)

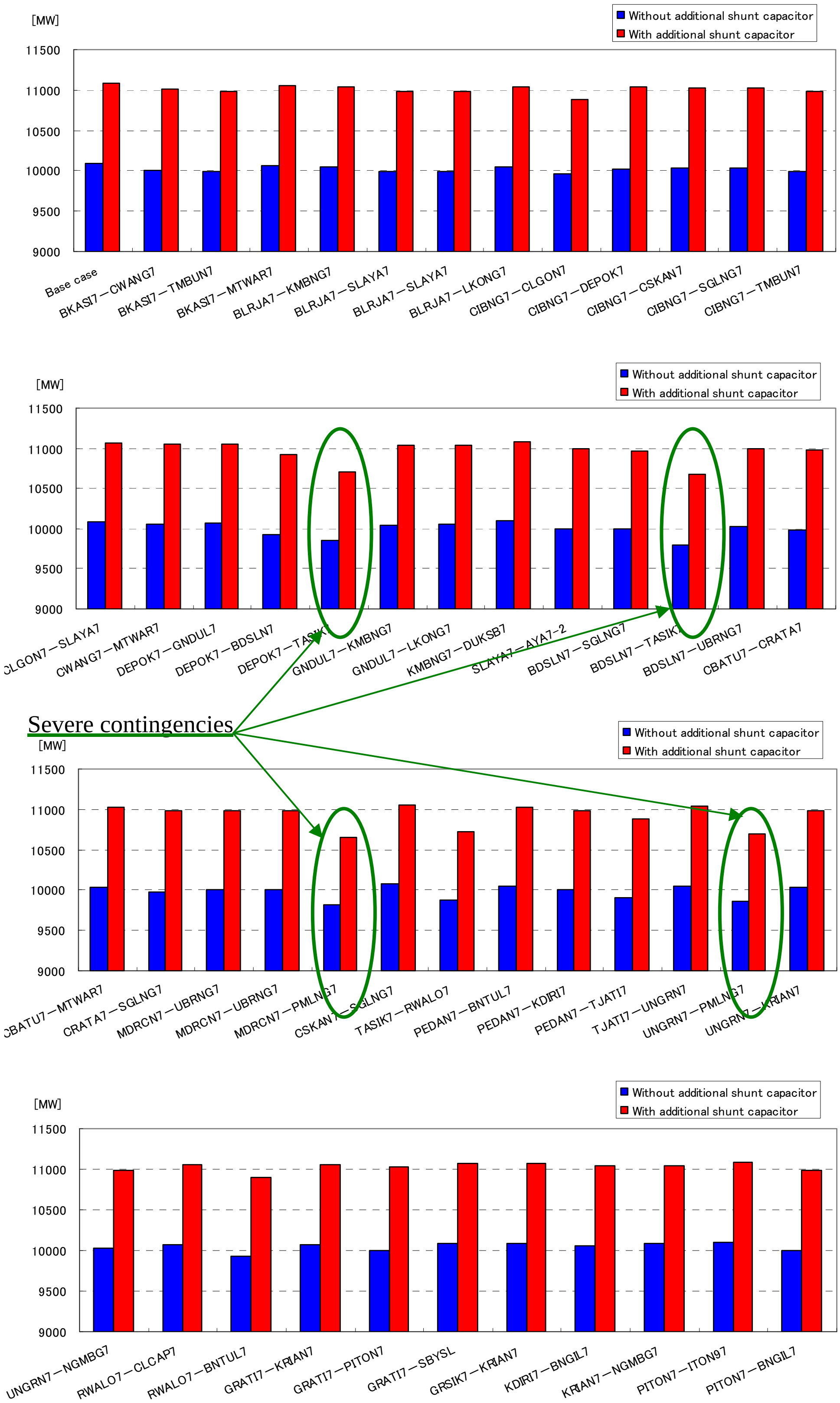
Table 5.20 shows the upper limits of the incremental power transfer under normal conditions in Scenario 1 and Scenario 2. Scenario 2 is considered to be more severe than Scenario 1 since the incremental power transfer in Scenario 2 is smaller than that in Scenario 1.

Table 5.20 Upper Limits of Incremental Power Transfer under Normal Condition in Scenario 1 and Scenario 2

	Scenario 1		Scenario 2	
	Without additional shunt capacitor	**With additional shunt capacitor**	**Without additional shunt capacitor**	**With additional shunt capacitor**
Normal condition	230	1210	150	800

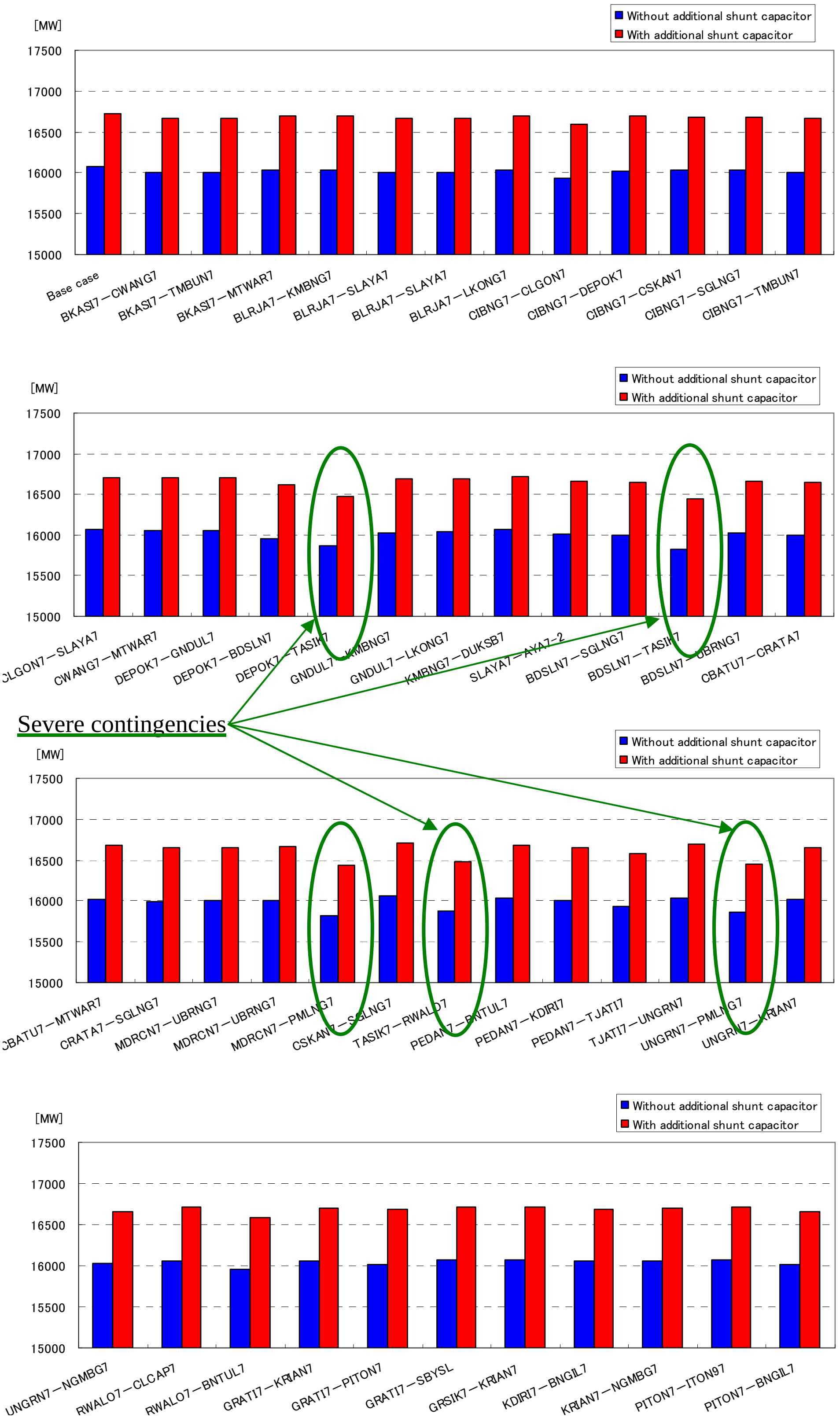
(2) Upper Limit of Power Demand under N-1 Contingency

Figure 5.33 shows the upper limits of the power demand with and without additional shunt capacitors under N-1 contingencies in Scenario 1 and Scenario 2. As can be seen from the figure, the upper limits of the power demand are increased due to additional shunt capacitors being the same as under normal conditions.



(Limits of power demand under N-1 contingencies indicated by green circle are lower than the estimated Jakarta peak demand in 2015)

Figure 5.33 Upper Limits of Power Demand with and without Additional Shunt Capacitors under N-1 Contingency in Scenario 1



(Limits of power demand under N-1 contingencies indicated by green circle are lower than the estimated Jakarta peak demand in 2015)

Figure 5.34 Upper Limits of Power Demand with and without Additional Shunt Capacitors under N-1 Contingency in Scenario 2

Table 5.21 shows the N-1 Contingencies under which incremental transfers were not increased due to a convergence error when a PV analysis was performed in the case of no additional shunt capacitors.

A PV analysis under N-1 contingencies shown in Table 5.21 were performed in order to calculate the limits of the power demand, using the conditions under which the total load in Region 1 was reduced by 300MW for Scenario 1 as the initial condition (total load in Regions 1 and 2 was reduced by 300MW for Scenario 2).

Table 5.21 Severe N-1 Contingencies

From	To	Jakarta Peak demand in 2015 [MW]		Transfer limit [MW]	
		Total load In Region 1	Total load In Region 1&2	Scenario 1	Scenario 2
				Total load in Region 1	Total load in Region 1&2
Cibinong	Cilegon	9,869	15,921	9,969	15,931
Depok	Tasikmalaya			9,859	15,861
Bandung selatan	Tasikmalaya			9,799	15,821
Mandirancan	Pemalang			9,819	15,821
Tasikmalaya	Rawalo			9,879	15,871
Ungaran	Pemalang			9,869	15,861

It was confirmed that the limits of the power demand under N-1 contingencies in Depok-Tasikmalaya line, Bandung selatan-Tasikmalaya line, Mandirancan-Pemalang line , Tasikmalaya-Rawalo line and Ungaran-Pemalang line were smaller than the demand estimated for the Jakarta peak in 2015 in the case of no additional shunt capacitors.

(3) Effects of the Generation Dispatching patterns and the Load Increasing scenarios on the Interconnection Power Flow at the Limit of Power Demand in the PV Analysis

In order to examine the relationship between voltage stability limits and interconnection power flows, a PV analysis was performed with different generation dispatching patterns in each Region at the initial conditions shown in Table 5.22. Figure 5.35 shows an example of the generation dispatching patterns during the initial conditions. In addition to Scenario 1 and Scenario 2 described in Chapter 5.2.3, the PV analysis was performed with different load increasing scenarios shown in Table 5.23 including the following scenario (Scenario 3) for comparison.

(Scenario 3)

A PV curve was drawn by simulating the increase in the loads of Regions 1, 2 and 3 from its peak power demand. In this case, the upper limit of power demand was taken as an evaluating value by increasing the power outputs of the generators that are located in areas other than Regions 1, 2 and 3 among the operating generators.

Table 5.22 Different Pattern of Generator Dispatching Scenario at Peak Power Demand in Each Region

	Generation dispatch at initial condition			
	Area	Generator output	Area	Generator output
Pattern 1	Region 1	Reduced by 300MW	Region 2	Increased by 300MW
Pattern 2	Region 1	Reduced by 300MW	Region 3	Increased by 300MW
Pattern 3	Region 1	Reduced by 300MW	Region 4	Increased by 300MW
Pattern 4	Region 2	Reduced by 300MW	Region 3	Increased by 300MW
Pattern 5	Region 2	Reduced by 300MW	Region 4	Increased by 300MW
Pattern 6	Region 3	Reduced by 300MW	Region 4	Increased by 300MW
Pattern 7	Region 1	Increased by 300MW	Region 2	Reduced by 300MW
Pattern 8	Region 1	Increased by 300MW	Region 3	Reduced by 300MW
Pattern 9	Region 1	Increased by 300MW	Region 4	Reduced by 300MW
Pattern 10	Region 2	Increased by 300MW	Region 3	Reduced by 300MW
Pattern 11	Region 2	Increased by 300MW	Region 4	Reduced by 300MW
Pattern 12	Region 3	Increased by 300MW	Region 4	Reduced by 300MW

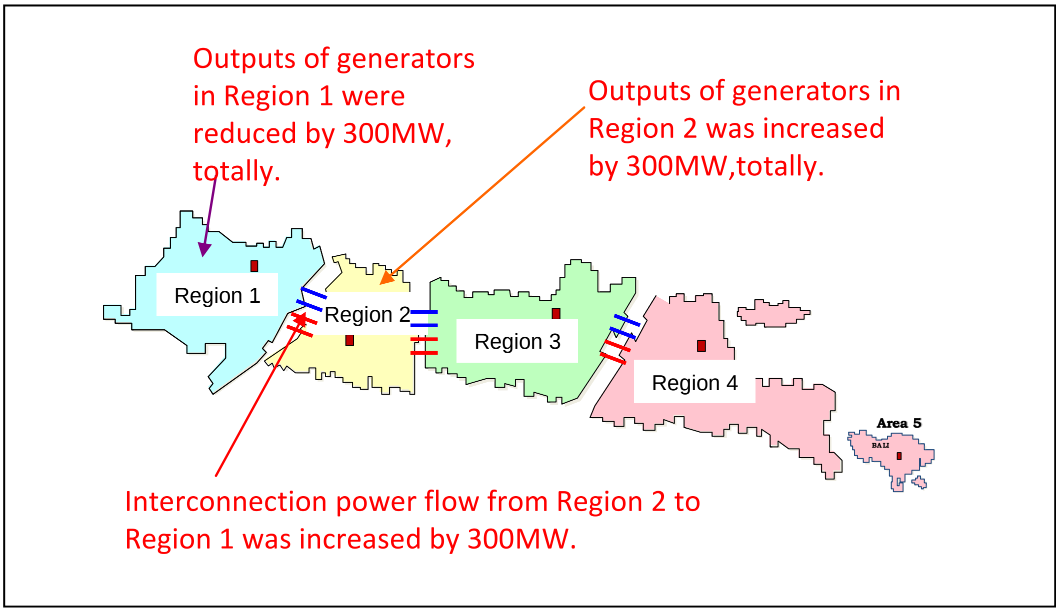


Figure 5.35 Generation Dispatching at Initial Condition in Pattern 1

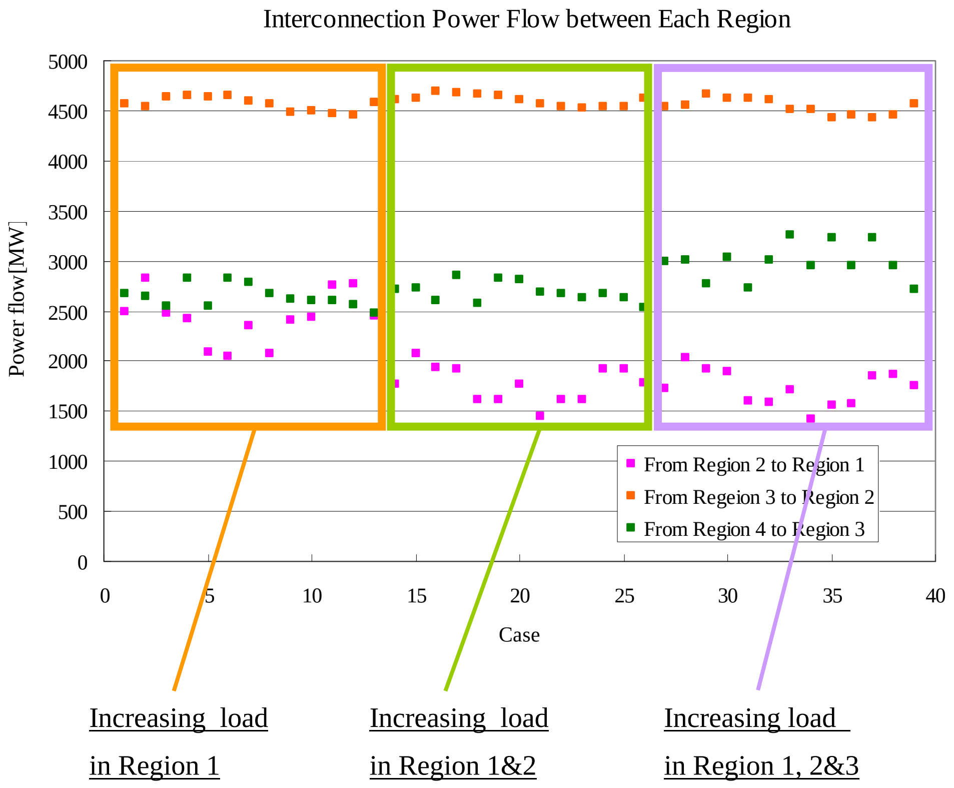
Table 5.23 Scenarios for Increase in Load and Generation Output

Scenario	Load Increasing Area	Generator Output Increasing Area
Scenario 1	Region 1	Region 2,3,4 and 5
Scenario 2	Region 1and 2	Region 3,4 and 5
Scenario 3	Region 1, 2 and 3	Region 4 and 5

Figure 5.36 shows the interconnection power flows between Region 1 and Region 2, between Region 2 and Region 3, and between Region 3 and Region 4 at the upper limit of the power demand

in the PV analysis. The horizontal axis of the figure shows 39 cases with a combination of 13 patterns (base pattern and 12 patterns shown in Table 5.22) and 3 scenarios shown in Table 5.23.

As can be seen from Figure 5.36, it has been confirmed that the interconnection power flows between Region 2 and Region 3 show a correlation with the voltage stability limits since the interconnection power flows at the voltage stability limits fall within a certain range, the power flows between Region 1 and Region 2 and those between Region 3 and Region 4 show large variations. Consequently, monitoring the power flow between Region 2 and Region 3 is considered to be effective for monitoring voltage stability.



Increasing load in Region 1

Increasing load in Region 1&2

Increasing load in Region 1, 2&3

Figure 5.36 Interconnection Power Flows at Voltage Stability Limits in Each Case

5.2.4 Transmission Loss Reduction

Table 5.24 shows the transmission losses in the Java-Bali system with and without additional shunt capacitors at Jakarta peak demand in 2015. In this study, the total transmission losses in the Java-Bali system (including 500kV, 150kV and 70kV networks) modeled in the PSS/E file were calculated for comparison. The transmission losses are reduced due to the installation of additional shunt capacitors since the system voltages are maintained at higher voltages and the power factor is improved.

Table 5.24 Transmission losses in the Java-Bali System with and without Additional Shunt Capacitors

	Amount of in-service shunt capacitors[MVar]	**Transmission losses[MW]**
Without additional shunt capacitors	2,495	716.9
With additional shunt capacitors	3,940	632.9
Difference	1,445	84.0

5.2.5 System Voltage under Off-peak Demand

(1) Active Power Load

Table 5.25 shows the total load in each Region under off-peak demand in 2015. Based on the discussion between PLN and the Study Team, the total load in each Region were assumed using the percentage of the off-peak demand (3:00) against the Java-Bali peak demand (19:00) (the percentage of the off-peak against the Java-Bali peak load is 73%) and the percentage of loads in each Region under the off-peak demand are shown in Table 5.26.

Table 5.25 Percentage of Load in each Region under Off-peak Demand

	Total	**Region 1**	**Region 2**	**Region 3**	**Region 4&5**
Off peak at 3:00	100%	42.1%	21.2%	14.0%	22.7%

Table 5.26 Active Power Load in Each Region under Off-peak Demand [MW]

	Total	**Region 1**	**Region 2**	**Region 3**	**Region 4**	**Region 5**
Off peak at 3:00	19,454	8,190	4,124	2,724	3,922	494

(2) Reactive Power Load

Basically, the reactive powers loads were estimated using P-Q correlation equations that are the same as Jakarta peak demand. If the differences between the estimated active power of the loads and the measured P values were large, the reactive power of loads was estimated using the constant power factor.

(3) Generator

Table 5.27 shows generation dispatching scenario under off-peak demand in 2015. The generator outputs of each fuel type were allocated in consideration of actual operations. The terminal voltages of the generators were set at 1.0pu.

Table 5.27 Generation Dispatching Scenario under Off- peak Demand in 2015

Fuel type	Setting
Coal	Output is adjusted for demand-supply balance
Gas	Minimum output
LNG	Minimum output
Oil	Minimum output
Hydro	Output is set based on actual record on 17 Oct 2012. Following reservoir type hydro power plants were set based on information from P3B: Cirata: 1×50 MW, Saguling: 1×60 MW, Jatiluhur: 1×19 MW
Geothermal	Maximum output

(4) System Voltages under Off-peak Demand

Figure 5.37 shows the voltage profiles at the 500kV system under the Jakarta peak and off-peak demand with additional shunt capacitors. It has been confirmed that the 500kV system voltages under off-peak demand are maintained appropriately, even if all additional shunt capacitors are in-service.

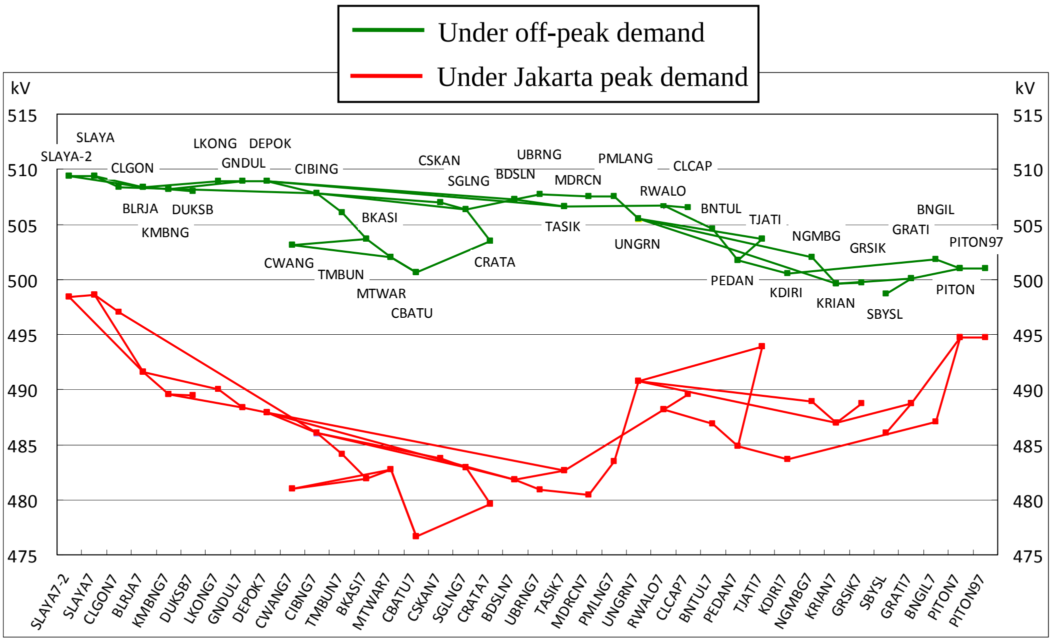


Figure 5.37 Voltage Profile at 500kV System under Jakarta Peak Demand and Off-peak Demand

(5) Amount of Shunt Capacitor Required to be switched off under Off-peak Demand

Some voltages at the 150kV and 70kV system exceed the acceptable range from 0.90pu to 1.05pu under normal or N-1 contingencies. Consequently, the shunt capacitors shown in Table 5.28 are necessary to be switched off under off-peak demand in order to satisfy the voltage criteria.

Table 5.28 Amount of Shunt Capacitors to be switched off under Off-peak Demand in 2015

Area	kV	Unit size [MVar]	No. of units	Total
Region 1	150	50	2	100
		25	1	25
	70	10	2	20
Region 2	150	25	1	25
	70	10	11	110
Total			17	280

In Jakarta and Java-Bali peak season in 2015, it is expected that the switching operations of the amount of shunt capacitors shown in Table 5.28 are necessary to maintain the system voltage appropriately, shunt capacitors are necessary to be switched on to meet the increasing demand in the morning and to be switched off after peak demand.

Chapter 6 Analysis and Countermeasures of Voltage in the Future Jakarta System (in 2021)

In this chapter, the long term voltage situations are analyzed by modeling the 2021 system as the future Jakarta system. The effects of the installation of power generators and transmission lines on the upper limits of the power demand are also analyzed.

6.1 Study and Analysis for Installing Shunt Capacitors

6.1.1 Supposed Active Load

Active power is applied to the PSS/E data at the 2021 Jakarta Peak Time (13:00) given by P3B JB.

Table 6.1 Regional Demand Applied as the Data in 2021

	Total	Region 1	Region 2	Region 3	Region 4	Region 5
Jakarta peak at 13:00	36,700	14,674	9,062	4812	7,217	935

6.1.2 Supposed Reactive Load

The load in 2015 is applied to the reactive load derived from the regression analysis of the measured active and reactive load. Thus, the accuracy of the year 2015 model is improved. However, it is too severe to apply the same correlations to the year 2021 load, because the difference of the demand is too large (up to 12GW). So, basically the same power factor of 2015’s load is applied to 2021’s load. To the loads of the new substations, the loads of the same substation name with a different bus sub code are applied (Table 6.2). If the same substation names do not exist, the original loads of PSS/E data from P3B JB are applied (Table 6.3)

Table 6.2 The Load of 2021 Data Applied the P.F. of the Same Substation Name with Different Bus Sub Code of 2015 Data

Bus Id	Substation	Voltage	Active Power	Applied Reactive Power by P3B	Applied P.f. in 2015 Data	Applied Reavtive Power
15208	KMYRN5-2	150.00	31.669	10.409	0.910069174	13.12541939
15220	CBDAK5-2	150.00	57.567	18.921	0.996304902	4.944245403
15221	TGBRU5-2	150.00	140.442	46.161	0.978234477	29.14207278
15222	CSW5-3	150.00	72.585	23.858	0.938361588	25.08938401
15238	ABADI5-2	150.00	61.017	20.055	0.949793372	19.09086787
15239	PINDA5-2	150.00	131.31	43.159	0.970001331	31.92140936
15245	DTIGA5-2	150.00	43.286	18.072	0.914929832	17.47078962
15253	BNTRO5-3	150.00	84.495	27.772	0.936057458	29.72932719
15256	DUKSB5-3	150.00	96.879	31.843	0.959665742	27.23690036
15259	LIPPO5-2	150.00	80.171	26.351	0.900002153	34.94537225
15260	SMBRT5-2	150.00	85.298	28.036	0.850000577	44.93343030
15273	CIPNG5-2	150.00	35.957	11.819	0.949636575	11.26724951
15274	GDRIA5-2	150.00	34.46	11.326	0.950000741	10.76005385
15275	PCRAN5-2	150.00	88.83	29.197	0.970004430	21.59343942
15276	PGLNG5-2	150.00	72.763	23.916	0.980581205	14.26980582
15277	TNAGA5-2	150.00	113.767	37.393	0.992877053	13.55459113
15284	CIAWI5-2	150.00	57.567	18.921	0.958743296	16.36475944

Table 6.3 The Load of 2021 Data Applied Original PSS/E Data (The Same Substation Name don't Exist in 2015 Data)

Bus Id	Substation	Voltage	Active Power	Applied Reactive Power by P3B	Applied P.f. in 2015 Data	Applied Reactive Power
25148	RJMDL5	150.00	57.76	18.985	—	18.985

6.1.3 Supposed Conditions of Generators

Given the larger amount of generation in 2021 than in 2015, the unit output of the coal plant should also be reduced. The other plants' power should be regulated in the same manner as of 2015. Terminal voltages are to be 1.00pu.

Table 6.4 Output Settings of Each Generator Type PSS/E Data in 2021

Fuel type	Setting
Coal	Maximum output, if possible. Otherwise, Adjusted to the demand.
Gas	Output is adjusted for demand-supply balance
LNG	Output is adjusted for demand-supply balance
Oil	Minimum output
Hydro	Output is set based on actual record on 17 Oct 2012. Following reservoir type hydro power plants were set based on information from P3B: Cirata: 2×98 MW Saguling: 2×147 MW Jatiluhur: 2×15 MW
Geothermal	Maximum output

6.1.4 System Configuration

Figure 6.1 shows the Java Bali system configuration supposed for 2021.

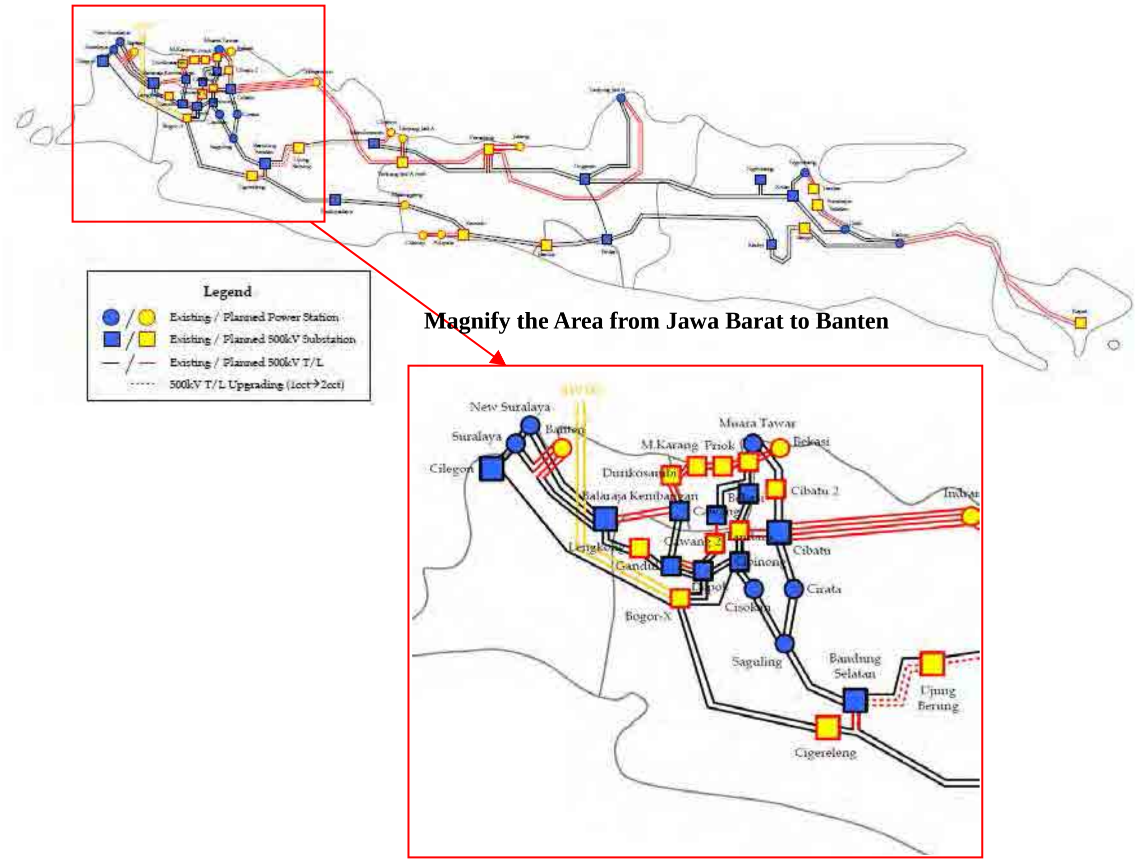


Figure 6.1 Supposed System Configuration in 2021 (Source: RUPTL2012-2021)

6.1.5 Voltage Criteria

Voltage is regulated to obey the Grid Code as in 2015.

6.1.6 Study of Installing the Additional Shunt Capacitors

The capacitor banks are supposed to be installed in accordance with the “Program Peningkatan Kualitas Tegangan “(released by P3B JB).The existing, on going, planned capacitor and capacitor compensating for the reactive power of HVDC are supposed to be installed.

To maintain the voltage following Grid Code under normal and N-1 contingency conditions, a capacitor bank of 6,055MVar should be installed in 2021.

Table 6.5 Additional Shunt Capacitors in 2021

	Type of Equipment	Installed Capacity	
Before Install	Capacitor	4,320 MVar	Involves 1800MVar of XBogor HVDC
	Reactor	-800 MVar	
After Install	Capacitor	6,055 MVar	
	Reactor	-800 MVar	
Increment	Capacity	1,735 MVar	

6.2 Validation of Installation of Additional Shunt Capacitors

6.2.1 Voltage Criteria

Thanks to the strengthened system, even though the capacitors are not installed, a 500kV System meets the Grid Code. However, the installation of the capacitors further improves the system voltage.

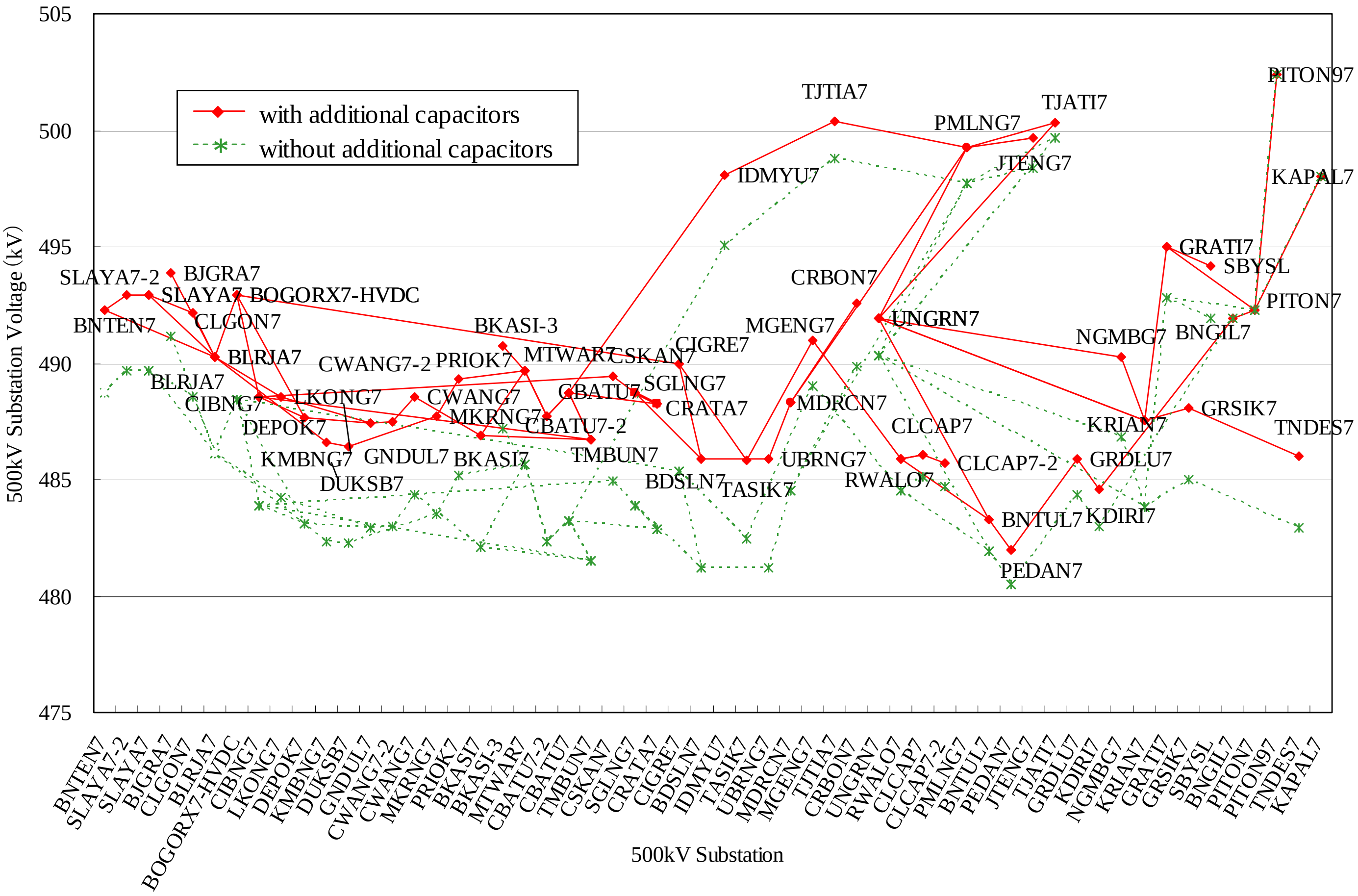


Figure 6.2 Voltage Profile with / without Capacitors Installed in 2021

6.2.2 Regional Balance of Reactive Power

The reactive power balances with / without installations of capacitors are compared as follows.

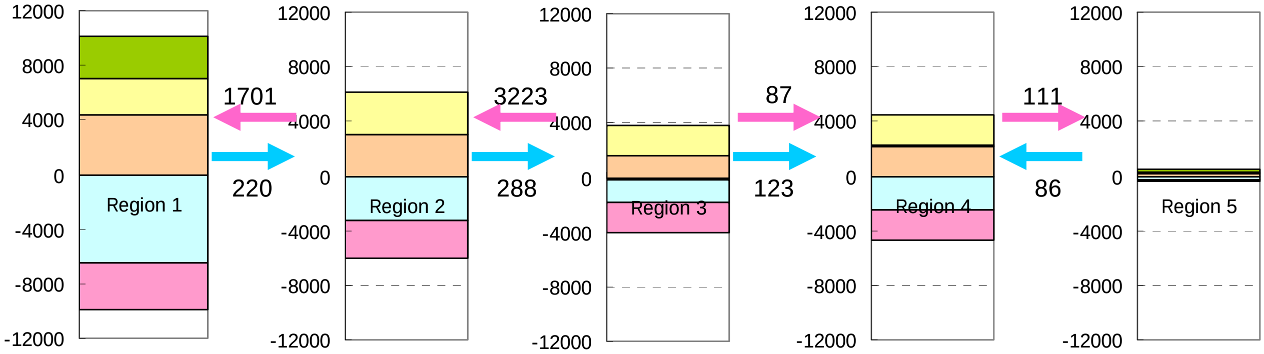


Figure 6.3 Regional Reactive Power Balance without Additional Capacitors in 2021

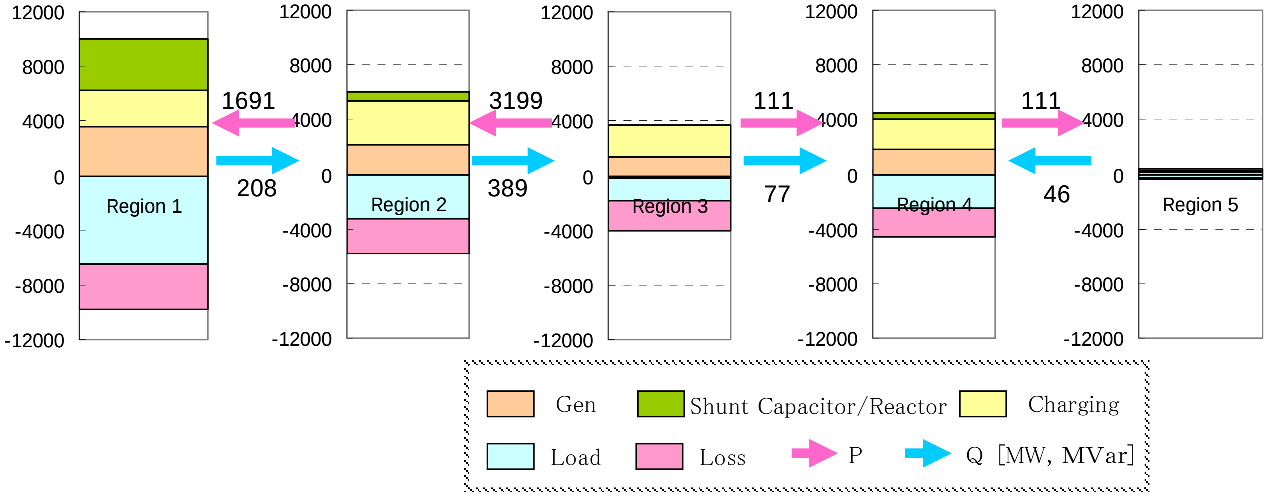


Figure 6.4 Regional Reactive Power Balance with Additional Capacitors in 2021

According to Figure 6.3 and Figure 6.4, reactive power flow is increased from Regions 1, 2 and 4 in which the capacitors reinforced to Region 3 where no capacitors increased.

Given that the capacitors are installed to meet the Grid Code under N-1 contingency conditions, reactive power is too much to balance under normal conditions in Regions 1 and 2. The remaining reactive power of Regions 1 and 2 improve the voltage of Region 3 (no additional capacitors installed) under normal conditions. The capacitor banks are installed at an effective point to raise the voltage to minimize the amount of capacitors. The loss of active power is reduced and the power of the slack generator in Region 3 is reduced, so the active power to Region 3 is reduced.

6.2.3 Verification of Improvement in Voltage Stability

In the same way as the study of the year 2015, voltage stability limits are verified by two scenarios of increasing demand.

(Scenario 1)
The PV curve was drawn by simulating the increase in the load of Jakarta (load of Region 1) from its peak power demand. In this case, the upper limit of the Jakarta power demand was taken as an an evaluating value by increasing the power outputs of the generators that are located in regions other than the Jakarta area (Regions 2, 3, 4 and 5) among the operating generators.

(Scenario 2)
The PV curve was drawn by simulating the increase in the loads of Western Java (loads of Regions 1 and 2) from its peak power demand. In this case, the upper limit of Western Java power demand was taken as an evaluating value by increasing the power outputs of the generators that are located in areas other than Regions 1 and 2 among the operating generators.

(Scenario 1)

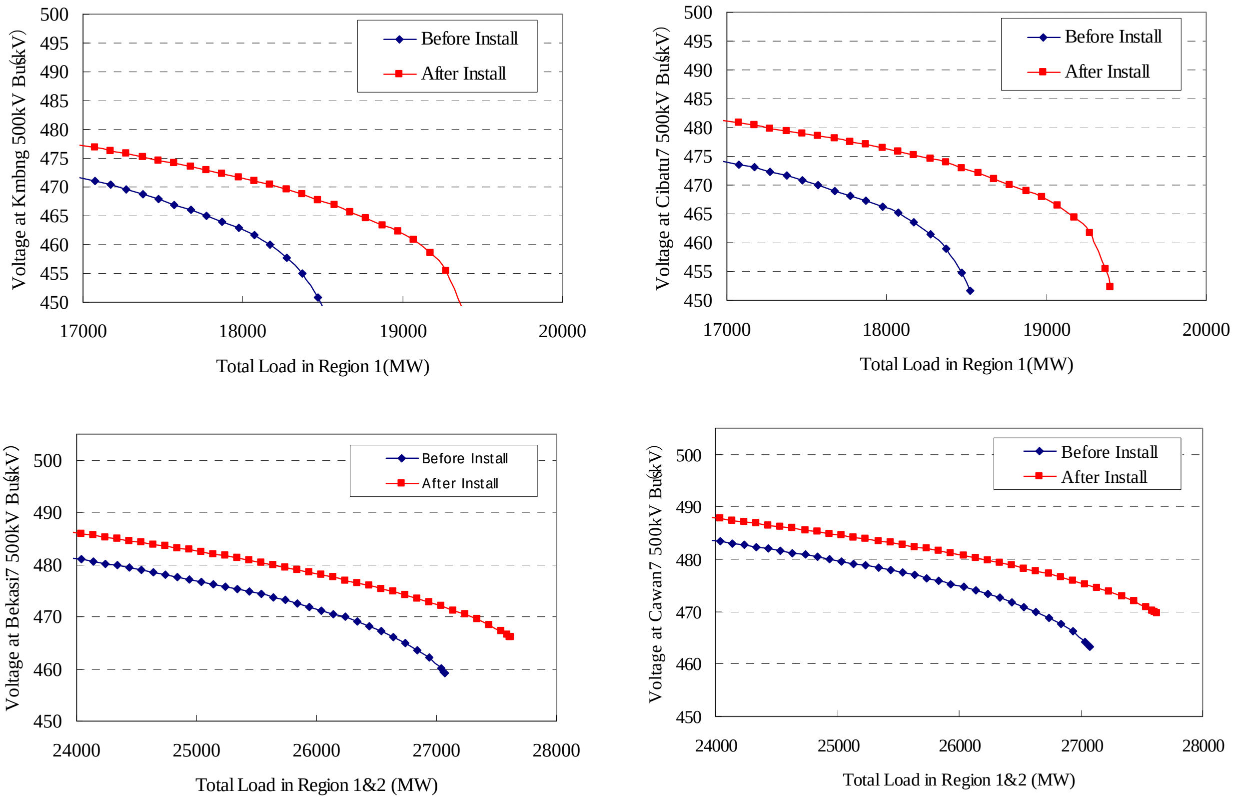


Figure 6.5 The Upper Limit of Jakarta Power Demand and 500kV Voltage

The Upper Limit of Jakarta Power Demand increases by 856MW or 6% of Region 1 demand (14,674MW).

(Scenario 2)

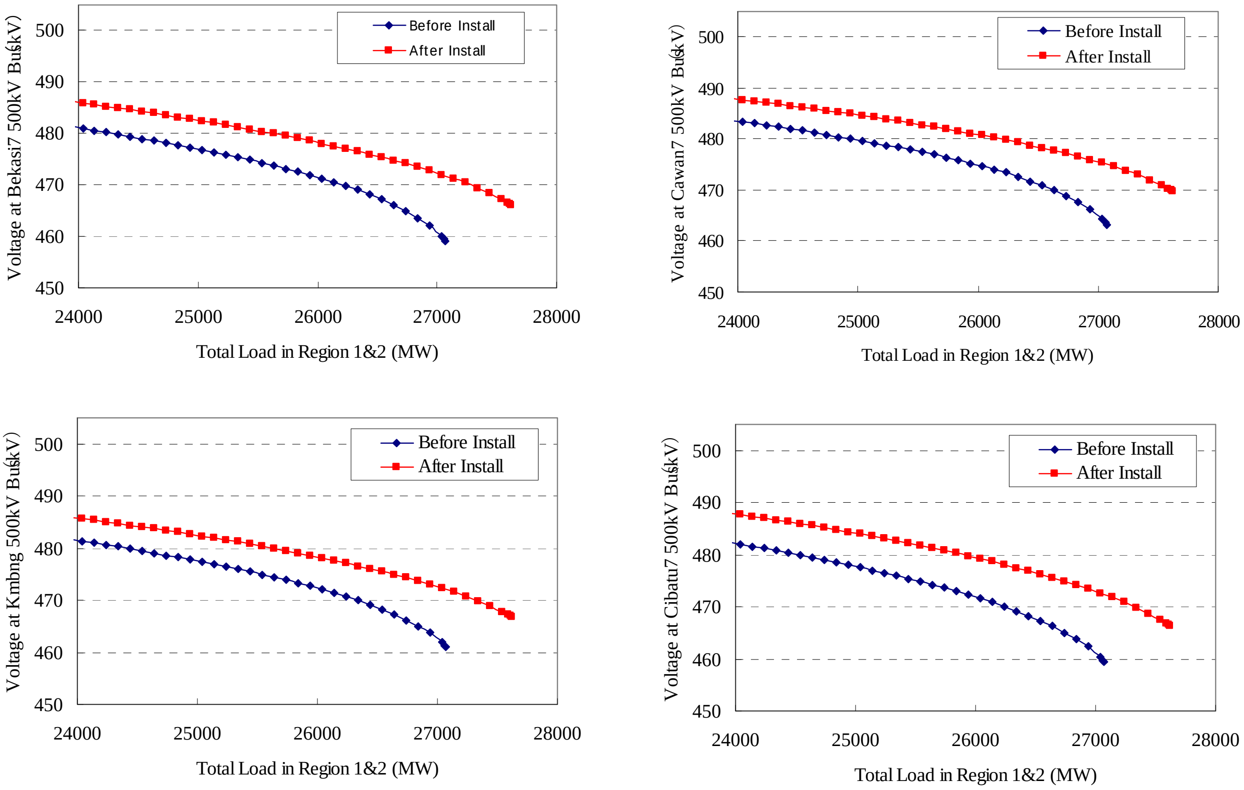


Figure 6.6 The Upper Limit of Western Java Power Demand and 500kV Voltage

Installing the Capacitors makes the upper limit of the Western Java power demand increase by 544MW or 2% of Regions 1 and 2 demands (23,735MW).

6.2.4 Validation of the Upper Limit of Jakarta Power Demand under the N-1 Contingency Condition.

In the same way as the study of 2015, the voltage stability limits when the 500kV line tripped are verified by two the scenarios of increasing the demand.

(Scenario 1)

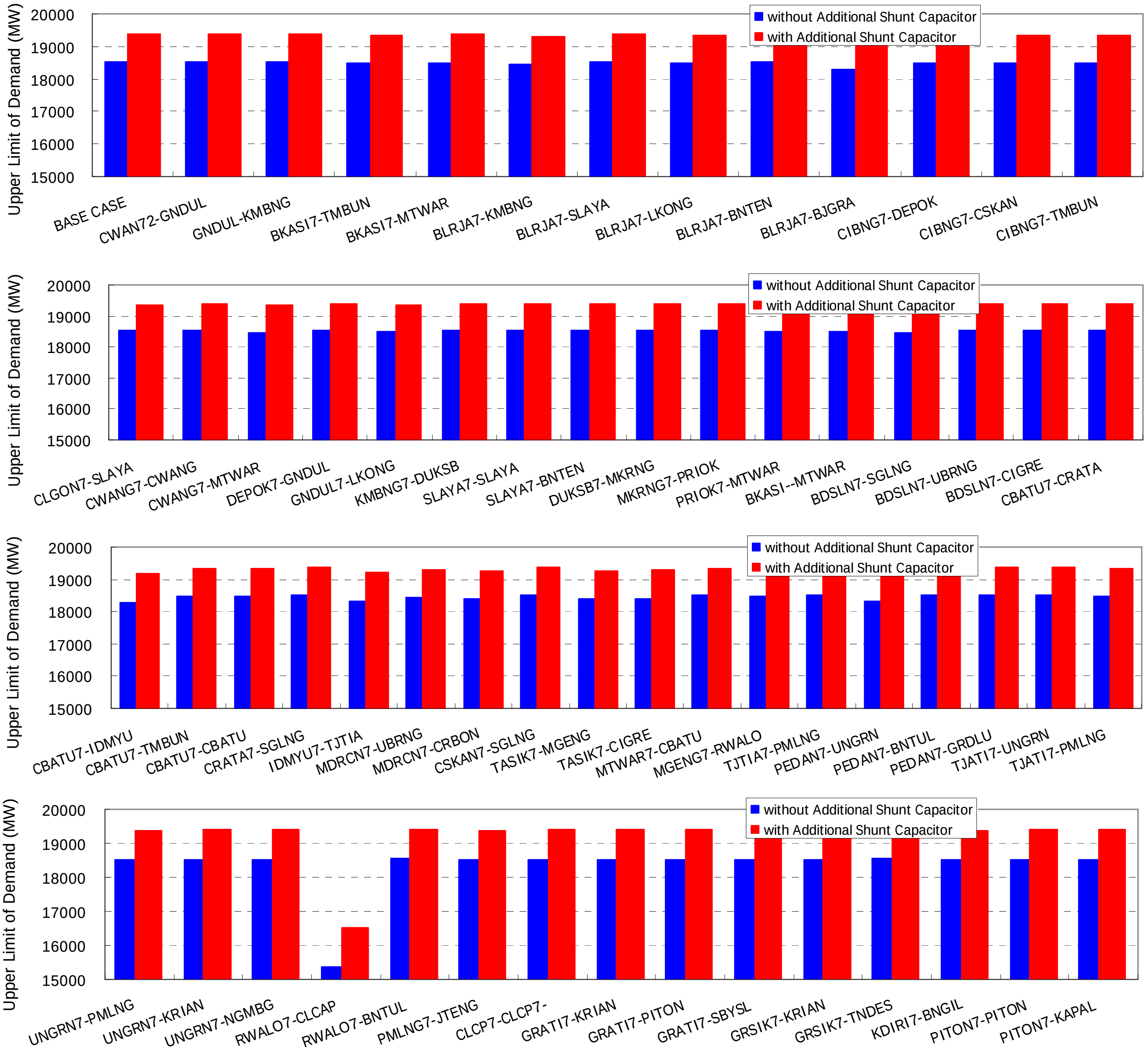


Figure 6.7 The Upper Limit of Jakarta Power Demand with and without Capacitors when the 500kV Line Trips

Under N-1 contingency conditions, installing the capacitors makes the upper limit of Jakarta Power Demand increase by 864MW or 6% of the Region 1 demand (14,674MW).

(Scenario 2)

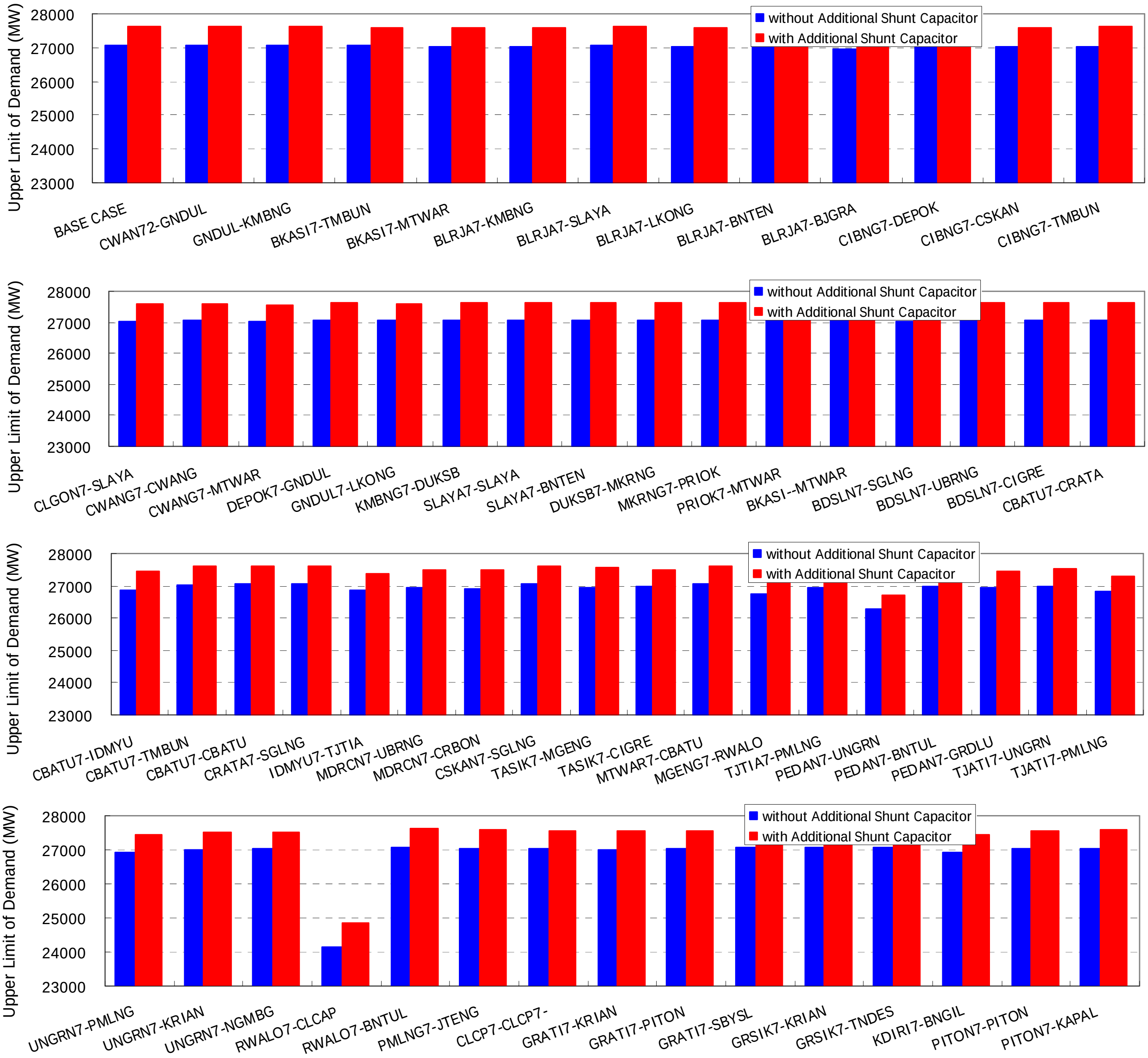


Figure 6.8 The Upper Limit of Western Java Power Demand with and without Capacitors when the 500kV Line Trip

Under the N-1 contingency condition, installing the capacitors causes the upper limit of the Western Java Power Demand increase by 544MW or 2.3% of the demand in Regions 1 and 2 (23,735MW).

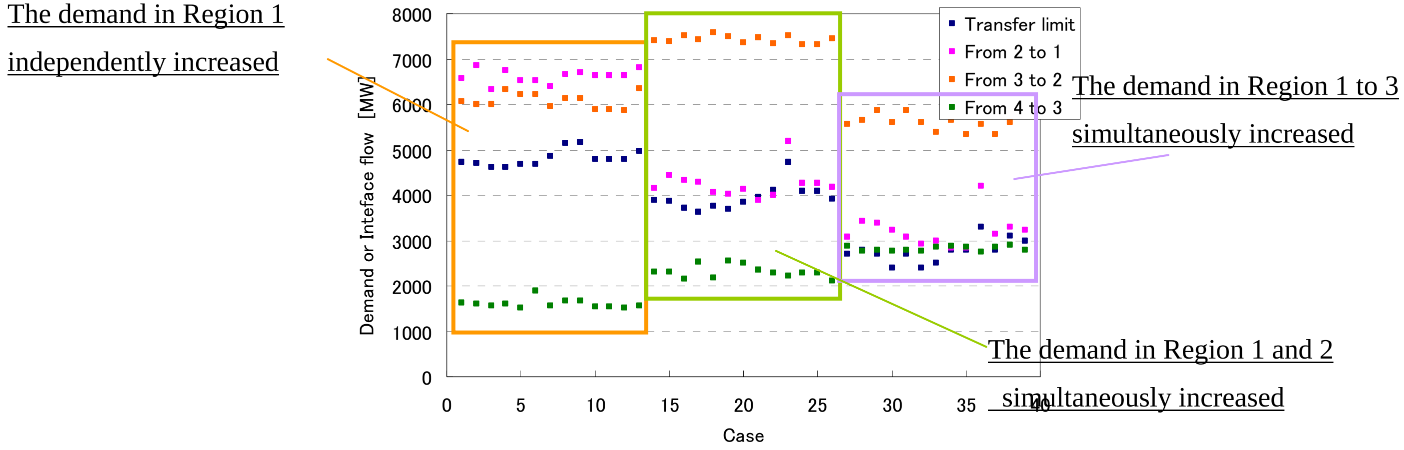
If the total increase of the demand is the same between the two scenarios, one is to increase the demand in Region 1 independently, the other is to increase the demand in Region 1 simultaneously with the one in Region 2. The demand of Region 1 in the former scenario is larger than the demand of Region 1 in the latter one. However, under the former scenario the increase of the upper limit is larger than the one under the latter scenario. So the weaker point of voltage stability is in Region 2 than in Region 1.

Under Scenario 1 (the above mentioned former case), generator outputs in Region 1 are fixed, under Scenario 2 (above mentioned latter case) generator outputs in Regions 1 and 2 are fixed. The increase of the upper limit of Jakarta power demand (Scenario 1) is larger than the upper limit of Jakarta and Western Java power demand (Scenario 2), so fixing the generator in Region 2 or raising generator outputs in Regions 3, 4 and 5 worsens the voltage stability.

Above all, under N-1 contingency conditions, the weaker point of the voltage stability is in Regions 2 to 4 in 2021.

6.2.5 Validation upon the Voltage Stability Limit of the Interface Flows between the Two Regions

In the same manner of 2015, the generator outputs and Regional demands are varied among the regions and the upper limits of the interface flows between the two Regions are analyzed for each case. Figure 6.9 shows the upper limit of the interface flow which was varied under three scenarios of demand increase and 13 scenarios of dispatching of the generators. The demand increase scenarios are the case where the demand in Region 1 independently increased, the case where the demand in Regions 1 and 2 simultaneously increased, and the case where the demand in Regions 1 to 3 simultaneously increased.



The demand in Region 1 independently increased

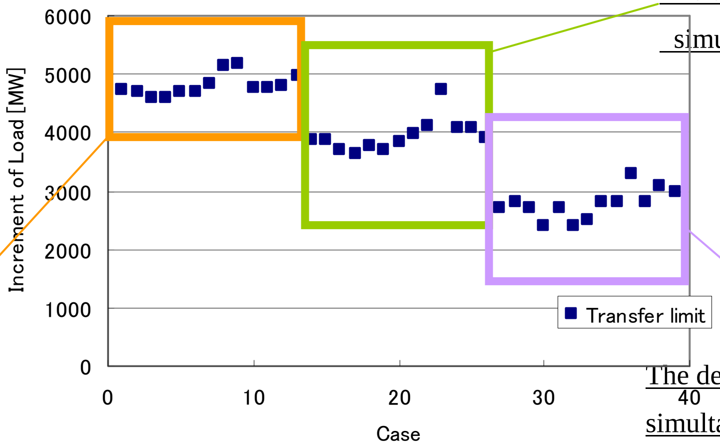
The demand in Region 1 to 3 simultaneously increased

The demand in Region 1 and 2 simultaneously increased

Figure 6.9 The Upper Limits of the Interface Flow between the Two Regions Applied the Various Patterns of Generation and Demand

The upper limits under the three scenarios of the demand increase differ from each other, but the upper limits under the different generation dispatching are almost the same.

The upper limits of the interface flows between Regions 3 and 2 in 2015 under various generation and demand scenarios are almost the same, but in 2021 the upper limits are different among those cases with different Regional demand patterns. Thus, the upper limits of the interface flow between Regions 3 and 2 cannot be an indicator of the estimation of voltage stability limitation in 2021.



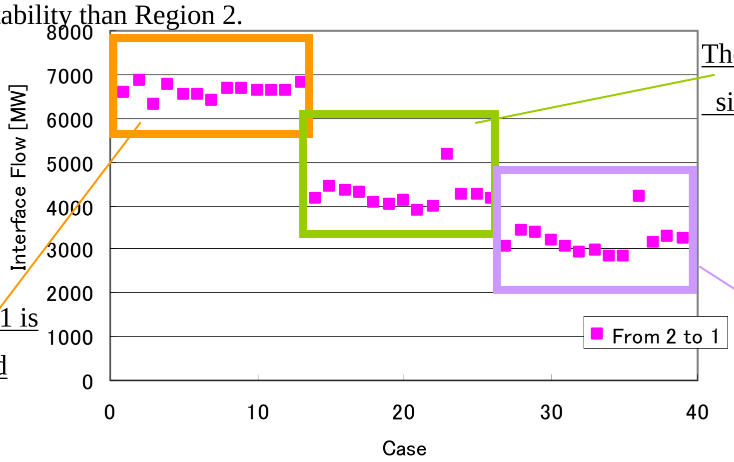
The demand in Regions 1 and 2 simultaneously increased

The demand in Region 1 independently increased

The demand in Regions 1 to 3 simultaneously increased

Figure 6.10 Demand Upper Limits under Various Demand and Generation Scenarios

Figure 6.10 shows the increment of the upper limit of demand under various scenarios that are the same as Figure 6.9. This shows when the demand in Region 1 independently increased. The increment of the upper limit is larger than the increment when the demand in Regions 1 and 2 simultaneously increased. This means that the demand of Region 2 has more influence over voltage limitations than the demand in Region 1. For the same reason, Region 3 has a higher influence on the voltage stability than Region 2.



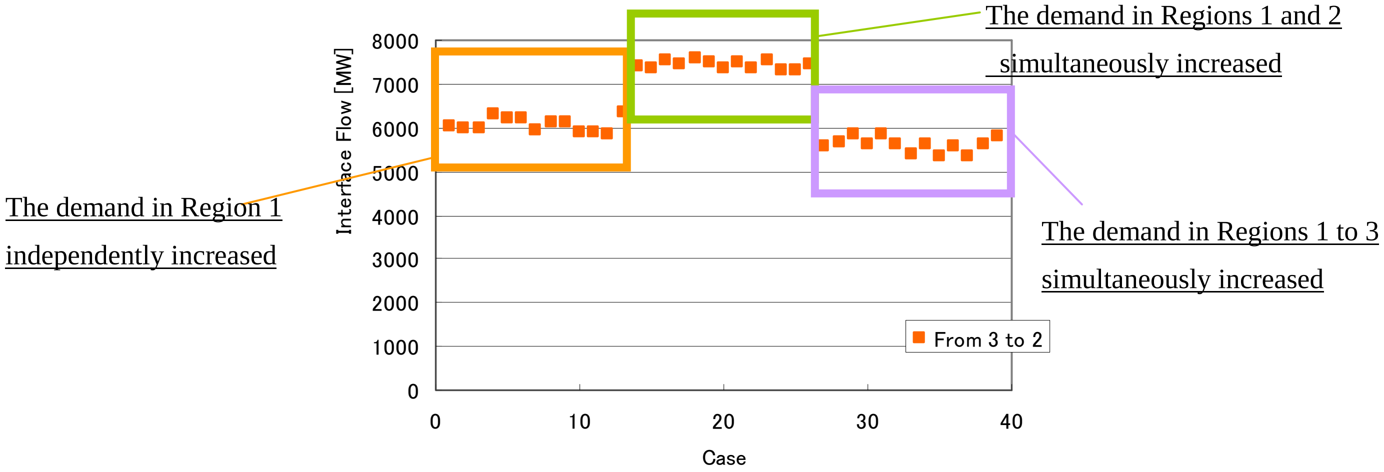
The demand in Regions 1 and 2 simultaneously increased

The demand in Region 1 is independently increased

The demand in Region 1 to 3 Is simultaneously increased

Figure 6.11 The Upper Limits of Interface Flow of Regions 2→1 under Various Scenarios of Generation and Demand

Figure 6.11 also shows that the demand in Region 2 has more influence over voltage limitations of interface flow between Regions 2 to 1 than the demand in Region 1. For the same reason, Region 3 has most influence over this interface flow.



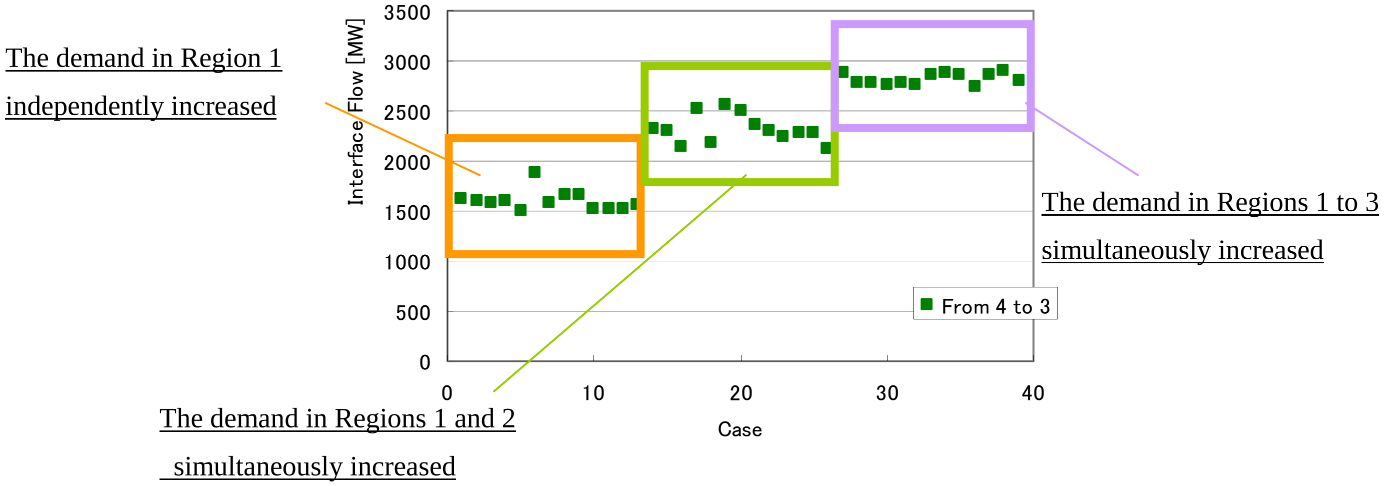
The demand in Regions 1 and 2 simultaneously increased

The demand in Region 1 independently increased

The demand in Regions 1 to 3 simultaneously increased

Figure 6.12 The Upper Limits of the Interface Flow of Regions 3→2 under Various Scenarios of Generation and Demand

For the same reason as mentioned above, in reference to the demand in Region 3 which is most influenced over the upper limit of the interface flow between Regions 3 and 2.



The demand in Region 1 independently increased

The demand in Regions 1 to 3 simultaneously increased

The demand in Regions 1 and 2 simultaneously increased

Figure 6.13 The Upper Limits of Interface Flow of Regions 4→3 under Various Scenarios of Generation and Demand

Figure 6.13 shows that the more dispersed the increase of demand is, the higher the upper limit of the interface flow increase is. This is a normal situation, so no specific point of weak voltage stability is found when referred to Figure 6.13.

6.2.6 Transmission Loss Reduction

Thanks to the additional capacitors, transmission losses in the Java Bali system are reduced as follows.

Table 6.6 Transmission Losses with / without Additional Capacitors

	Capacitor Total [MVar]	Transmission Loss [MW]
Without Capacitors	4,295	671.9
With Capacitors	6,055	636.5
Difference	1,760	35.4

6.3 Effects of Installation of Power Plant

The effects of installing the power generators for voltage maintenance in and around Jakarta were calculated using the Java Bali system model. The candidate sites were selected via a discussion with PLN among the planned power stations near the Jakarta metropolitan area as shown in Table 6.7 and Figure 6.14. The capacities of the generators set as the data of the PSS/E files made by PLN were used. (Thus, the capacity of Bekasi Thermal Power was different from the latest RUPTL)

Table 6.7 Power Plants Targeted for the Study

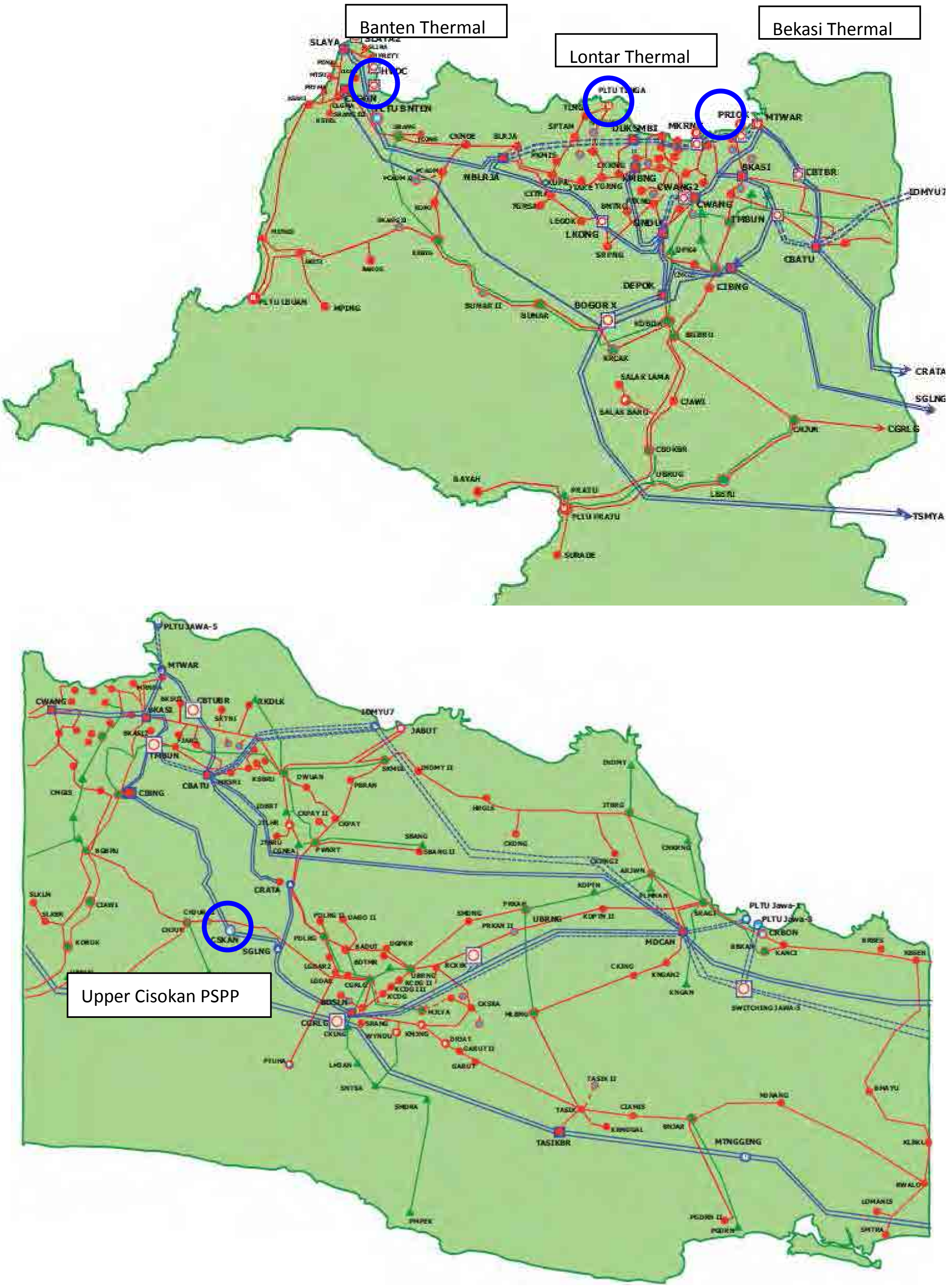
Name of Power Plants	Owner	Generation Capacity	Region	Commissioning Year
Banten Thermal	IPP	1×660	West Java	2016
Bekasi Thermal	PLN	2×1,000	Eastern part of Jakarta	2018-2019
Lontar Thermal Expansion	PLN	1x315 MW	Western part of Jakarta	2016
Upper Cisokan Pumpedstorage Hydropower Plant	PLN	4×260	Region 2	2016

The effects of the voltage maintenance were calculated based on the conditions mentioned below.

- The system model of the PSS/E software for the Jakarta peak demand in 2021 was used. This model has the load of region 1 of 14,674 MW and the combined total load of regions 1 and 2 totalling 23,735 MW.
- The cases with the installation of the target power plants and the cases without the targets were compared. Models of the cases without the target power plants were made by allocating the compensating power outputs for the decreased outputs of the target power plants to the outputs of available power generators in the whole Java system in proportion to their power generation capacities.
- The effects of the voltage maintenance were evaluated from the capability of power transmission to the Jakarta metropolitan area. The two kinds of scenarios categorized by the methodologies of

increasing power demand and power generation outputs were set as described in Section 5.2 and 6.1. The upper limit of Jakarta power demand in the base case of scenario 1 was around 19,400 MW which is larger than the peak load of Region 1 of 14,674 MW by 4,725 MW. The upper limit of the power demand of Jakarta and West Java in the base case of scenario 2 was around 27,624 MW which is larger than the peak load of Regions 1 and 2 of 23,735 MW by 3,889 MW.

The study in this section does not necessarily recommend the need for expanding the upper limit of the power demand but just compares the countermeasures against lowering voltage and their effects of the installation of the candidate facilities.


Banten Thermal

Lontar Thermal

Bekasi Thermal

Upper Cisokan PSPP

Figure 6.14 Sites of Targeted Power Plants

Table 6.8 shows the results of the study in scenario 1. The decrease of the upper limit of Jakarta power demand (The upper limit of the power demand in Region 1) from the base case was observed at 221 MW when Banten thermal power station (625 MW) would not be installed. The decrease of the upper limit of Jakarta power demand from the base case was observed at 1,418 MW when Bekasi thermal power station (2,000 MW) would not be installed. The decreases of the upper limits of Jakarta power demand by decreasing 1 MW of power output are also presented in the right side column for evaluation of the effects that differ among the locations because the decrease of the upper limit of the power demand correlates with the amount of power outputs. The large absolute values of those indicate the high effects.

The site of Lontar power plant has the highest effect. The decrease of the upper limit of Jakarta power demand was around 1.64 MW by decreasing 1MW of the power output. The reason considered for this could be that Lontar power station is located near the demand center of Jakarta and the power station is directly connected to the 150 kV system of Jakarta.

Table 6.8 The Effects of the Installation of the Main Power Generators in and around Jakarta on the Voltage Maintenance (Scenario 1)

Study Cases	Decrease of Power Output (MW)	Upper Limit of Jakarta Power Demand (MW)	Decrease of Upper Limit of Jakarta Power Demand (MW)	Decrease of Upper Limit of Jakarta Power Demand by decreasing 1MW Power Output (MW)
Base Case	-	19,400.96	0	-
Without Banten Thermal	625	19,179.71	▲ 221	▲ 0.35
Without Bekasi Thermal	2,000	17,982.84	▲ 1,418	▲ 0.71
Without Lontar Thermal	315	18,883.46	▲ 518	▲ 1.6
Without Upper Cisokan Pumped Storage Hydropower	150	19,299.09	▲ 102	▲ 0.68

Table 6.9 shows the results of the study in scenario 2. Although the decrease of the limit of the power demand of Jakarta and West Java by decreasing 1MW of power output is lower than the decrease of the limit of Jakarta Power Demand in scenario 1. The trend of the differences among the cases is the same as scenario 1.

Table 6.9 Effects of Installation of Main Power Generators in around Jakarta on Voltage Maintenance (Scenario 2)

Study Cases	Decrease of Power Output (MW)	Upper Limit of Jakarta Power Demand (MW)	Decrease of Upper Limit of Jakarta Power Demand (MW)	Decrease of Upper Limit of Jakarta Power Demand by decreasing 1MW Power Output (MW)
Base Case	-	27,623.89	0	-
Without Banten Thermal	625	27,483.89	▲ 140	▲ 0.22
Without Bekasi Thermal	2,000	26,588.27	▲ 1,036	▲ 0.52
Without Lontar Thermal	315	27,320.77	▲ 303	▲ 0.96
Without Upper Cisokan Pumped Storage Hydropower	150	27,535.14	▲ 89	▲ 0.59

6.4 Effects of Installation of Power Transmission Lines

The effects of the installation of the main power transmission lines in and around Jakarta were calculated by using the Java Bali system model in 2021. The transmission lines and substations were selected as the candidates through discussion with PLN among the planned transmission lines and substations near the Jakarta metropolitan area as shown in Table 6.10 and Figure 6.15.

Table 6.10 Transmission Lines Targeted for the Study

Base Case
500 kV Transmission Line between Muara Tawar Substation- Priok-Muara Karang Substation - Duri Kosambi Substation
500 kV Muara Tawar Substation and Priok Substation
500 kV Transmission Line between Muara Tawar Substation- Priok Substation
500 kV Transmission Line between Cawang Substation – Gandul Substation
500 kV Transmission Line between Cibatu Substation – Tambun Substation
500 kV Transmission Line between Duri Kosambi Substation – Kembangan Substation- Balaraja Substation
HVDC Smatra - Bogor (2,500 MW)

The effects of voltage maintenance were evaluated based on the capability of power transmission to the Jakarta metropolitan area in the same manner as the study of the installation of a power plant.

Table 6.11 shows the results of the study in scenario 1.

The upper limit of Jakarta power demand is decreased by 1,064 MW from the upper limit in the base case in case that the 500 kV transmission lines between Muara Tawar substation – Priok substation-Muara Karang substation- Duri Kosambi substation are not installed. This case is the case without 500 kV Priok and Muara Karang substations that the largest amount of decrease of the upper limit of power demand is estimated. The upper limit of Jakarta power demand decreased by 996 MW from the upper limit in the base case in the case minus the installation of 500 kV Muara Tawar substation and 500 kV Priok substation with the transmission lines between those intervals. The effect of the reinforcement of the power transmission system in the north Jakarta side was discovered to be large from the results of both study cases. The overloaded situations are observed in some 500 kV substations in the case of a 500 kV Priok substation and a 500 kV Muara Karang substation.

In the same manner, the case without the 500 kV Duri Kosambi substation – Kembangan substation – Balaraja substation would reduce the limit of Jakarta power demand by 73 MW and its effects were discovered to be quite substantial. Those transmission lines assume the role of rerouting the power flow from the western side received at Balaraja substation to the northern part of Jakarta.

Table 6.12 shows the results of the study of scenario 2. The decreases of the limit of Jakarta and West Java power demand is lower than the decreases of the limit of Jakarta power demand in scenario 1. The result shows that the limit of the power demand seems to be determined by the situations of other areas where the transmission lines in and around Jakarta cannot have a significant impact.

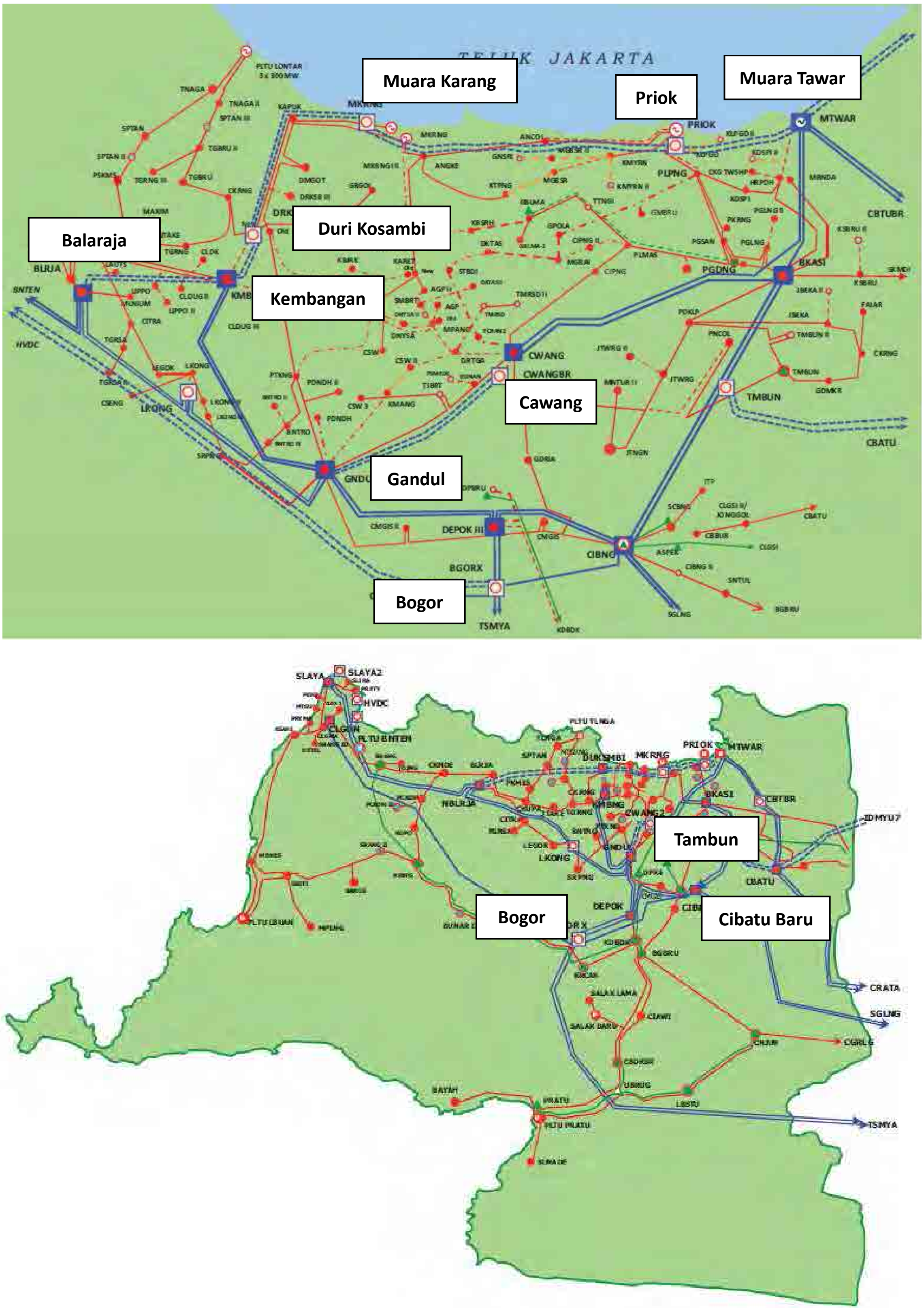


Figure 6.15 Sites of Targeted Transmission Lines and Substations

Table 6.11 Effects of Installation of Main Power Transmission Lines and Substations in around Jakarta on Voltage Maintenance (Scenario 1)

Study Cases	Decrease of Power Output (MW)	Upper Limit of Jakarta Power Demand (MW)	Decrease of Upper Limit of Jakarta Power Demand (MW)
Base Case	19,401	0	-
Without 500 kV Transmission Line between Muara Tawar Substation- Priok-Muara Karang Substation - Duri Kosambi Substation	18,336	▲ 1,064	-
Without 500 kV Muara Tawar Substation and Priok Substation	18,405	▲ 996	
Without 500 kV Transmission Line between Muara Tawar Substation- Priok Substation	19,030	▲ 371	-
Without 500 kV Transmission Line between Cawang Substation – Gandul Substation	19,347	▲ 54	-
Without 500 kV Transmission Line between Cibatu Substation – Tambun Substation	19,240	▲ 161	-
Without 500 kV Transmission Line between Duri Kosambi Substation – Kembangan Substation- Balaraja Substation	18,928	▲ 473	-
Without HVDC Smatra - Bogor (2,500 MW)	18,630	▲ 771	▲ 0.30825

Table 6.12 Effects of Installation of Main Power Transmission Lines and Substations in around Jakarta on Voltage Maintenance (Scenario 2)

Study Cases	Decrease of Power Output (MW)	Upper Limit of Jakarta Power Demand (MW)	Decrease of Upper Limit of Jakarta Power Demand (MW)
Base Case	27,624	0	-
Without 500 kV Transmission Line between Muara Tawar Substation- Priok-Muara Karang Substation - Duri Kosambi Substation	27,359	▲ 265	
Without 500 kV Muara Tawar Substation and Priok Substation	27,495	▲ 129	
Without 500 kV Transmission Line between Muara Tawar Substation- Priok Substation	27,507	▲ 117	
Without 500 kV Transmission Line between Cawang Substation – Gandul Substation	27,613	▲ 11	
Without 500 kV Transmission Line between Cibatu Substation – Tambun Substation	27,559	▲ 65	
Without 500 kV Transmission Line between Duri Kosambi Substation – Kembangan Substation- Balaraja Substation	27,518	▲ 106	
Without HVDC Smatra - Bogor (2,500 MW)	26,658	▲ 966	▲ 0.38650

6.5 Effects of the installation of Capacitors on the increase in Power Flow

This section discusses the effects of the shunt capacitors installed at 500 kV buses on the voltage instability by comparing their effects. In the same manner as in section 7.2 and 7.3, the effects of the voltage maintenance were evaluated per the capability of power transmission to the Jakarta Metropolitan area from a voltage maintenance perspective. The two kinds of scenarios were set out as mentioned in the previous sections. The following steps were taken for the calculations.

- A total of 300 MVar shunt capacitor has been installed at a 500 kV bus of a substation.
- Calculate the incremental limit of the Jakarta power demand (MW)
- Calculate the incremental limit of Jakarta power demand (MW) per a capacity of 1MVar of the installed shunt capacitor.
- The abovementioned calculation is repeated by changing the location of the installed shunt capacitors.

Figure 6.16 and Figure 6.17 show the results of the study in scenario 1 (Sources of the incremental power demand of Jakarta (Power demand of Region 1) are allocated to the power generation in Region 2 and 3). The vertical line shows the incremental limit of the Jakarta power demand per 1 MVar shunt capacitor. A pink colored line in the figure indicates the substations on the route of the 500 kV transmission lines in the southern part of Java from Cigereleng substation to Pedan substation. The locations with the highest effects are Priok, Cawang, Bekasi and Muara Tawar substations located in the northern part of Jakarta marked by a red colored circle in the figure. Based on the results, the reactive power compensation at the power-receiving end in Region 1 is found to have a large effect on expanding the upper limit of Jakarta’s power demand in case of supplying the power of Region 2 and 3 to the incremental load of Jakarta (load of Region 1).

Figure 6.18 and Figure 6.19 show the results of the study in scenario 2. The locations with the highest effects are Matengen, Ciracap, and Rawalo substations located at the receiving end of the power flow from Region 3 to Region 2 on the route of the 500 kV transmission lines in the southern part of Java from Cigereleng to Peadan substation. From the results, the reactive power compensation on the route of the 500 kV transmission line in south Java at the border between Region 2 and 3 is found to have a large effect on expanding the upper limit of the power demand of Jakarta and west Java in case of supplying the power of Region 3 to the incremental load of Region 1 and 2.

As pointed out in Section 6.3, the results of the study of the installation of the transmission lines and substations in and around Jakarta suggested that the limit of power demand would be determined by the situations in other areas where the transmission lines in and around Jakarta are not capable of having a significant impact. Actually, based on the results of the study in this section, the increase in power flow on the 500 kV transmission line in the southern part of Java is considered to be a bottleneck of scenario 2.

It has been considered that the effects of the shunt capacitors differ from the different patterns of power demand expansion and increases in the power outputs of the power sources. As already mentioned, the limits of the power demand far exceeds the peak demand, the results of the study in this section does not present the necessity of the countermeasures to expand the limit of power demand.

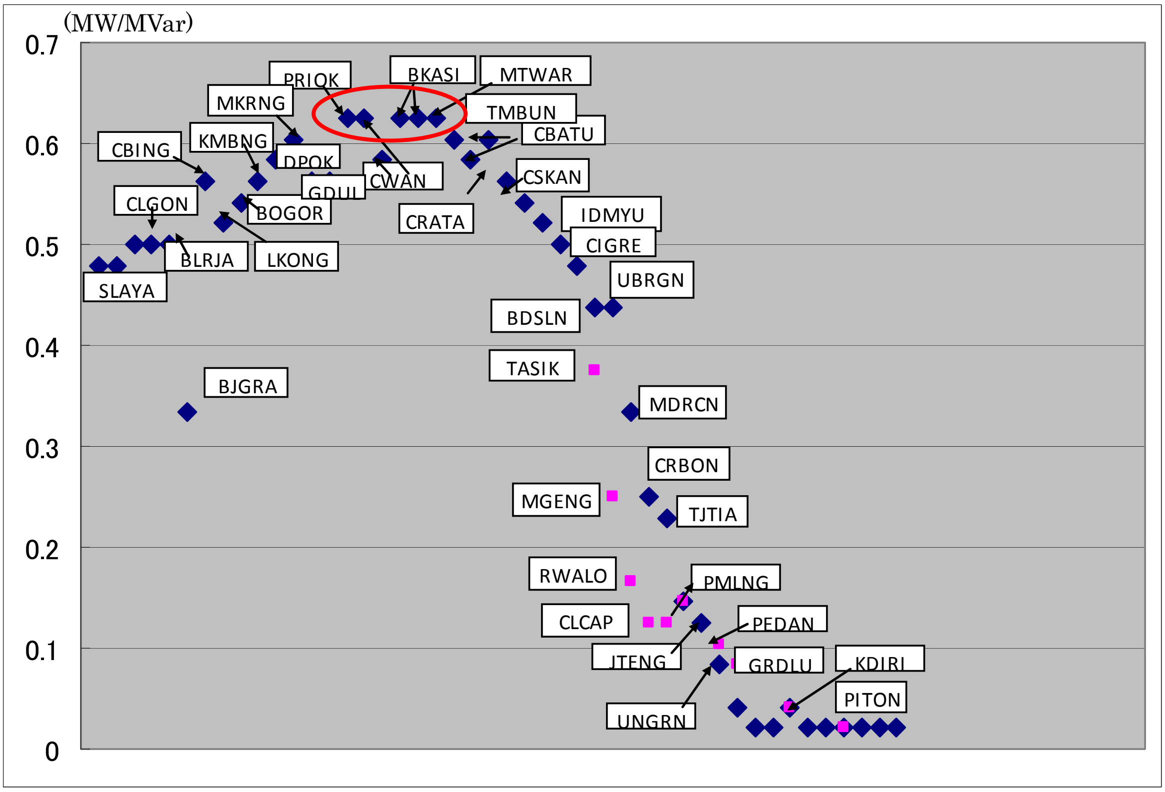
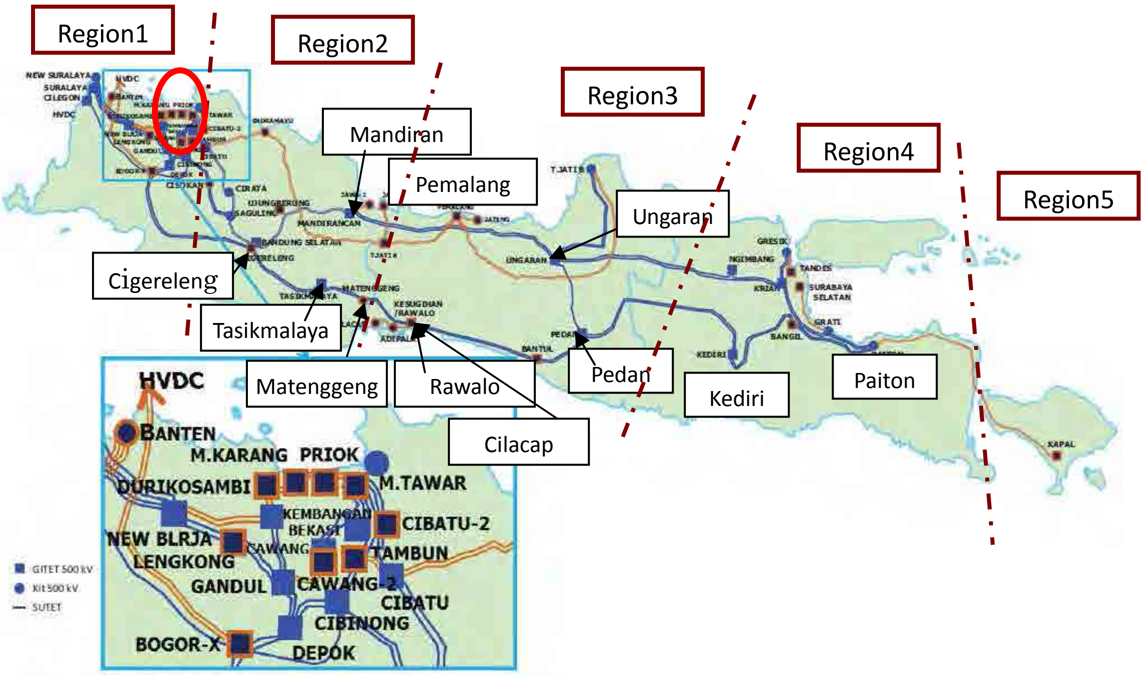


Figure 6.16 Effects of Shunt Capacitors Installed at Substations on Increasing Power Flow in the East Part from Region 2 (Scenario 1)



(Areas marked by a red circle has a relatively large effect of installation of shunt capacitors.)

Figure 6.17 Location with Highest Effects of Shunt Capacitors Installed at Substations on Increasing Power Flow in the East Part from Region 2 (Scenario 1)

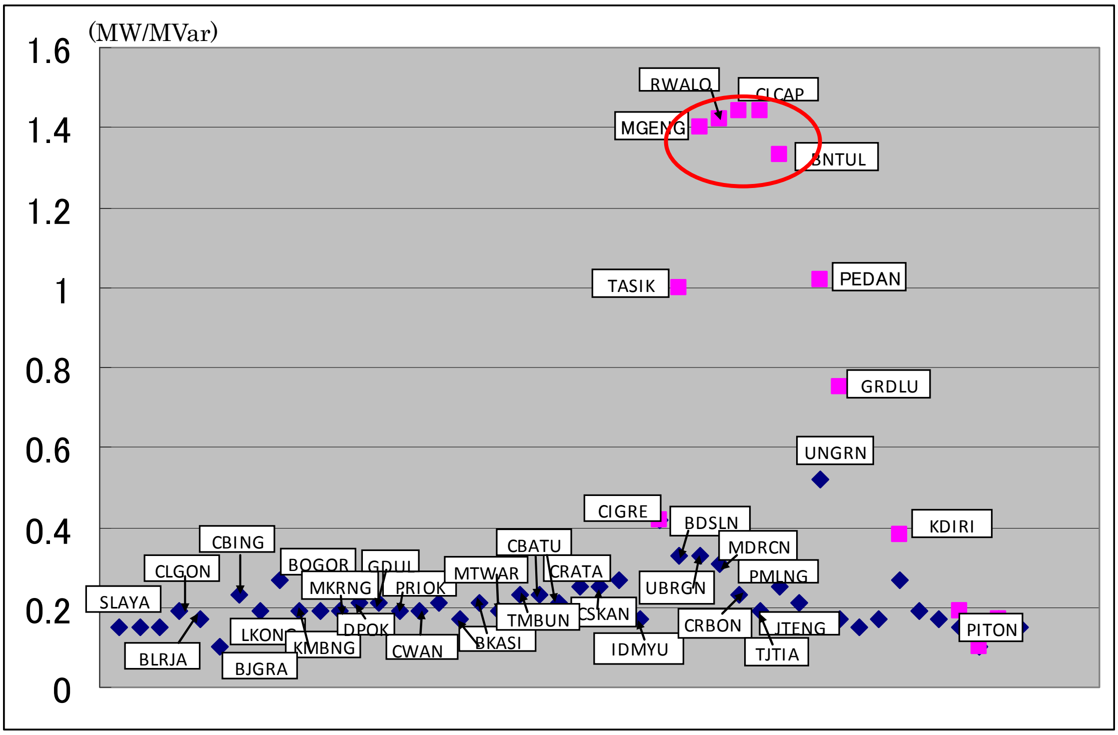
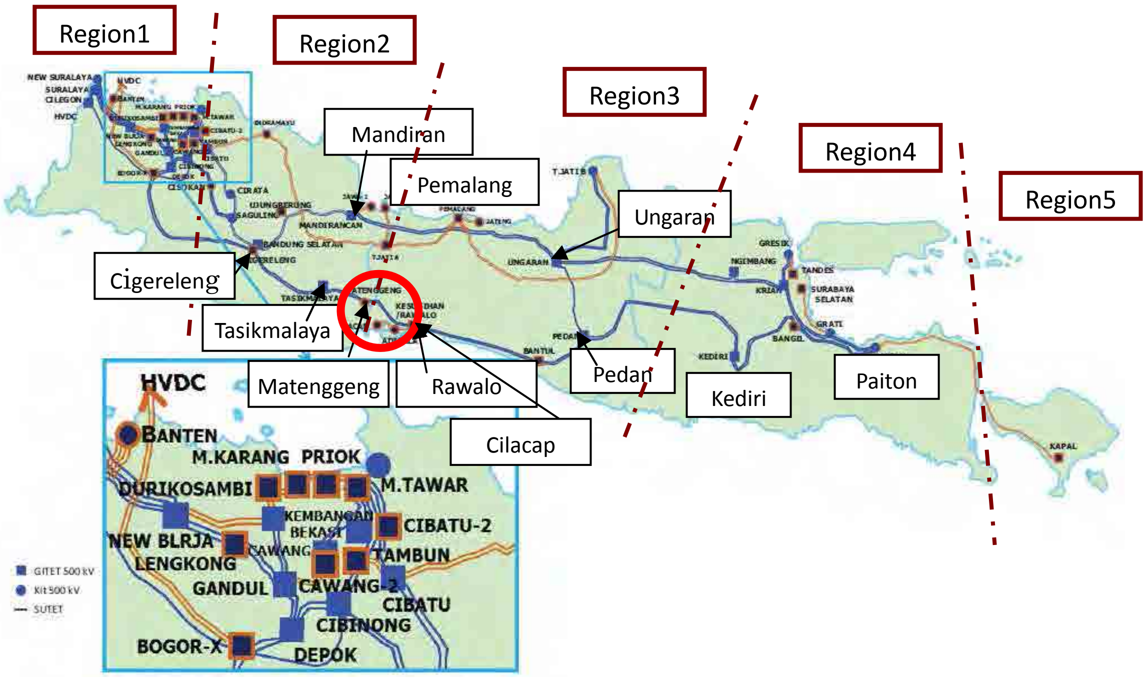


Figure 6.18 Effects of Shunt Capacitors Installed at Substations on Increasing Power Flow in the East Part from Region 2 (Scenario 2)



(Areas marked by a red circle have a relatively large effect of installation of shunt capacitors.)

Figure 6.19 Location with Highest Effects of Shunt Capacitors Installed at Substations on Increasing Power Flow in the East Part from Region 2 (Scenario 2)

Chapter 7 Countermeasures against Voltage Drops

This chapter describes the countermeasures against the voltage drops including the introduction of new methodologies of system voltage control that can be applied to the Jakarta metropolitan area in addition to the installation of shunt capacitors that is confirmed to be effective from the results of the study in the previous chapters.

7.1 Shunt Capacitor

Based on the analysis in the former clause, necessary amount of shunt capacitors for each year are shown in the Table 7.1.

Table 7.1 Necessary amount of Shunt Capacitors for Each Year [MVar]

Area	Result of P3B study and DIgSILENT data		Year 2015	Year 2021
	Existing	On-going & planned		
Region 1	260	1,705	1,950	6,055※
Region 2	70	170	1,080	
Region 3	75	75	100	
Region 4	370	370	635	
Region 5	175	175	175	
Total	950	2,495	3,940	

※ Including Shunt capacitors (1,800MVar) for Java-Sumatra 3,000MW HVDC transmission system

7.2 Introduction of New Voltage Control Scheme

7.2.1 Needs for New Voltage Control Scheme

At present, terminal voltage control of generators, switching of shunt capacitors and changing tap position of transformers are conducted by manual operation in response to the demand fluctuation.

In Java-Bali system, it is estimated that voltage control operation by the system operators will increase due to the expansion of the network, increase of the controlled equipment and complication of system characteristics. This may lead to ineffective operation of the voltage control equipment. To avoid these prospects, voltage control improvement is strongly needed. These are two types of voltage & reactive power control schemes such as Local VQC and Central VQC, which are adopted in the power companies.

7.2.2 Local VQC

The conceptual structure of Local VQC is shown in Figure 7.1. In this scheme, generator terminal voltage is maintained constantly by AVR. Tap position of the transformers and ON/OFF status of shunt capacitors are coordinately controlled by Local VQC.

Local VQC controls V & Q control equipment so as to keep the voltage and reactive power to the predetermined reference value in each substation.

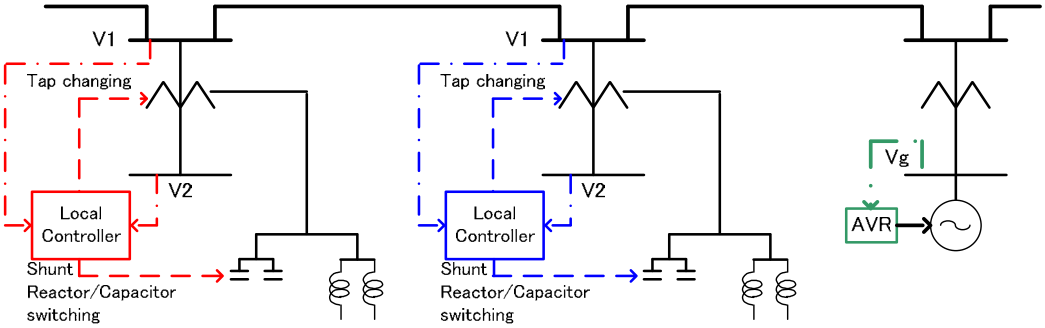


Figure 7.1 Local VQC Scheme

(1) Voltage control in substation

VQC adjusts bus voltage and reactive power of the transformer within the set band by automatic changing of transformer tap position and switching of shunt capacitors and reactors.

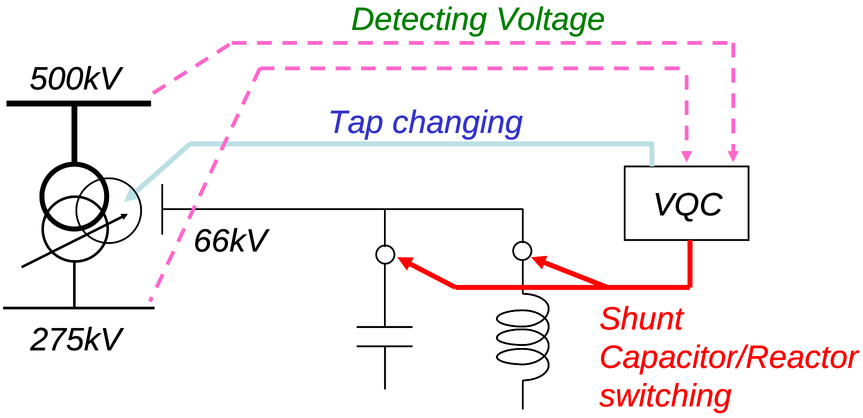


Figure 7.2 Voltage Control Method by Local VQC

Figure 7.3 shows an example of VQC operating characteristics. This VQC controls tap position and ON/OFF status of shunt capacitors by detecting the deviation between the reference voltage and measured voltage of primary and secondary side.

In case that the primary side voltage drops, VQC issues the instruction to switch ON shunt capacitors and the voltage is restored. In the same manner, if the secondary side voltage drops, tap position of transformer is raised and the voltage is restored.

An example of voltage control pattern is shown in Figure 7.4. In this example, the primary voltage is varied up and down in response to demand fluctuation. Meanwhile the secondary voltage is kept constant throughout the day.

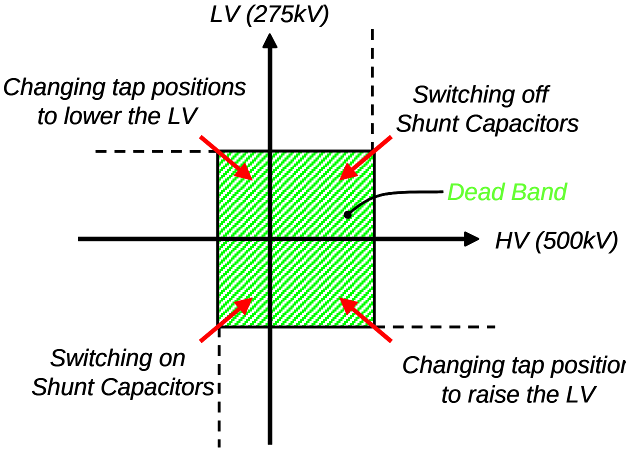


Figure 7.3 Operating Characteristics of Local VQC

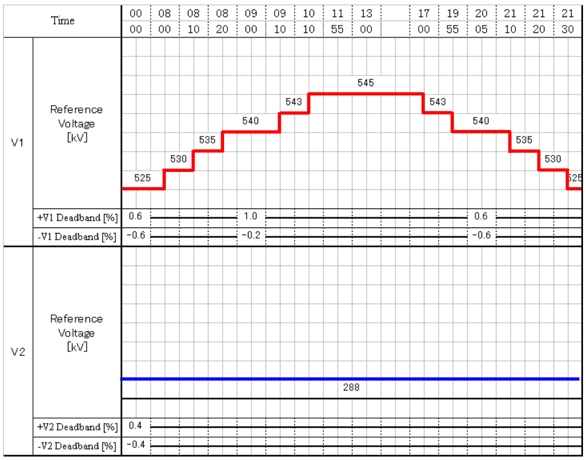


Figure 7.4 Voltage Control Pattern of Local VQC

(2) Introduction of PSVR (Power System Voltage Regulator) to the generators

Generally, AVR (Automatic Voltage controller) is applied to generators for the terminal voltage control. AVR detects the terminal voltage and adjusts it constantly by controlling field current of exciter. In case AVR is applied, reactive power output of the generator will not reach its upper limit and there is still a margin for voltage control even if system voltage drops.

On the other hand, PSVR controls the high side voltage of step-up transformer which is near to the system. Therefore reactive power margin of generator can be fully utilized and system voltage can be maintained against the fast demand fluctuation.

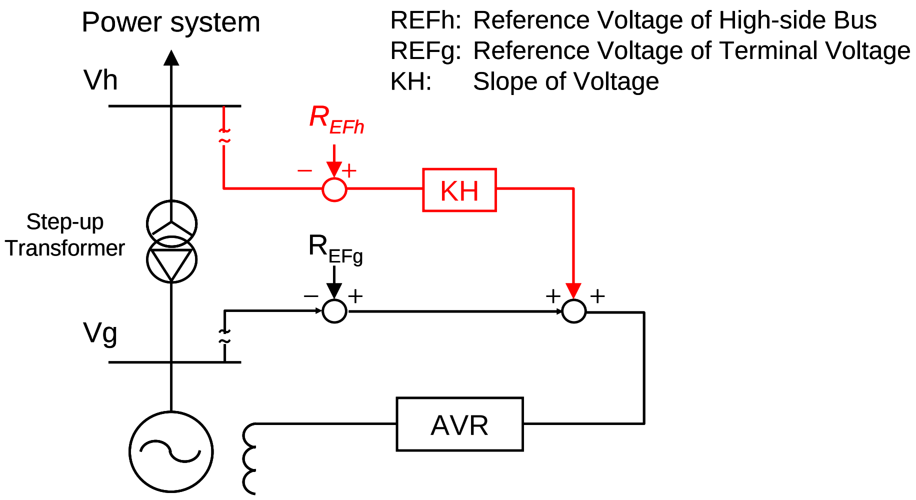


Figure 7.5 PSVR Control Scheme

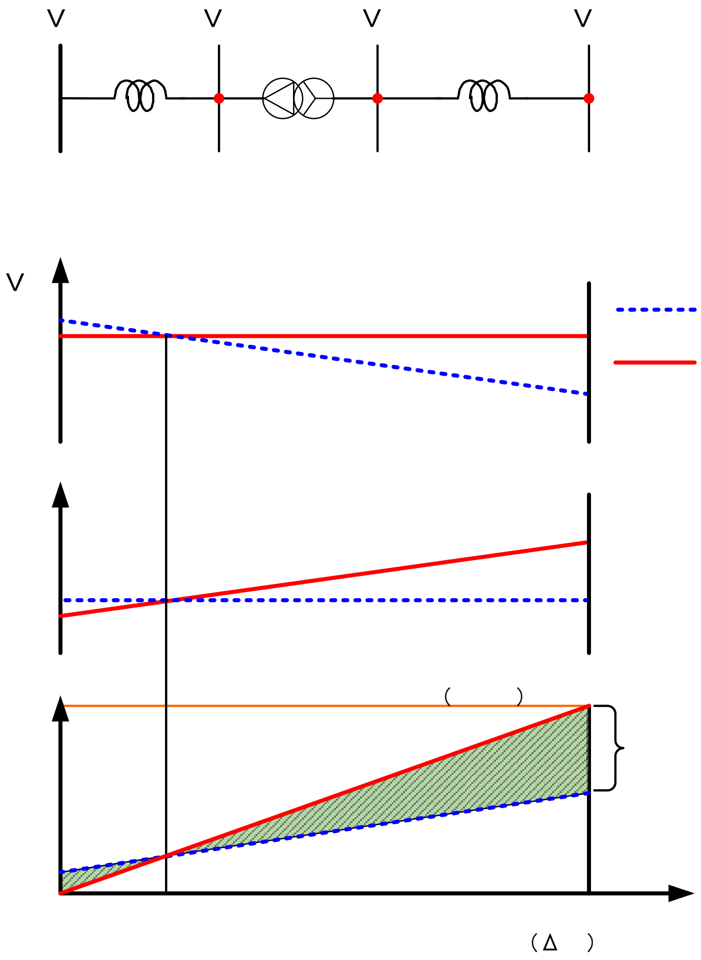


Figure 7.6 Control Characteristics of PSVR and AVR

7.2.3 Central VQC

The conceptual diagram of Central VQC is shown in Figure 7.7. Based on the monitored online data, voltage control signal is sent out to the power stations and substations from central load dispatching center etc.

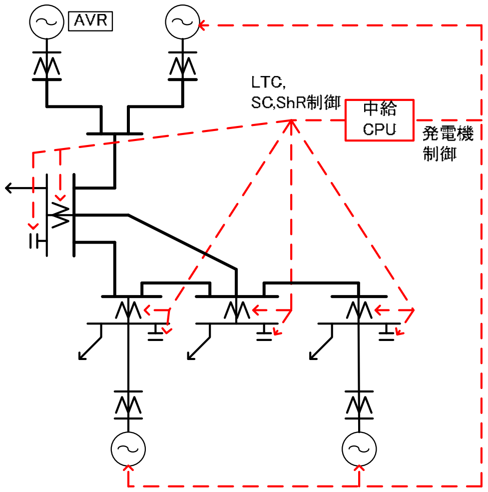
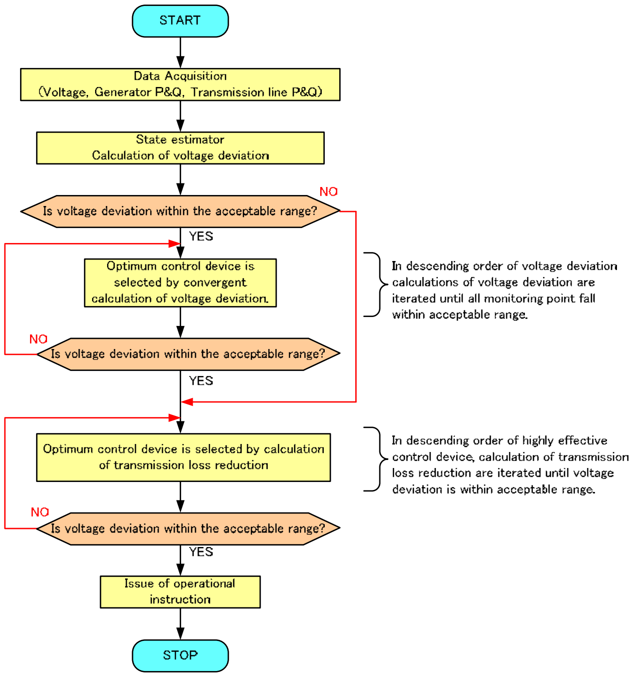


Figure 7.7 Central VQC

Figure 7.8 shows an example of Central VQC algorithm. As an evaluation function, this algorithm adopts the voltage deviation at the monitored points and minimization of transmission loss of the monitored transmission lines.



In descending order of voltage deviation calculations of voltage deviation are iterated until all monitoring point fall within acceptable range.

In descending order of highly effective control device, calculation of transmission loss reduction are iterated until voltage deviation is within acceptable range.

Figure 7.8 Example of the Algorithm of Central VQC

7.3 System Monitoring and Control

7.3.1 Voltage Monitoring

To conduct appropriate state estimation and security analysis, calibration of detected value such as monitored voltage error is important and the related rule should be established.

7.3.2 Monitored Value and Calibration of the input Value to Voltage Controller

Voltage drop along the wiring from potential transformer to the secondary point of voltage detection should be calibrated. The detected voltage of VQC or PSVR is accurate since it adopts the average of line voltages. It can also be corrected by imputing the calibrated value which varies with the wiring length.

7.3.3 As-needed Calibration of detected Voltage

It is hard to maintain initial accuracy of PT due to the characteristics change caused by aging and or ambient temperature. For example following task rule is recommended:

"If the detected value continuously differs more than 2 kV by comparing the monitored value at two points in a substation, investigation and countermeasure should be implemented."

7.4 Introduction of PMU

(1) Trend of PMU technology

PMU (Phasor Measurement Unit) can widely measure time synchronized voltage phase angle by using GPS (Global Positioning System), etc. WAMS (Wide Area Monitoring System) which is based on this PMU technology, is currently applied in many countries including Europe and the US and utilized for real-time power system monitoring. Furthermore WAMPAC (Wide Area Monitoring, Protection and Control) is being developed, which uses the monitored system information acquired by PMU.

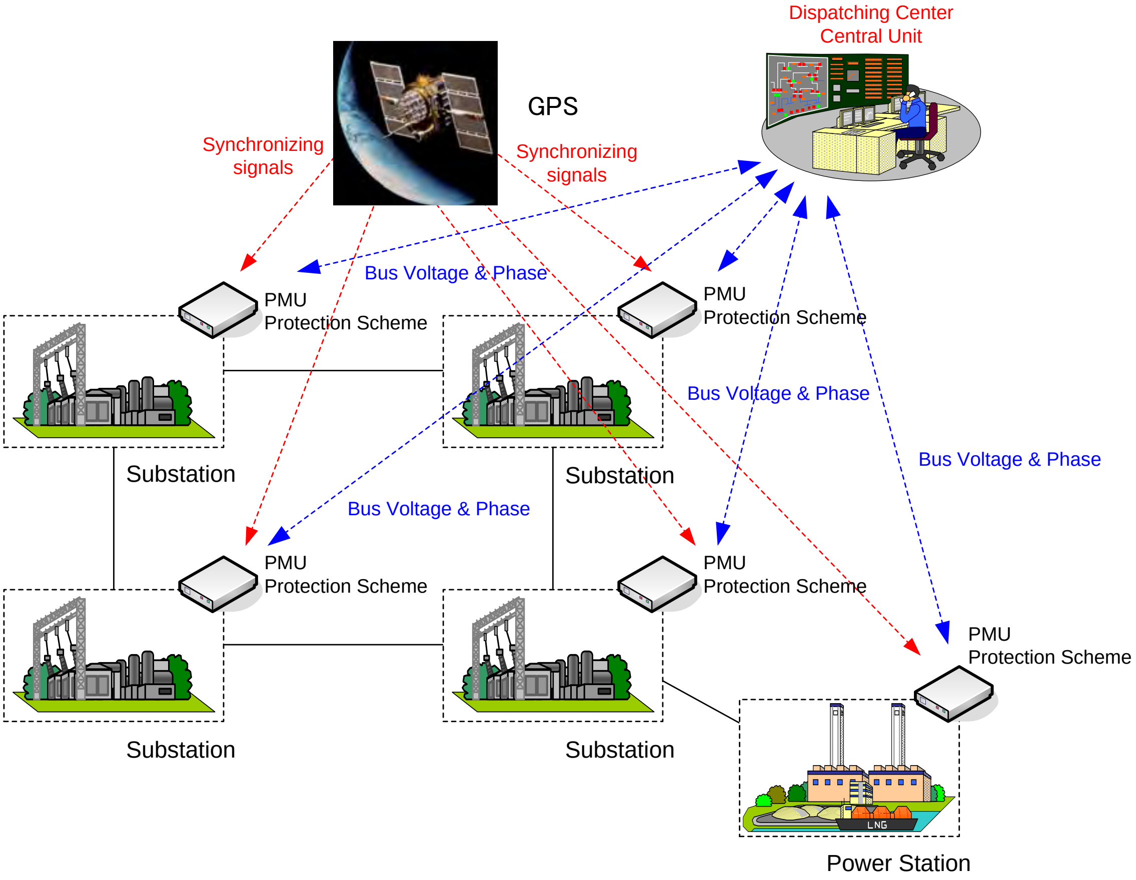


Figure 7.9 Conceptual Structure of WAMPAC

As for the application of PMU technology, NASPI (North American Synchrophasor Initiative) presented future roadmap in "Synchrophasor Technology Roadmap (March 13, 2009)".

< By the year 2014 >

- Postmortem forensic analysis of all grid disturbances
- Monitoring and visualization of angle differences, voltage stability, frequency, and thermal overloads
- Power plant monitoring and integration, including intermittent resources and distributed generation
- Power system restoration
- Static model benchmarking
- State estimation
- Automated control of local assets

< By the year 2019 >

- Alarming for situational awareness tools
- Day- and hour-ahead operations planning
- Real-time automated grid controls and adaptive protection on a wide-area basis
- Congestion management
- Inter-area oscillation damping modulation controls
- System integrity protection schemes
- Dynamic model benchmarking
- Dynamic line ratings and VAR support
- Automatically manage frequency and voltage response from load
- Distribution network monitoring, restoration and self-healing

(2) Accuracy improvement of State Estimation

JICA Study Team conducted a survey on EMS installed in P3B Load Dispatching Operation Training Center. The same type of EMS is installed in Central Load Dispatching Center. This EMS also has the function to perform security analysis using power flow data created by State Estimator. If P3B operators can utilize this function effectively, it will result in ensuring reliable power system operation. However, according to the interview with a trainer, it turned out that State Estimation didn't converge well and the function of security analysis could not be used yet. The possible causes are as follows:

- Quite a number of real-time data are missing.
- Some network parameters such as generator and step-up transformer but not been correctly input to power flow data.

In order to improve network monitoring function, following measures will be necessary along with the feasibility study on the introduction of PMU:

- Collecting accurate network parameters
- Securing necessary data by the improving telecommunication facility

7.5 Synchronous Condenser

As with generator, synchronous condenser can generate and absorb reactive power. It improves voltage stability and synchronous stability by its fast and continuous response to the voltage fluctuation. Although it has high functionality, it is not economical due to high construction cost, complicated maintenance and large power loss compared with shunt capacitors and shunt reactors, In this study, the option to introduce synchronous condenser was excluded since because voltage stability can be maintained with the additional shunt capacitors.

7.6 Countermeasures against Voltage Drop

From the study results described earlier, there are following countermeasures against voltage drop in the Jakarta system.

	Countermeasures
A	In addition to existing and planned shunt capacitors in Java Bali system (see section 3.1.3), following shunt capacitors are needed to be installed: ● By 2015, 1,445 MVar in Java system (Total in 2015: 3,940 MVar) ● By 2021, Total: 6,055 MVar in Java system (Incremental amount from 2015 is 315 MVar excluding 1,800 MVar for Java-Sumatra 3,000 MW HVDC transmission line)
B	Installation of Local VQC in addition to the countermeasure A
C	Installation of Central VQC in addition to the countermeasure A

Table 7.2 Existing and planned Shunt Capacitors in Java Bali System

Existing shunt capacitors in Java Bali system	950 MVar
Ongoing shunt capacitors	475 MVar
Planed shunt capacitors	1,070 MVar
Total	2,495 MVar

As described in the beginning of this chapter, voltage control operation by the system operators will increase and ineffective operation of the voltage control equipment will be expected according to the expansion of the network scale of Java Bali system, increase of the controlled equipment and complication of system characteristics. It is necessary to decide carefully when to introduce VQC scheme in consideration of system voltage profile and system operator's workload.

Each option is analyzed and compared in Chapter 9.

Chapter 8 Impact of the Blackout to the Economic and Industrial Activities in the Jakarta Metropolitan Area

8.1 Objective of the Impact Evaluation

It is important to give consideration to the impact of voltage drop or blackout to electricity user when studying measurements for improving stability of transmission system. This chapter evaluates qualitatively such impacts on electricity consumers especially focusing on industrial sector and IPP entities in Jakarta Metropolitan Area.

8.2 Subject and Methodology

Interviews were conducted with below subjects including an IPP entity supplying electricity to the industrial park. This IPP entity has connected to the PLN's transmission system.

(1) A factory located in the industrial park
(2) An administrative office in the industrial park
(3) IPP entity supplying electricity to the above industrial park

8.3 Interviewed Items

Interviews were conducted focusing on the following points.

(a) General Information (power supply condition, etc)
(b) Emergency Power Generator and Uninterruptible Power Supply (UPS)
(c) Emergency Response System for Blackout, Restoration Time after Blackout
(d) Risk Management for Blackout (Insurance etc)
(e) Impact on Economic Activities

8.4 Results

This subchapter shows the results of the interviews with each subject.

8.4.1 Factory in Industrial Park

From an interview with the factory which manufactures electricity supply facilities, it has become obvous that it does not specificially adopt measures for blackout such as installing emergency generators or insurance. This factory says that there are no serious impacts except suspending the production line. However, concerns remain about security (e.g. secondary disasters or accidents).

(a) General Information

The factory made an agreement with power supplier (an IPP entity), and the power supplier has to manage about the power usage including maintenances of power receiving facilities etc.

(b) Emergency Power Generator and Uninterruptible Power Supply (UPS)

No installation.

(c) Emergency Response System for Blackout, Restoration Time after Blackout

The factory entrusts the entire work related to power receiving including electricity restoration. There are no production facilities to take any restarting time, and immediate restart can be possible.

(d) Risk Management for Blackout (Insurance etc)

No risk managements for blackout.

(e) Impact on Economic Activities

No impacts.

8.4.2 Administrative Office the Industrial Park

According to explanations from administrative office, there are about 100 business entities in this industrial park and they have been struggling with voltage drop issue. There are no specific measures for blackout since its power supplier (an IPP entity) manages electricity usage comprehensively. If blackout caused by voltage drop occurred, there may be some difficulties in recovering the production line.

(a) General Information

Every entity in the industrial area has made agreements with power supplier directly and received electricity as 20kV voltage through buried double-circuit cable line with automatic switching devices. The power supplier monitors all usage of electricity consumers. The power supplier has connected to the transmission system of PLN and may have been affected by accidents of PLN side.

(b) Emergency Power Generator and Uninterruptible Power Supply (UPS)

The administrative office does not understand the situation about usage of both continuous and emergency generator. Before then, an entity installed a continuous generator, but stopped it due to rising fuel cost.

(c) Emergency Response System for Blackout, Restoration Time after Blackout

The power supplier conducts entire power recovery. In case of a generating accident caused by frequency fluctuation of PLN side, it took about 6 hours. Power failure from an accident of buried cables recovers after about 30 minutes.

(d) Risk Management for Blackout (Insurance etc)

No risk managements for blackout.

(e) Impact on Economic Activities

The administrative office receives a surge of complains about voltage drop from business entities in the industrial area, because the voltage level frequently exceeds the allowable range as specified in the Grid Code. The measurements for voltage drop show little progress because the power supplier says that this problem caused by PLN side, although the administrative office has asked the power supplier.

The voltage drop affects most business entities in the industrial area to stop their production processes. When such business entities question the administrative office how to establish the measurements, the office tells them to conduct tap-changing of receiving facilities. However, it is difficult to establish individual measurements because tap-changing has risks for facility damages when the voltage level rises.

8.4.3 IPP Entity

This IPP entity supplies power to approximately 1,800 electricity users. The interview revealed that only 1 user has installed a small emergency generator and the other users have not established any measurements for blackout such as installing emergency generators. If a blackout originating in voltage drop occurs, there may be some troubles with security (secondary disasters or accidents) and recovery works.

(a) General Information

This IPP entity supplies power to some industrial areas, and sells electricity to PLN though their connected transmission system.

(b) Emergency Power Generator and Uninterruptible Power Supply (UPS)

Only 1 electricity user has installed a small emergency generator in approximately 1,800 users receiving electricity from the IPP entity.

(c) Emergency Response System for Blackout, Restoration Time after Blackout

The IPP entity manages everything related to electricity usage including restoration.

(d) Risk Management for Blackout (Insurance etc)

The IPP entity has not established any risk managements for blackout such as insurance. However, the IPP entity refunds the demand charge in 10% the hour, to compensate electricity users. IPP entity also recommends 40 precise factories to install UPS as measurements for blackouts and low quality of electricity.

(e) Impact on Economic Activities

The voltage level frequently drops below the normal condition as specified in the Grid Code. The IPP entity has tried to increase generation to improve voltage drops, which unfortunately does not contribute due to the significant impact from PLN side.

8.4.4 Conclusion

As explained above, these interviews show that voltage drop is one of the issues common to those who are operating in the industrial park, as well as to the power supplier. Despite its frequent occurrence, they do not necessarily have the resolution to avoid impact on their activities and operations.

8.5 Consideration

To consider the potential to attract business entities to Indonesia through the improvement of the quality of electricity, this subchapter assist to understand the situation that what businesses are in Indonesia. The consideration especially refers the number of Japanese-affiliated business entities here.

8.5.1 Japanese-affiliated Business Entities

According to a report published by Teikoku Data Bank (TDB) in 2012, the number of Japanese-affiliated business entities is 1,266 in Indonesia. Looking at it by the type of business, 692 entities (54.7%) are manufacturers which include more than 120 automobile-related. The main production process affected by the quality of electricity is painting operation for automobile-related, and the quality of painting operation does not matter if the types of vehicle are not required to equip good application of paint.

Table 8.1 Japanese-affiliated Business Entities in Indonesia

Type of Business	Number	Component (%)
Construction	59	4.7
Manufacturer	692	54.7
Wholesale	275	21.7
Retail	20	1.6
Transportation, Communication	63	5.0
Services	87	6.9
Real Estate	7	0.6
Other Business	63	5.0
Total	1266	100

Rank	Type of Detailed Business	Number	Component (%)
1	Automobile Component	35	2.8
1	Automobile Handing	35	2.8
3	Other Investment Business	31	2.4
4	Goods Wholesale	26	2.1
5	Electric Equipment Wholesale	25	2.0
6	Civil and Engineering Construction	20	1.6
7	Resin for Industrial Use	19	1.5
7	Steel / Steel Products Wholesale	19	1.5
9	Automobile Internal Combustion Products	17	1.3
9	Chemical Products Wholesale	17	1.3

Source: Fact-finding Survey on Japanese-affiliated Business Entities in Indonesia (Teikoku Data Bank)

8.5.2 Business Risks in Indonesia

The questionnaire study conducted by Japan External Trade Organization (JETRO) in 2011 reveals that the biggest business risk is inadequate infrastructure to consider moving into Indonesia for Japanese-affiliated business entities. The inadequate infrastructure is not always including the quality of electricity, but seems to relate it.

Table 8.2 shows the results of questionnaire studies about the type of business risks in Asian countries including Indonesia for all business from 2008 to 2010. Table B shows the results of that by the manufacturers and non-manufacturers in 2010.

Table 8.2 Results of JETRO's Questionnaire Studies for All Business (2008-2010)

Unit: Percent

	Response Rate in Business Risks on Inadequate Infrastructure in Asian Countries			
		2010	2009	2008
1	India	64.3	56.7	58.7
2	Viet Nam	54.2	41.8	55.7
3	Indonesia	34.0	27.7	29.9
4	The Philippines	29.7	26.8	28.0
5	China	13.6	15.7	16.8
6	Thailand	11.6	9.4	10.3
7	Malaysia	8.2	8.7	5.6
8	Singapore	1.4	1.9	2.3

	Business Risks in Indonesia			
		2010	2009	2008
1	Inadequate Infrastructure	34.0	27.7	29.9
2	Law Systems and Operations	24.4	19.9	22.6
3	Exchange Risk	21.0	26.2	32.6
4	Maturity of Related Business	15.0	7.8	10.6
5	Labor Difficulties	14.7	9.7	12.0
6	Tax Risks	10.5	10.3	11.3
7	Protection of Intellectual Property	5.7	7.2	6.6
8	Rising Labor Costs	4.5	4.4	8.6

Source: Summary of the questionnaire study about overseas expansion of Japanese Companies in 2010

Table 8.3 Results of JETRO's Questionnaire Studies by Manufacturers and Non-manufacturers

Unit: Percent

	Response Rate in Business Risks on Inadequate Infrastructure in Asian Countries		
		Manufacturers	Non-Manufacturers
1	India	63.4	66.4
2	Viet Nam	53.6	55.2
3	Indonesia	31.8	38.6
4	The Philippines	30.5	27.8
5	China	13.3	14.3
6	Thailand	10.4	14.4
7	Malaysia	9.4	5.2
8	Singapore	2.1	0.0

	Business Risks in Indonesia		
		Manufacturers	Non-Manufacturers
1	Inadequate Infrastructure	31.8	38.6
2	Law Systems and Operations	22.6	28.1
3	Exchange Risk	23.0	16.7
4	Maturity of Related Business	13.4	18.4
5	Labor Difficulties	14.2	15.8
6	Tax Risks	13.4	18.4
7	Protection of Intellectual Property	5.9	5.3
8	Rising Labor Costs	4.6	4.4

Source: Summary of the questionnaire study about overseas expansion of Japanese Companies in 2010

8.5.3 Conclusion

Out of 1,266 Japanese companies, there are 692 (54.7%) manufactures and includes over 120 of automobile-related companies. Compared to other industries, automobile-related operations are not substantially unaffected by power quality issues.

However, according to the said questionnaire, more than 30% of Japanese companies answered that the biggest business risk in Indonesia is inadequate infrastructure. Improving power quality may contribute to attract various industries such as electronics and machine to start business in Indonesia.

Chapter 9 Technical and Economic Comparison of Implementation of Countermeasures against Voltage Drops

This chapter discusses the efficiency and effectiveness of the countermeasures against voltage drops proposed in chapter 7 from technical and economical perspective.

9.1 The Costs of Countermeasures against the Voltage Drops

This section estimates the cost of the countermeasures against the voltage drops. As described in section 7.5, measures to improve the voltage drops in Jakarta are considered as follows.

Measures	Contents
A	Installation of shunt capacitors in Jakarta and West Java
B	Along with the installation of shunt capacitors in Jakarta and West Java, a Local VQC scheme is applied.
C	Along with the installation of shunt capacitors in Jakarta and West Java, a Central VQC scheme is applied.

The assumption of cost estimation of the measures to improve the voltage drops are assumed as follows.

- The shunt capacitors will be installed in 2015 and 2021 respectively in addition to the existing and planned ones resulted from the studies described in Chapter 5 and Chapter 6.
- The installed capacities of the shunt capacitors at each substation in 2015 are shown in Table 5.11 and Table 5.12 (Total: 1,445 MVar)
- The total installed capacity of the shunt capacitors in 2021 is 315 MVar that consists of 9 units of 25 MVar for 150 kV substations and 9 units of 10 MVar for 70 kV substations. The shunt capacitors are basically connected to 150 kV bus-bars at the 150 kV substation and 22 kV bus-bars at the 70 kV substation.
- Table 9.1 shows the assumed unit costs of the shunt capacitors

Table 9.1 Unit Costs of the Shunt Capacitors

kV	**Unit size [MVar]**	**Electrical Works (Rp.)**	**Civil Works (Rp.)**	**Total (Rp.)**
150	50	7,650,000,000	2,220,000 ,000	9,870,000 ,000
150	25	5,970,000,000	1,100,000,000	7,070,000,000
70	10	3,200,000,000	700,000,000	3,900,000,000
(22)	10	1,850,000,000	200,000,000	2,050,000,000

※ The cost of the compact type shunt capacitors from the Japanese standard is applied for 22 kV.

- Table 9.2 shows a rough cost estimation of the Central VQC scheme

Table 9.2 Rough Cost Estimation of Central VQC Scheme

Items	Cost
Software (including middleware and factory tests)	160 million JPY
Hardware (including maintenance in factories)	50 million JPY
Total	210 million JPY

- Table 9.3 shows the conditions for a rough cost estimation of the centralized voltage and reactive power control system.

Table 9.3 Conditions for Rough Cost Estimation of Centralized Voltage and Reactive Power Control System

System configuration	Installation of a server computer in JCC (a redundant system) Installation of a terminal unit in each ACC (total 5 units)
Monitoring item	Busbar voltage at substation and reactive power of interconnection line, etc.
Voltage control device	Generator terminal voltage / Tap position of transformer / shunt capacitor and reactor
Operation	Whole Java-Bali system are controlled by JCC Data acquisition and control signal output to voltage controller in ACC operating area are implemented by ACC JCC exchanges data with ACC via communication data link between JCC and ACC
Telecommunications facilities	Excluding telecommunications facilities costs between JCC and ACC Excluding telecommunications facilities costs between JCC/ACC and the power station/substation

- Table 9.4 shows a rough estimation purchasing independent type of VQCs.

Table 9.4 A Rough Price Estimation of Independent Type VQCs

	for 500/150kV Substation	for 150/70kV Substation
Functional Unit	US$ 168,575	US$ 312,175 Function Unit & I/O Unit in 1 Unit
Input/Output Unit	US$ 262,227 2 Unit / 1 Substation	
Backup Voltage Regulator	US$ 41,624	US$ 41,624
Total	US$ 472,425	US$ 353,799

(Without Installation Cost)

- Table 9.5 shows requirements for independent type of VQCs.

Table 9.5 Requirements for Independent Type of VQC to Estimate the Price

	for 500/150kV Substation	for 150/70kV Substation
Installing Sites	1 equipment / 1 site × 34 sites	1 equipment / 1 site on which capacitors installed × 51 sites
Functional Requirements	・Integral control by primary voltage ・Integral control by secondary voltage ・Time Scheduling of Setting Value × 5 sets ＋ a blackstart setting	・Integral control by reactive power on primary side ・Integral control by secondary voltage ・Time scheduling of Setting Value × 5 sets
	・High Speed Capacitors / Reactors Control by primary voltage and continuing time ・Weekday and holiday setting, automatic time adjustment ・Manual switching of Voltage Detecting Buses, control banks	
Specified equipment for controlling	On load tapchagers of transformers / Shunt capacitors and reactors	
Components	1 VQC unit with 1 Backup voltage regulator for each substation	

Table 9.6 shows the estimated cost for each measure.

Table 9.6 Roughly Estimated Cost for Each Measure

Plan	A	B	C
Static Capacitor	38.0 million USD in 2015 8.2 million USD in 2021	38.0 million USD in 2015 8.2 million USD in 2021	38.0 million USD in 2015 8.2 million USD in 2021
VQC	-	Local VQC 34.1 million USD	Central VQC 2.19 million USD
Total	46.2 million USD	80.3 million USD	48.39 million USD

* 1USD = 96.1 JPY = 10,000 IDR

According to PLN’s opinion, PLN is able to finance based on their budget and has the capability to implement conventional countermeasures such as capacitors, however, they need to conduct further studies for more advanced countermeasures such as an online security assessment and monitoring.

9.2 Benefits of Taking Measures

Benefits of taking measures for system voltage improvement are considered as follows.

- Normal operation of power system user’s electric machines and power generators and securing their long lifespan
- Avoiding a black-out caused by a voltage collapse
- Transmission line loss reduction

As mentioned in section 4.2.3, based on the results of the simulation of the current power system, there would be the possibility of a large blackout caused by a voltage collapse if any countermeasures to prevent voltage drops are not taken in the Jakarta metropolitan area. Thus, it is considered that the benefits of taking measures to improve voltage include the avoidance of blackouts. However, its quantitative evaluation is equivalent to the the cost of the social and economic damages due to a power supply interruption which is difficult to predict. And also, it is difficult to grasp the quantitative social and economic damage of the normal operation of the user's electric machines and power generators. Thus, in this study, only the benefits of loss reduction is considered to be a benefit that can be calculated quantitatively excluding the benefits brought about due to the avoidance of blackouts and the benefits from normal operation of user's machines.

Assumption in calculating benefits derived from transmission loss reduction are set out as follows.

- Evaluation period is set as 15 years from 2015 when the measures are assumed to be implemented. PLN states that the life time of the facilities of the countermeasures is basically 30 years, however, the half of this evaluation period is used for this study in consideration of the urgency of implementing the measures with the shunt capacitors.

- The transmission line loss reduction is calculated from the results of the simulation of 2015 in comparison of cases with shunt capacitors and cases without them as the countermeasures to prevent system voltage drops during Jakarta peak demand period. The results shown in section 5.2.4 indicates that the transmission loss reduction is 84 MW during the peak time in 2015.

- The following conditions are set out for the energy loss calculation (MWh) from the peak loss (MW).
  - Load Factor: 70% (70-71% assumed in RUPTL)
  - Loss Factor = 0.15 x Load Factor + 0.85 x Load Factor ^2(= 0.5215)
  - Annual loss (kWh) = peak loss (kW) x 8760 (h) x Loss Factor

- The effect of the installation of the shunt capacitors on the loss reduction becomes larger in latter years than the previous ones due to the increase of power demand. However, its effects are assumed constant from 2015 when the countermeasures are implemented for the severe side evaluation.

- A discount rate is assumed to be 10%

- 0.06 USD is set as the unit loss value through the discussion with PLN

Table 9.7 shows the results of the calculation of the benefits per the transmission line loss reduction.

Its present value at 2015 evaluated for 15 years will total 135 million USD.

Table 9.7 Result of Calculation of Benefit by Transmission Line Loss Reduction

Year	Loss at Peak	Annual Loss	Loss Value	After Discount	Year	Loss at Peak	Annual Loss	Loss Value	After Discount
	MW	MWh	million USD	million USD		MW	MWh	million USD	million USD
2015	84	383740.6	23.0	23.0	2023	84	383740.56	23.0	10.7
2016	84	383740.6	23.0	20.9	2024	84	383740.56	23.0	9.8
2017	84	383740.6	23.0	19.0	2025	84	383740.56	23.0	8.9
2018	84	383740.6	23.0	17.3	2026	84	383740.56	23.0	8.1
2019	84	383740.6	23.0	15.7	2027	84	383740.56	23.0	7.3
2020	84	383740.6	23.0	14.3	2028	84	383740.56	23.0	6.7
2021	84	383740.6	23.0	13.0	2029	84	383740.56	23.0	6.1
2022	84	383740.6	23.0	11.8	Total (Million USD)				135.1

9.3 Technical Comparison of Countermeasures against Voltage Drops

Table 9.8 shows a technical comparison of each countermeasure to prevent voltage drops. (mentioned in Section 7.5)

Although it is reasonable to apply countermeasure A at present, it will be necessary to change the option to countermeasures B or C in response to the system growth, network complication, and increase of control equipment. When comparing the cost, Countermeasure C is less expensive than countermeasure B. When having priority over speedy recovery after a large disturbance such as a fault, Study Team recommend to install additional shunt capacitors and independent VQCs in Jakarta and Western Java.

Table 9.8 Technical Comparison of Countermeasures

Aspects	Countermeasure A	Countermeasure B	Countermeasure C
	Installation of shunt capacitors	Adding to the installation of shunt capacitors, a Local VQC scheme is applied.	Adding to the installation of shunt capacitors, a Central VQC scheme is applied.
Installation	Costs for installation of the telecommunication between JCC and ACC will not be incurred.Installation of shunt capacitors	Costs for installation of the telecommunication between JCC and ACC will not be incurred.	Along with the installation of shunt capacitors, a Central VQC scheme is applied.
Voltage Regulation, Operation of Control Device	Operators have to Control the generators, Shunt Capacitors / Reactors, Taps of Transformers manually. In response to the system complication, operation of voltage regulation will increase. Voltage regulation will depend on the operators Experience and Instinct, so the quality of voltage will not be equal or regulation might be late.	In the case of large disturbance, VQCs will respond to the voltage deviation soon. Setting of each substation or power station has to be determined in coordination with other substations or power stations.	Because the control interval is 30 sec. to 2 minutes, in case of a large disturbance, the recovery of the voltage fluctuation takes a certain amount of time. Setting of each substation has to be determined in coordination with other substations. It is possible to control the system voltage in consideration of minimizing the active power loss of the target point or all the system. As the premise of central control, state estimation has to be convergent. So a deficiency of telemetering or input data causes inadequate control.
Evaluation	F	E	G

Legend E:Excelent, G:Good, F:Fair

Chapter 10 Recommendations

10.1 Installation of Shunt Capacitors

Following are recommended for the installation of the shunt capacitors.

- Full implementation of the installation of the shunt capacitors of the on-going 475 MVar and planned 1,070 MVar by PLN and P3B
- Additional installation of the shunt capacitors of 1,445 MVar up to 2015 and 315 Mvar up to 2021
- Enhancement of power supply reliability by selecting the installation locations for the shunt capacitors through utilizing power cables from the perspective of future system configuration, confirming the specifications of circuit breakers and selecting the shunt capacitors with high endurable performance for electric surges

In addition to the on-going 475 MVar and planned 1,070 MVar installation by PLN and P3B, the amount of shunt capacitors requiredby 2015 is shown in Table 5.11 and Table 5.12 (a total of 1,445 MVar) and 315 MVar is also required by 2021.

It is important to select their installation locations in consideration of the future facilities layout/composition of substations securing the spaces for emergency works. It is possible to utilize the lands of the substations by applying the power cables for connections of shunt capacitors. Circuit breakers for shunt capacitors should be designed in consideration of the switching surges flowing into the facilities by frequent switching operation. For those kinds of facilities, the number of failures can be reduced by applying the shunt capacitors with high enduring specifications for electric surges and by confirming switching abilities of their circuit breakers.

A we shall see in section 10.4, annual review for reactive power sources plan is recommended.

10.2 Voltage Control and System Monitoring

10.2.1 Voltage Control in the Power Station and Substation

The following are recommended regarding voltage control in the power station and substation.

- Changing the rule to authorize making a decision on tap position of the step-up transformer to P3B for new and additional generators including the IPP power station.
- Changing the voltage control mode of the large capacity generators from AVR to AQR

P3B has plans to change the tap position of the generator step-up transformer with an off-load tap changer to a higher tap position in the Suralaya and Muaratawar thermal power station. System voltages are expected to be improved by expediting the change in the tap position of the step-up transformer to a higher tap position in order to raise the system voltage. Studies on the tap position of the step-up transformer for new and additional generators are mainly performed by the PLN Certification Department and rarely performed by a local independent certification company. Currently, P3B is not involved in this study and the nominal tap position is selected for the step-up transformer of new and additional generators in many cases.

Currently, JCC and ACC request power stations to increase the generator reactive power outputs up to the limit of the facilities when the system voltage drops significantly due to the demand increase. If the system voltage will be improved due to power system reinforcements and the installation of shunt capacitors, the moderate voltage control method of power generators according to the demand and system conditions will be required. Currently, AQRs are applied to generators at the Cirata hydro power station. The application of AVR to large capacity generators such as Cirata hydro power station is one of the options in order to more contribute to the voltage stability by these generators.

10.2.2 Application of Voltage Control Scheme

Following is recommended for the voltage and reactive power control scheme applied in the near future.

- When having priority on speedy recovery after a large disturbance in system with a large number of controlled equipments and its complicated characteristics, it is recommended to install additional shunt capacitors and apply independent VQCs in Jakarta.

Currently, shunt capacitors are always-on on weekdays and always-off on holidays, switched manually via EMS in JCC and ACC. This On/off switching should be operated depending on the demand fluctuation in response to the expected increase of shunt reactors and capacitors. Accordingly, automatic on/off switching will be necessary to reduce the workloads of operators. In addition, when the system voltage is improved, automatic adjustment for tap positions of the transformers will be necessary along with coordinated controls between power stations and substations.

As for the application of the centralized voltage and reactive power control scheme, following conditions are required.

i) Appropriate maintenance of online data and network data

ii) Achieving an accurate state estimation in EMS

iii) Installation of telecommunication facilities between JCC/ACC and the power station/ substation

When the above conditions are met and there is a necessity for voltage control with consideration of reducing transmission losses within the power system or transmission facilities, study on the application of the centralized control scheme is recommended .

Similar conditions are required in applying PMU such as achieving an accurate state estimation in EMS and the installation of telecommunication facilities.

10.2.3 System Monitoring Function

Following is recommended for the system monitoring function.

- Enhancing network data maintenance for SCADA system in order to have the security analysis function operate more efficiently based on the results of the state estimator

Although state estimator and security analysis function are equipped with SCADA installed in JCC,the results of the state estimator are not accurate since the maintenance of network data is not enough due to the rapid expansion of the power system. As a result, the security analysis is not working sufficiently. Among others, parameters for the step-up transformers and transmission lines need to be inputted appropriately.

Moreover, SCADA online data seems to have some errors including missing data, error of positive/negative signs and the multiplying factor. The maintenance of online data can offer more accurate state estimator results. The Study Team recommends that P3B allocates more human resources and financial resources to the maintenance of network data and online data.

10.3 Management of Facility and Analysis Data

Following are recommended regarding the management of facilities and analysis data.

- Preparing a data book of facilities including generators, transmission lines, transformers, and shunt reactor/capacitor, etc.
- Establishment of a workflow for the appropriate maintenance of analysis data.

In P3B, facility management division and the protective relay division are in charge of facility data such as the transmission line, transformer, and shunt reactor / capacitor, etc. The Study Team recommends that the P3B operation system division prepares a data book of facilities in order to manage facility data appropriately.

The Study Team also recommends that P3B establish a workflow to modify analysis data used in the planning system division based on the actual parameters when new and additional facilities start operations.

10.4 Periodical Planning of Reactive Power Sources and Its Review

The following is recommended for the plan of the reactive power sources

- Annual or periodical planning of reactive power sources such as installation of shunt capacitors

In order to maintain the system voltage adequately, additional reactive power sources such as shunt capacitors are required to be installed in accordance with the increase in power demand. It is recommended that planning and review of reactive power sources such as installation of shunt capacitors should be implemented periodically or annually. Its long term plan would not give accurate results since the reactive load forecast is based on the actual measurement data, whereas power demand is increasing sharply.

It is also required that the shunt capacitors and shunt reactors should be planned so as to maintain system voltage in the target voltage ranges in comprehensive consideration of the methodologies of voltage control such as generator terminal voltages, reactive power outputs and tap changers of transformer windings.

10.5 Installation of Power Plants and Transmission Lines in and around Jakarta

Following is recommended for installation of power plants and transmission lines in and around Jakarta

- Ensure steady project implementation of power generators directly connected to the power supply system in Jakarta Metropolitan Area and 500 kV substations in the northern part of Jakarta for maintenance of voltage stability.

In this study, effects of the installation of main power stations and transmission lines/substations are evaluated by calculating the upper limit of power that can be transmitted to Jakarta based on the Java-Bali system model as of 2021. As a result, it was found that Banten thermal power, Bekasi thermal power, Lontar thermal power extension and Upper Cisokan pumped storage power station contribute to the voltage maintenance. Among others, extension of Lontar thermal power plant has a large impact, sinceit supplies power directly to the 150 kV system in Jakarta .

As for transmission lines and substations, newly installed intervals of the 500 kV transmission lines have a large impact on the voltage maintenance, especially 500 kV transmission lines between Muara Tawar-Priok-Muara Karang-Duri Kosambi, Muara Tawar-Priok substation. Installation of 500 kV substations located on those routes also has significant impact. Moreover, the transmission line between 500 kV Duri Kosambi-Kembangan-Balaraja substation is effective, which bypass the power flow from west to the northern part of Jakarta.

10.6 Frequency Conditions and Recommendation

10.6.1 Monitoring Values and Status

The following are recommended to realize the economic load dispatching.

- Installation of the application program of ELD into the SCADA system
- Collection of necessary data for the ELD program
- Study of institutions to realize the ELD program

Although JCC continually monitors enough data such as frequency, area control error (ACE), load frequency control (LFC) etc., it does not have ELD function of SCADA to control the frequency or demand and supply balance, which currently relies on the operators' knowledge and skill.

In order to utilize ELD function, JCC needs to install the ELD program, input the data for the generators such as the types of fuel, prices of fuel, thermal efficiency, generator efficiency based on the water level of the dam, ramping rate and so on. Furthermore, JCC also needs to provide data transmission such as generator output, the water level, the acceptable signal of LFC (up link), and the instruction value of the generator output (down link). It is necessary to frame a system to put the economic dispatching into practice.

This ELD function enables optimal dispatching of generators and positive economic impact derived from reducing fuel costs.

10.6.2 Securement of the Spinning Reserve

The following are recommended to secure the spinning reserve.

- Study of the system to have the incentive to secure the appropriate spinning reserve of the Java-Bali system
- Development of the generation control system to enable LFC operation
- Consolidated list of conditions concerning LFC operation

Currently, JCC has an LFC function to control PLN group's generators, but on the other hand, IPPs do not respond to the LFC control since the agreement of monetary compensation has not been reached.

Although the power plants are required to keep the LFC above 2.5% as stipulated in the Grid Code, there are some cases where it is difficult to secure the LFC amount when maximum power output has the priority.

The Study team recommends creating rules for giving incentive for power producers to provide their generation capacity, developing generators which have large amount of LFC such as Cirata Hydro power plant, and improving existing generators to meet LFC target such as the case of Suralaya power station. Considering maintenance outage of the generators, enough amount of LFC is necessary.

Table 10.1 Example of Power stations and Applied Speed Droop

Power Station	Speed Droop	Constraints
Cirata Hydro	4%	LFC is unavailable under 30MW
Suralaya Coal	6.6%	

Table 10.1 shows an example of the applied speed droop. The smaller the value is, the higher the sensitivity to the frequency deviation become. For example, Cirata Hydro power station is large enough to handle frequency deviation between 30 to 126MW. It is reasonable to set Cirata at a lower value than Suralaya since its frequency control capability is higher than that of Suralaya. The Study Team recommends listing up the characteristics of generators such as the speed droop, LFC capability etc., and to share the knowledge among the control centers, review the list periodically under the integrated management of JCC.

10.6.3 Frequency Control Method

Following is recommended to enable the quick response of the generators.

- Changing the generation instruction from manual control via phone to direct control via SCADA

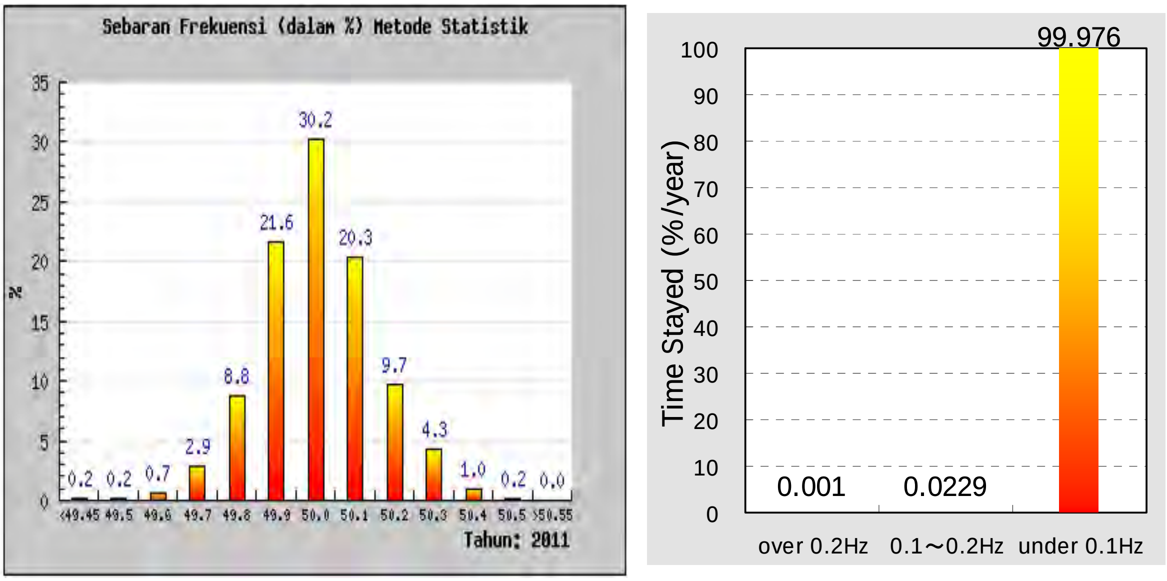
JCC is responsible for dispatching of the generators and regulates the output of power stations directly over the phone. In the case of power stations connected to 150 or 70kV system, JCC regulates the power output through ACC. According to the site survey, JCC requests the output regulation every 15 to 20 minutes during the morning hours when there is a large demand increase. This manual control method may lead to the frequency deviation since there is a difficulty in responding unexpected frequency deviation and demand fluctuation.

Table 10.2 Generator Output Regulation

Voltage Level	Order by Whom	Operation by Whom	Tool of Order
500 kV	JCC	Operators in Power Stations	Telephone
150-70 kV	ACC		Telephone

In order to improve the situation, it is effective to apply the on-line regulation via SCADA by inputting the power output value or mouse clicking for frequent dispatching. In consideration of expected power development with coal power plants, it will be more difficult to catch up with the demand since those generators are not able to increase the power rapidly. The Study Team recommends direct dispatching of generators in JCC via SCADA .

10.6.4 Proper Understanding of Limitation of Generators



Java Bali System
(1 January 2011 – 31 December 2011)

Tokyo Electric Power Company
(1 April 2010 – 31 March 2010)

Source: Evaluasi Operasi Sistem Jawa Bali 2011 (Left), Tokyo Electric Power Company (Right)

Figure 10.1 System Frequency Distribution

The following are recommended to enable effective dispatch using forecasts for the next several minutes to hours.

- Collecting the information on restrictions which influence the generator output
- Sharing the above information among the operators

When monitoring the operational reserve, it is important to check not only the reserve for the next several hours, but for the next several minutes which could be confirmed by monitoring total LFC capability.

In order to respond to the fluctuating demand, it is required to confirm the increasing rate of the generator output. For example, Suralaya thermal provides a three ramping rate, 2, 5 or 10 MW/min selectable.

Concerning coal power plants, output regulation is prohibited when the number of mills is changed for 10 to several tens of minutes. The same thing can be said of thermal unit over 600MW, when the number of boiler feed pumps changed. During the hammering of the Electrostatic Precipitator or valve test, the generator output cannot be changed either. In the case of LNG thermal power plant, minimum output is limited since it has to constantly burn the Boil-Off gas which is naturally vaporized from the equipment to lower the pressure. Further, minimum output is raised when the LNG carrier arrives. As mentioned above, there are various limitations for each generator.

Given that a number of generators over 600MW will be installed in line with the expansion of Java Bali System from now on, it will become increasingly necessary for the operators to share the knowledge of these restrictions.

Figure 10.1 shows the fluctuation of system frequency both in Japan and Jakarta. TEPCO controls the frequency within the range of 49.9 to 50.1Hz at a rate of 99.976% in a year, which includes 2011.3.11 when the Great East Japan Earthquake occurred. The fluctuation over 0.2Hz was only 221sec.

As seen from the above, we’d like to recommend continuing practices such as sharing information and experiences among the operators to improve the frequency control.

（Column） ELD and LFC

ELD : Economic Load Dispatch

For the frequency control under demand fluctuation in several tens of minutes to several hours (time range called “tertiary control”), operators in the control center forecast the daily demand curve, make the schedule of controlling generator output based on their forecast, and instruct to maintain the frequency according to the schedule.

In these instructions, computerized system enables to select the best combination of changing the generator outputs. Such operation is called “ELD” short for “Economic Load Dispatching” (or “EDC” short for “Economic Dispatch and Control”). It is effective to minimize the generating cost.

LFC : Load Frequency Control

There will be a difference between real and forecasted demand in several minutes to several tens of minutes (time range called “secondary control”) due to demand fluctuation caused by sudden change of weather condition or social activities. When the computerized system in the control center detects the frequency deviation, it controls the generation as appropriate to the deviation. Such control is called “LFC” short for “Load Frequency Control” (or “AGC” short for “Automatic Generation Control”). Securing of generators which are available to respond the LFC signal is effective to maintain the frequency under short term demand mismatch.