Final Report on

Feasibility Study on Adjustable Speed

Pumped Storage Generation Technology

January 2012

Japan International Cooperation Agency (JICA)

Tokyo Electric Power Company

Tokyo Electric Power Services

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Contents

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Abbreviations

Abbreviations	Words
ABB	ABB (former Asea Brown Boveri)
APK	Research Planning and Coordination
AVR	Automatic Voltage Regulator
ASPS	Adjustable Speed Pumped Storage
AS-PSPP	Adjustable Speed Pumped Storage Power Plant
B/C	Benefit by Cost
BDEW	Federal Association of the Energy and Water Industry
C/C	Combined Cycle
CECRE	Control Center of Renewable Energies
DSM	Demand Side Management
EEG	Renewable Energy Sources Act
EEX	European Energy Exchange
EIE	General Directorate of Electric Power Resources Survey and Development Administration
ELES	Elekto Slovenija
EMRA	Energy Market Regulatory Authority
EMS	Energy Management System
EnBW	EnBW Energie Baden-Württemberg
ENEL	Ente Nazionale per l’Energia eLettrica
ENTSO-E	European Network of Transmission System Operators for Electricity
EPS	Engineering, Procurement and Construction
EU	European Union
EUAS	Electric Generation Company
EVN	Vietnam Electricity
FRT	Fault Ride Through
GDP	Gross Domestic Product
GF	Governor Free
GT	Gas Turbine
GTO	Gate Turn Off
HSE	Holding Slovenske Elektrarne
ICB	International Competitive Bidding
IE	Institute of Energy
IEA	International Energy Agency
IPP	Independent Power Producer
JEPIC	Japan Electric Power Information Center
JICA	Japan International Cooperation Agency
LF	Load Factor
LFC	Load Frequency Control
LNG	Liquified Natural Gas
LVRT	Low Voltage Ride Through
MEMR	Ministry of Energy and Mineral Resources
MOIT	Ministry of Industry and Trade
MONRE	Ministry of Natural Resources and Environment
MP	Master Plan
MPI	Ministry of Planning and Investment
NCC	National Control Center
NLDC	National Load Dispatch Center
P3B	Penyaluran Dan Pusat Pengatur Beban
PDP	Power Development Plan

PLN	PT. Perushaan Umum Listrik Negara Persero
PPA	Power Purchase Agreement
PSPP	Pumped Storage Power Plant
PSS	Power System Stabilizer
PV	Photovoltaic Cell
REE	Red Electrica De España
RUPTL	Long Term Electricity Development Plan
RWE	RWE (former Rheinisch-Westfälisches Elektrizitätswerk)
SCADA	Supervisory Control and Data Acquisition
SCR	Silicon Controlled Rectifier
SENG	Soške Elektrarne Nova Gorica
SPO	State Planning Organization
ST	Steam Turbine
TEAS	Turkish Electricity Generation and Transmission Company
TEDAS	Turkish Electricity Distribution Company
TEIAS	Turkish Electricity Transmission Corporation
TEK	Turkish Electricity Authority
TEPCO	Tokyo Electric Power Company, Inc
TEPSCO	Tokyo Electric Power Services Co., Ltd.
TETAS	Turkish Electricity Trading and Contracting Co.Inc
TL	Türk Lirası
TOR	Terms Of Reference
TSO	Transmission System Operator
TUBITAK	The Scientific and Technological Research Council of Turkey
TYNDP	Ten Year Network Development Plan
UCTE	Union for the Coordination of Transmission of Electricity
USC	United States Cent
USD	United States Dollar
VCGM	Vietnam Competitive Generation Market

Abbreviations	Words	Turkish
APK	Research Planning and Coordination	Araştırma Planlama Koordinasyon
BOTAS	Petroleum Pipeline Corporation	Boru Hatları ile Petrol Taşıma A.Ş.
DPT	State Planning Organization	Devlet Planlama Teşkilatı Müsteşarlığı
DSI	General Directorate of State Hydraulic Works	Devlet Su İşleri
DGP	Balancing Power Market	Dengeleme Güç Piyasası
EIE	General Directorate of Electric Power Resources Survey and Development Administration	Elektrik Isleri Etüt Idaresi Genel Müdürlügü
ETKB	Ministry of Energy and Natural Resources	Enerji ve Tabii Kaynaklar Bakanl
EPDK	Energy Market Regulatory Authority	Enerji Piyasası Düzenleme Kurumu
EUAS	Electric Generation Company	Elektirik Üretim Anonim Şirketi
KCETAS	Kayseri Region Electricity Company	Kayseri ve Civari Elektrik T.A.S
MTA	General Directorate of Mineral Research & Exploration	Maden Tetkik ve Arama Genel Müdürlüğü
OIB	Privatization Administration	Özelleştirme İdaresi Başkanlığı
PMUM	Market Financial Settlement Center	Piyasa Mali Uzlastirma Merkezi
PYS	Market Management System	Piyasa Yönetim Sistemi
TAEK	Turkish Atomic Energy Authority	Türkiye Atom Enerjisi Kurumu

TEAS	Turkish Electricity Generation and Transmission Company	Türkiye Elektrik Anonim Şirketi
TEDAS	Turkish Electricity Distribution Company	Türkiye Elektrik Dağıtım Anonim Şirketi
TEIAS	Turkish Electricity Transmission Corporation	Türkiye Elektrik İşleri Anonim Şirketi
TEK	Turkish Electricity Authority	Türkiye Elektrik Kurumu
TETAS	Turkish Electricity Trading and Contracting Co.Inc	Türkiye Elektrik Ticaret ve Taahhüt A.Ş.
TKI	Turkish Coal Enterprises	Türkiye Kömür İşletmeleri
TTK	Turkish Hardcoal Authority	Türkiye Taşkömürü Kurumu
TÜBİTAK	The Scientific and Technological Research Council of Turkey	Türkiye Bilimsel ve Teknolojik Araştırma Kurumu

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Chapter 1 Outline of the Study

1.1 Background of the Study

According to the "New Growth Strategy" issued by the Cabinet on June 18, 2010, it is stated that the technologies and experiences in the field related to environment, which Japan has strength, are to be utilized as an engine for sustainable development of Asia, as one of the strategies. In the field of energy, it is known that Japan has comparative advantage in the technology of Adjustable Speed Pumped Storage generation. This Study focus on surveying the feasibility of application of the Adjustable Speed Pumped Storage generation technology to Turkey and Asian countries.

1.2 Purpose of the Study and TOR

1.2.1 Purpose of the Study

Feasibility of introducing Adjustable Speed Pumped Storage generation system to Asian region is studied, for the purpose of contributing project formation in Asia in the future. Expected outcomes of the Study are following.

- Effects of introducing Adjustable Speed Pumped Storage generation system, in network operation and economic aspect, conditions of application, and so on are clarified.
- Feasibility of application of the Adjustable Speed Pumped Storage generation system to Asia is clarified.

1.2.2 Target Area

The target area of the Study is Europe, Turkey, and Asia.

1.2.3 TOR

Contents of the study are stated following.

(a) Investigate Adjustable Speed PS Generation Technology

Through the questionnaire etc., ASPS Generation technologies of Japanese manufacturers are investigated.

(b) Site Investigation in Europe

Situations in Europe, such as renewable energy development, PSPP operation, power plant development, PSPP development, network operation including international interconnection, are investigated. Following sites will be investigated.

- ❖ PSPP Generation Company in Germany, PSPP in Austria
- ❖ TSO and Wind Power Plant in Spain
- ❖ TSO and PSPP in Italy, Adjustable Speed PSPP in Slovenia

(c) Site Investigation and Discussion on Study Result in Turkey

Based on the site investigation, the effects of network operation and economy will be clarified.

(d) Criteria of Introducing Adjustable Speed PSPP

Based upon the investigation of ASPS generation technology and the result of feasibility of introducing ASPS in Turkey, the criteria of introducing ASPS, which is able to apply in other countries, is studied.

(e) Feasibility of Introducing Adjustable Speed PSPP in Asia

Following situations in Asia are investigated in order to collect the latest information which cannot be obtained in the work in Japan, and the results of feasibility of introducing ASPS are explained and discussed with related organizations.

- ❖ Operation of PSPP
- ❖ Power Plant development, PSPP development
- ❖ Network operation including international interconnection

Vietnam and Indonesia are planned to be the target countries.

1.3 Methodology of the Study

1.3.1 Overall Flow of the Work

Figure 1.1 shows the basic flow of the Study and Figure 1.2 shows the outline of the schedule.

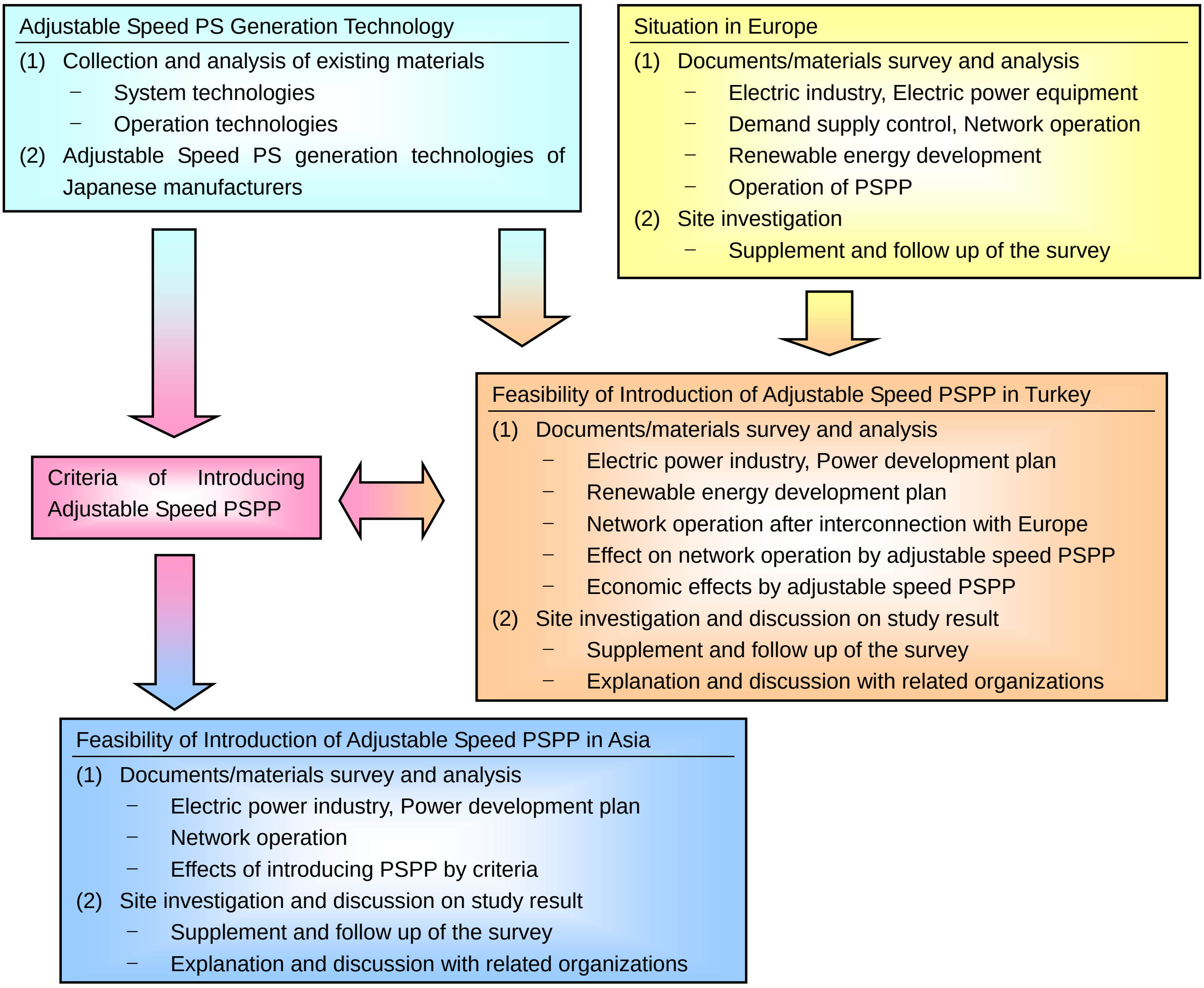


Figure 1.1 Basic Flow of the Study

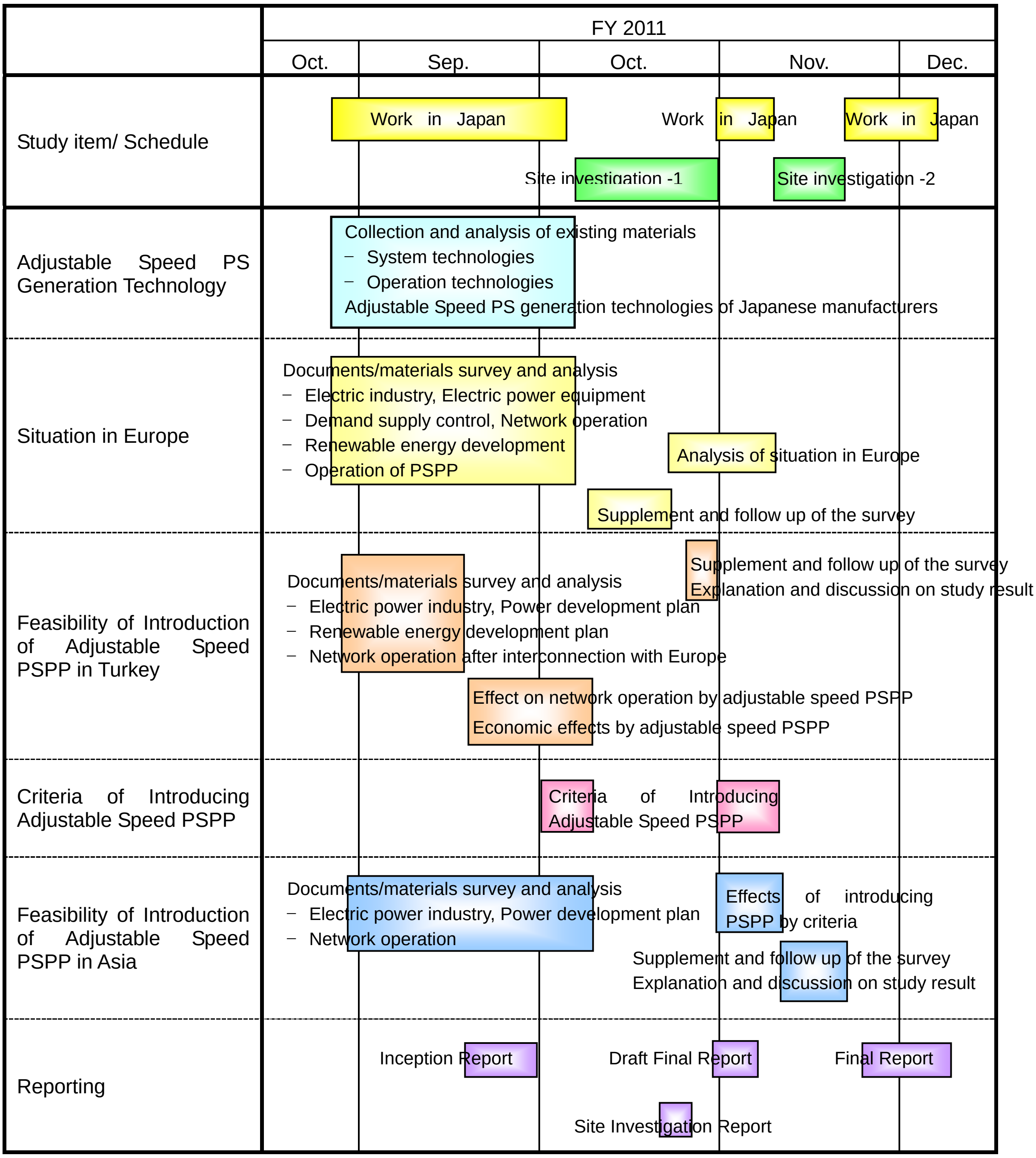


Figure 1.2 Outline of the Schedule

1.4 Study Organization and Site Investigation Achievements

1.4.1 Organization of the Study Team

Figure 1.3 shows the organization of the Study Team and the Staffing Plan, respectively

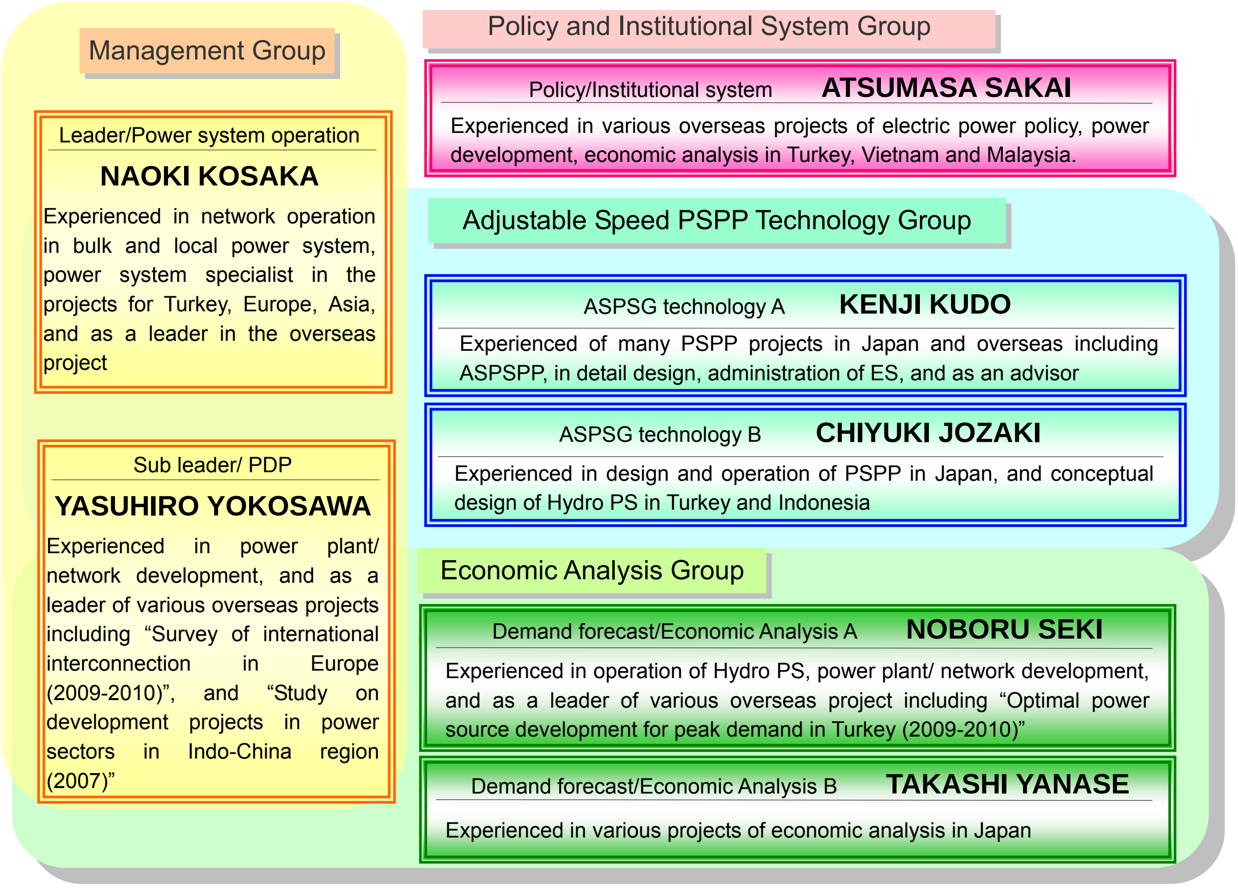


Figure 1.3 Organization of Study Team

1.4.2 Site Investigation Achievements

The First Site Investigation was conducted in October 11-29, 2011.

Oct 12 RWE (Power Producer in Germany)
Oct 13 REE (TSO in Spain)
Oct 14 Eurus Energy (Wind Power Plant Operator in Spain)
Oct 14 Kops II PSPP (Austria)
Oct 17 Entracque PSPP（ENEL, Italy）
Oct 19 Terna (TSO in Italy)
Oct 21 Avce PSPP (Slovenia)
Oct 24 JICA Turkey Office
Oct 24-27 EIE
Oct 25-26 TEIAS (TSO in Turkey)
Oct 26 Workshop on Adjustable Speed PSPP at EIE
Oct 27 EMRA
Oct 27 EUAS（Power Producer in Turkey）

The Second Site Investigation was conducted in November 13-19, 2011.

Nov 14 JICA Vietnam Office
Nov 14 EVN (Power Company in Vietnam)
Nov 15 Institute of Energy
Nov 15 NLDC (TSO in Vietnam)
Nov 15 MOIT
Nov 17 P3B (Network operator for Java and Bali of Indonesia)
Nov 17 JICA Indonesia Office
Nov 18 PLN (Power Company in Indonesia)

Chapter 2 Adjustable Speed Pumped Storage Technology and Advantages in Power System Operation

2.1 Features and Installation Record of Adjustable Speed Pumped Storage Power Plant

2.1.1 Technical Features of Adjustable Speed Pumped Storage System

Adjustable Speed Pumped Storage system (ASPS system) allows input power to be adjusted in pumping operations in addition to general features of conventional pumped storage power plants for peak demand. Furthermore, in both generating and pumping operation, ASPS system has the ability to control the output and input power more quickly than conventional pumped storage power plant. The main features of ASPS are as follows.

- Figure 2.1shows a comparison of ASPS system and Constant speed pumped storage system (Conventional pumped storage system). The main difference between the two systems is in the excitation and the rotor structure of the generator-motor.

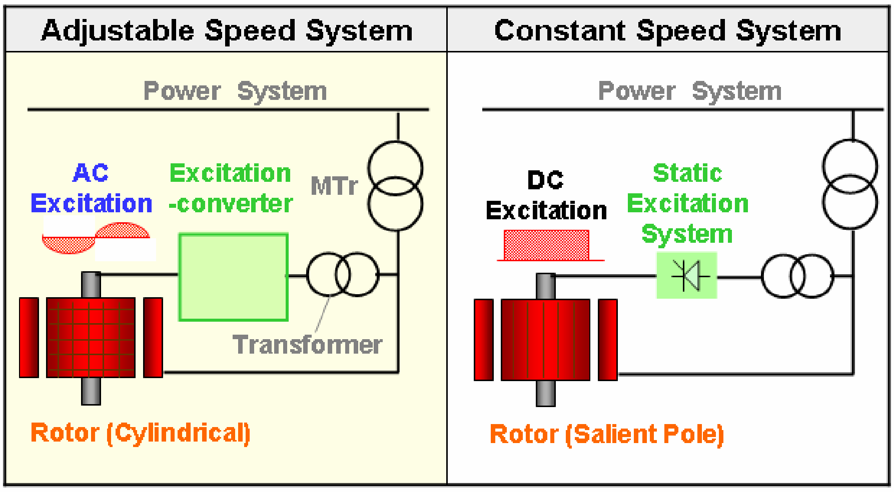


Figure 2.1 Comparison of System Configuration

- In Constant speed pumped storage system, the rotor of the generator-motor is composed of salient pole rotor windings and the static excitation system supplies direct current to the rotor winding.

- On the other hand, in ASPS system, the rotor of the generator-motor is cylindrical type, consisting of three-phase winding. Through the control of the alternating excitation current frequency supplied to three-phase winding by the excitation converter, the rotor speed is adjusted.

- By three-phase alternating current supplied to the rotor of the generator motor, the rotating magnetic field is generated on the rotor. When this rotating speed of the magnetic field on the rotor, mechanical speed of the rotor and rotating speed of the magnetic field of the stator are defined as n2, nr and n1 respectively as shown in the Figure 2.2, the relationship between n2, nr and n1 is shown as n1=n2+nr.

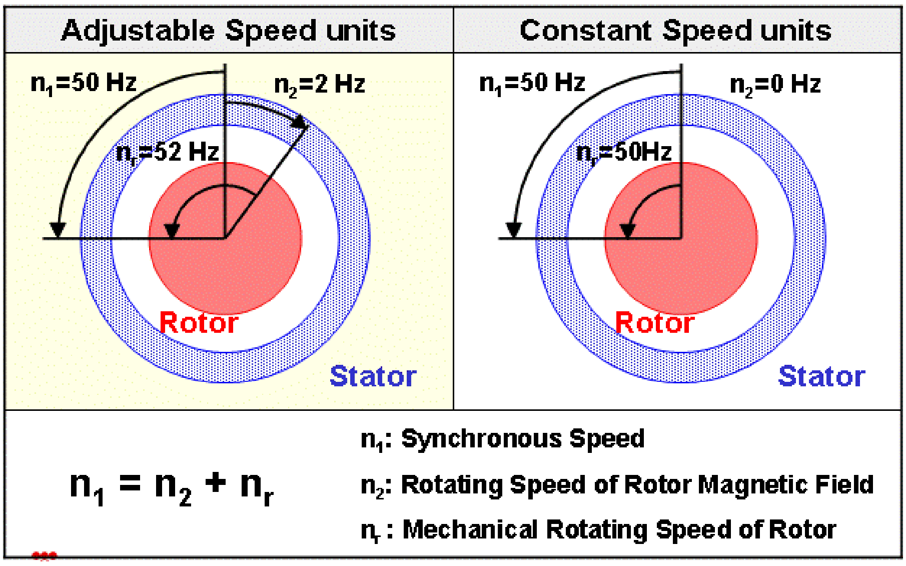


Figure 2.2 Relation between synchronous speed and rotating speed

- In other words, when synchronous speed is defined as n1, n2 is the subtraction of nr (mechanical speed of the rotor) from n1. Consequently if the rotor winding is excited at low frequencies equivalent to n2, the rotor can be rotated at any mechanical speed as far as the generator-motor is synchronized with the power system.

- There are two types of excitation system for supplying three-phase alternating current to the rotor winding. One is the inverter/converter type. Here, after 50Hz or 60Hz AC power is rectified to DC power, the DC power is converted to low-frequency AC power. The other is cycloconverter type. Here, 50Hz or 60Hz AC power is converted directly into low-frequency AC power.

ASPS system can control input power in pumping operation by adjusting the rotating speed of the generator-motor. Due to this unique power control, the ASPS system can contribute to AFC operation during low load period of night time and weekend instead of a number of existing thermal power plants. In addition, ASPS system will play an important role in absorbing the fluctuations of the power output from renewable energy sources such as wind power and solar power. Hence, in Japan, the benefit of ASPS system has been recognized from the viewpoint of environment as well as operability and economics. The operational benefit of ASPS system is as follows.

- As shown in Figure 2.3, the rotating speed of constant speed machine is invariable, so the relationship between pump head and pump input is defined as a single curve determined by pump characteristics. On the other hand, adjustable speed system can adjust its input power to any point by adjusting the rotating speed because pump input varies in proportion to the cube of rotating speed. Thus, since ASPS system can control input power in pumping operations, ASPS system in pumping mode contributes to improving Load Frequency Control (LFC) capacity in power system.

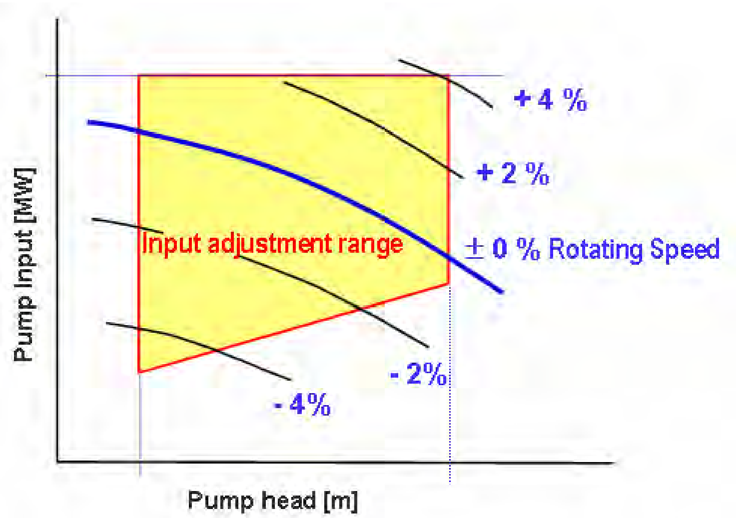


Figure 2.3　Relation between Pump Head and Motor Input

- By adjusting the rotating speed of the pump-turbine optimally according to head and discharge characteristics, ASPS system can operate at the best efficiency point (see Figure 2.4). Moreover, Turbine vibration and cavitation can be greatly suppressed during operation at low load or low head condition, so ASPS system can expand partial load range and ASPS system in generating mode contributes to improve LFC capacity in power system.

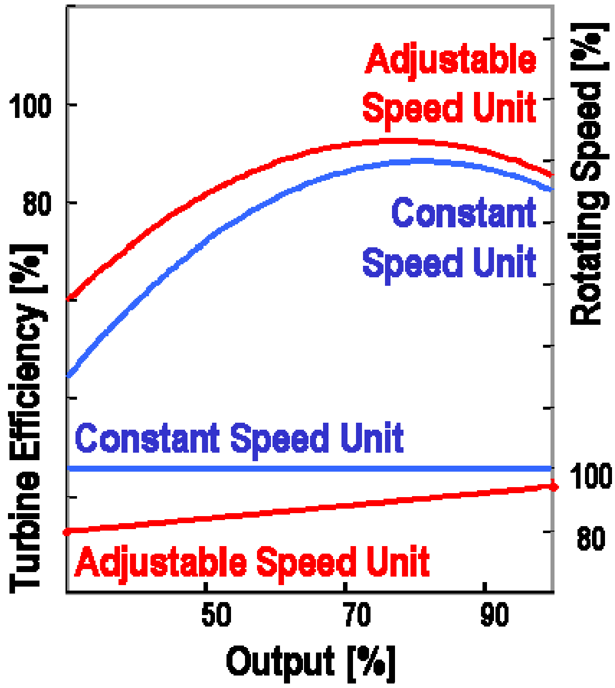


Figure 2.4 Improvement of Efficiency at Turbine Operation

- By utilizing the inertia energy of the rotor, power input/output can be controlled rapidly, so ASPS system is able to contribute to the stabilization of the power system.

2.1.2 Experiences of Adjustable Speed Pumped Storage System

As the wind power plants and solar power plants increase in order to reduce CO2 emission, necessity for additional power sources for supply control. From this background, opportunity of introducing ASPS, which has advantage in controlling its output, is increasing both within and out of Japan. Table 2.1 shows the commissioned ASPS project, and Table 2.2 shows the planned ASPS project.

As the Table 2.1 shows, it is clear that most of the ASPS system have been installed in Japan by Japanese manufacturers. So far, Tokyo, Hokkaido, Kansai Electric Power Companies, Electric Power Development Corporation, and Kyushu Electric Power Company have already installed ASPS systems, and other projects of ASPS are started in Kansai, Hokkaido and Tokyo Electric Power Companies, and in addition, Chubu Electric Power Company is considering installing it.

There are many projects of ASPS in overseas as well. In the United States, there are couples of ASPS projects in California and other states, and in Europe, Switzerland and Portugal plan to install ASPS systems. Regarding Japanese manufacturer, Mitsubishi Electric Corporation has supplied the 200MW generator for ASPS in Slovenia.[1]

Table 2.1 Commissioned ASPS Project

Owner (Country)	Power Station	Capacity * unit	Main Manufacturer	Operation in
Tokyo Electric Power Co.	Yagisawa	80MW * 1	Toshiba	1990
Hokkaido Electric Power Co.	Takami	100MW * 1	Mitsubishi	1993
Kansai Electric Power Co.	Okawachi	320MW * 2	Hitachi	1995
Tokyo Electric Power Co.	Shiobara	300MW * 1	Toshiba	1995
Electric Power Development Co.	Okukiyotsu No.2	300MW * 1	Toshiba	1995
Electric Power Development Co.	Yambaru sea water	30MW * 1	Toshiba	1999
Germany	Goldisthal	300MW * 2	ANDRIZ	2003
Kyushu Electric Po. Co.	Omarugawa	300MW * 4	Hitachi, Mitsubishi	2007
Slovenia	Avce	200MW * 1	Mitsubishi	2010

Table 2.2 Planned ASPS Project

Owner (Country)	Power Station	Capacity * unit	Main Manufacturer	Operation in
Kansai Electric Power Co.	Okutataragi	320MW * 2	Hitachi	2014
Hokkaido Electric Power Co.	Kyogoku	200MW * 1	Toshiba	2015
Switzerland	Nant de Drance	250MW * 4	ALSTOM	2015
Switzerland	Linth-Limmern	250MW * 2	ALSTOM	2015
Portugal	Vende Nova Ⅲ	400MW * 2	SIEMENS	2015
India	Tehri	250MW * 4	ALSTOM	
Tokyo Electric Power Co.	Kazunogawa	400MW * 2	Toshiba	2020

1 The Nikkei Shimbun, 2011/1/19, et.al.

2.1.3 Comparison of Adjustable Speed Pumped Storage Technology

To clarify the need for ASPS system, the advantages and disadvantages of ASPS system as power source for load adjustment is analyzed.

(1) ASPS Technology of Japanese Manufacturers

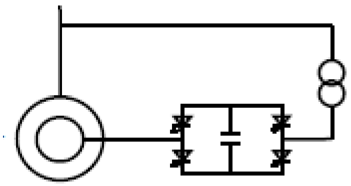
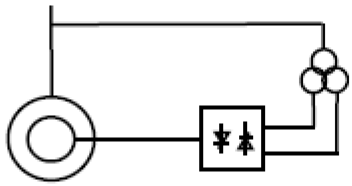
In terms of the basic configuration of ASPS technology, there is no significant difference between Japanese manufacturers. However, in the excitation converter and the rotor coil end support, each manufacturer has his own original system. The outline and the features are described below.

(a) Excitation System

In Constant speed pumped storage system, the rotor of the generator-motor is composed of salient pole rotor windings and the static excitation system supplies direct current to the rotor winding. On the other hand, in ASPS system, the rotor of the generator-motor is cylindrical type, consisting of three-phase winding. Through supplying the alternating current to the three-phase rotor windings from the excitation system, the generator-motor can continue synchronized operation varying the rotor speed.

As shown in Table 2.3, there are two types of excitation system for supplying three-phase alternating current to the rotor winding. One is the inverter/converter type. Here, after 50Hz or 60Hz AC power is rectified to DC power, the DC power is converted to low-frequency AC power. The other is cycloconverter type. Here, 50Hz or 60Hz AC power is converted directly into low-frequency AC power.

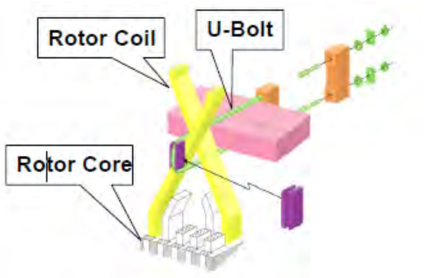
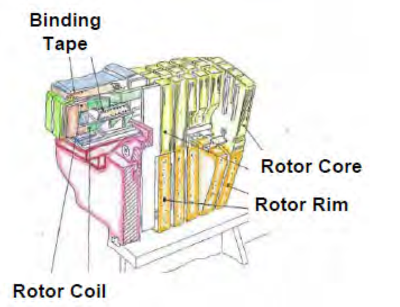
Table 2.3 Comparison of Excitation Converter

Type	Inverter/Converter	Cycloconverter
Figure		
Outline	After 50Hz or 60Hz AC power is rectified to DC power, the DC power is converted to low-frequency AC power. The semiconductor device used in the converter is self-commutated thyristor such as GTO.	50Hz or 60Hz AC power is converted directly into low-frequency AC power. The semiconductor device used in the converter is external-commutated thyristor such as SCR.
Features	✓ No reactive power is required on power supply side. ✓ No need to increase generator-motor capacity for compensating reactive power.	✓ Easy to realize higher inverter output voltage. ✓ Total number of parts of the system is much less than Inverter/Converter type.

(b) Rotor Coil End Support System

In ASPS system, the rotor of the generator-motor is cylindrical type, consisting of three-phase winding. During operation, centrifugal force acts on the rotor coil end. Therefore, the rotor coil end requires a special support structure. As shown in Table 2.4, there are two (2) methods of the rotor coil end support system; one is U-shape bolt support type and the other is Bind-tape support type.

Table 2.4 Comparison of Rotor Coil End Support

Type	U-shape Bolt Support System	Bind-tape Support System
Figure		
Outline	Rotor coil end is suppored by U-bolt and support ring with strong structural strength placed in inner peripheral side of the rotor coil end.	Rotor coil end is supported by the binding tape wound around the outer periphery. The binding tape is made of stainless steel wire or high-strength fiber material.
Features	✓ Short installation time and small displacement ✓ Good cooling and easy maintenance	✓ Simple structure ✓ This system has been used long time in the past in the induction machine, which is technically established.

(2) Comparison of ASPS System and Conventional Pumped Storage System

As ASPS system consists of large excitation equipment and specially designed generator-motor rotor, construction cost of ASPS system is relatively high compared to that of conventional pumped storage system. Based on these, the advantages and disadvantages of ASPS are compared quantitatively in Table 2.5.

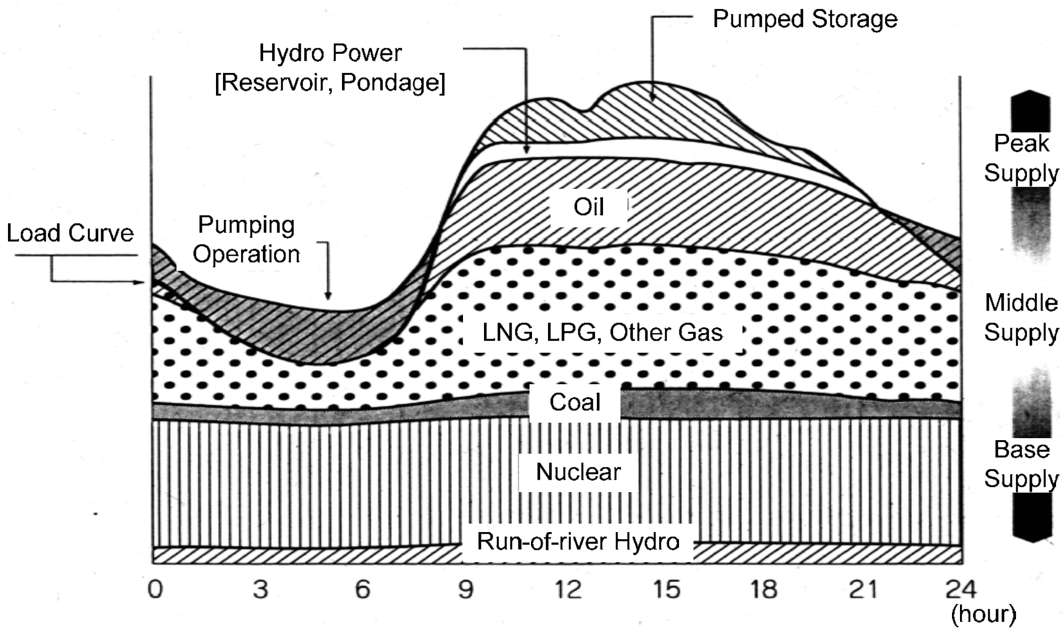
Table 2.5 Comparison of Adjustable Speed System and Constant Speed System

	Constant Speed System	Adjustable Speed System	Remarks
Dam Volume	almost same		Adjustable can utilize water level much lower than Constant.
Cavern Volume	100 %	105 %	Adjustable needs a bit of additional space for Rotor and Excitation system.
Cost for Turbine & Generator inc. Excitation System	100 %	140 %	Adjustable costs a lot for Rotor and Excitation system.
Turbine Efficiency	100 %	0.5% improvement for Max output, much (more) improved 2.5% at partial load	In Turbine mode, Adjustable can operate suitable speed in terms of efficiency
Operation range in turbine mode	50 – 100 %	30 – 100 %	In adjustable, Improvement of turbine characteristics can extend operation range.
Operation range in pump mode	Constant	70 – 100 %	Adjustable make operation range variable (input power changes in proportion to the cube of rotating speed)
Response time of output/input (normal operation)	0 -100% / 60sec	0 -100% / 60sec	Constant depends on turbine characteristics. Adjustable follows the command precisely with electric control.
Response time of output/input (transient)	impossible	20MW / 0.1sec	Adjustable realize fast control by converting rotating energy to electrical energy

2.2 Roles of Adjustable Speed Pumped Storage Power Plant in Demand-Supply Control and Power System Operation

2.2.1 Demand-Supply Control Taking Account of Characteristics of Power Sources

For the Demand-Supply control of the electric power, generally, operation plans of each power plant are determined by the preceding day to match the forecasted demand of the target day, taking account of fuel plan, facility maintenance plan, weather forecast, and so on. Since the fuel price, the efficiency, and the output control rate are different by each power source, the economically optimal generation plan is created considering those conditions. Figure 2.5 shows the operation of each power source to deal with the power demand change in Japan.



Run-of-river Hydro:	Generate by the natural flow of the river
Nuclear:	Operate at rated output
Coal Fired:	Full output as base supply
LNG Fired:	With good operatability, used as base and middle supply
Oil Fired:	Considering economic efficiency, used as peak supply
Reservoir, Pondage Hydro:	With hourly-based control operation, used as peak supply
Pumped Storage:	With good controllability, used to meet rapid demand change

Figure 2.5 Demand-Supply Control for each Power Sources

On the target day, outputs of power plants are controlled in accordance with the actual change of demand of electricity. As the result of keeping the demand and supply balance, the frequency of supplied electricity is kept constant. Capabilities of control for each power source are shown Figure 2.6 and Table 2.6.

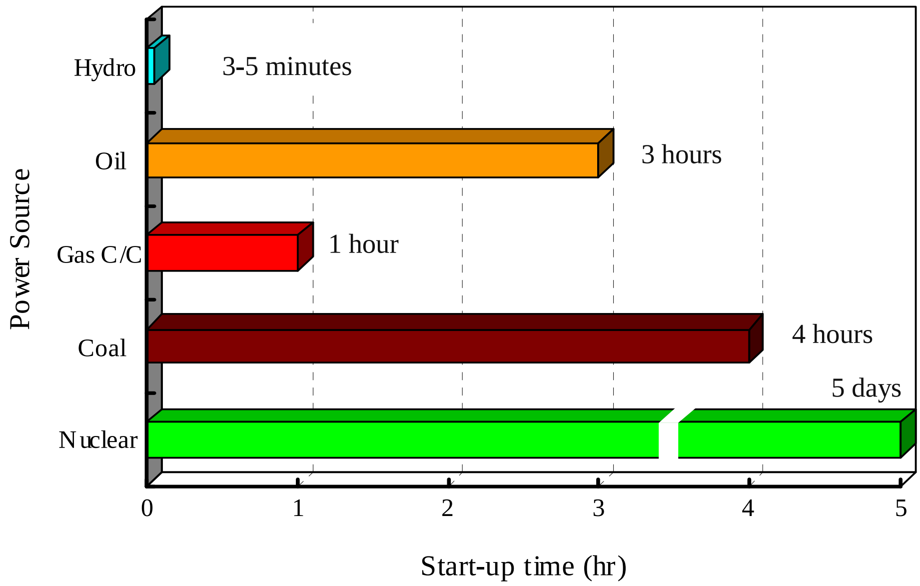


Figure 2.6 Startup Time After 8 hours Shutdown

Table 2.6 Output Change Rate

Power Source	Output Change Rate
Hydro	50～60% / min
Oil Fired	1～3% / min
Gas Combined Cycle	5% / min
Coal Fired	1～3% / min
Nuclear	—

PSPP has, as the characteristics of hydro power plant, the ability of quick startup and high rate of output change, comparing with other power sources. From these characteristics, PSPP has advantages in power system operation as following uses, in addition to the characteristics in the scheduled power supply in peak hours.

- Supply for unscheduled shutdown of other power plant
- Control for the large demand change such as in the morning hours
- Reserves such as spinning reserve (control for fluctuations in seconds to a minute), or operation reserve (control for one to several minutes)
- Power flow adjustment, or voltage control in the case of trouble in transmission network
- Starting point of restoration in the case of wide area disturbance
- Overall reduction of fuel cost by operating base supply power sources at efficient output during light load hours

2.2.2 Roles of Pumped Storage Power Plant in Demand-Supply Control and Power System Operation

In order to operate the power system stably and efficiently as well as keeping up the supply reliability, measures of (a) demand supply control, (b) economic dispatching, and (c) ancillary service should be conducted appropriately. A PSPP can be utilized to implement these measures effectively.

(a) Demand Supply Control

The purpose of demand supply control is to prepare the output reserve for demand changes and keep supplying generation output corresponding to the demand. PSPP is utilized for this purpose as follows:

- Supply for peak demand

  Generating operation is scheduled in peak demand hours of the day. In order for this, the pumping-up operation is implemented in off-peak hours to prepare for the high demand of the following day, or occasionally for a couple of days later.

- Supply for unscheduled power source outages

  PSPP can be the backup for unscheduled power outage by supplying power quickly, that is, quick startup from standby or pump-up shedding from pumping operation. By keeping the demand supply balance in a short time and keeping the frequency of the network constant, unwanted load shedding can be avoided.

- Supply for large demand fluctuation

  From the characteristics of quick output changes as stated, PSPP can be used to adjust demand and supply effectively by generating operation in large demand rising hours such as in the morning (Figure 2.7).

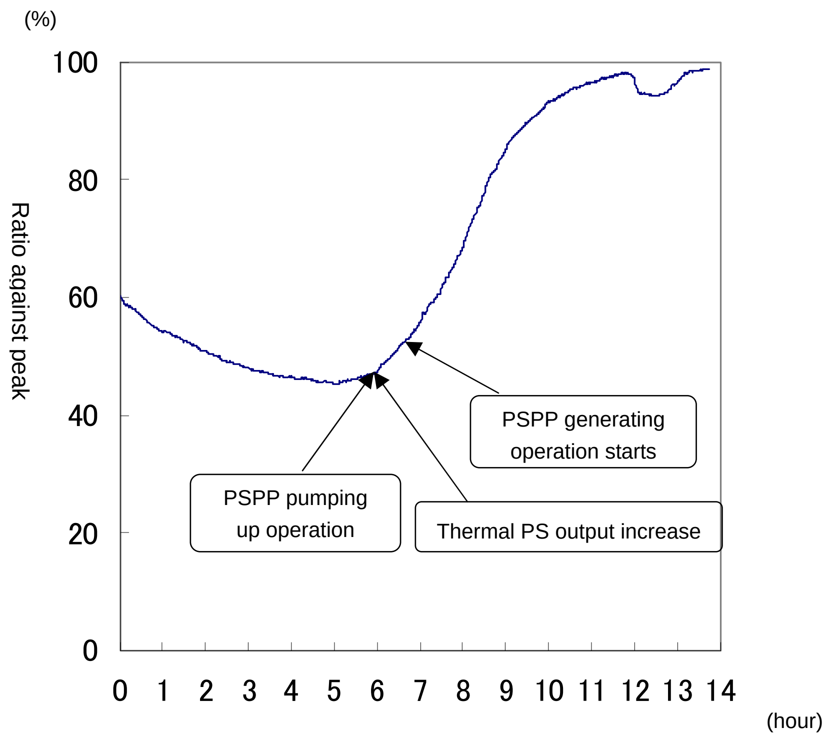


Figure 2.7 Operations of generators in demand rising hours

(b) Economic Dispatching

A PSPP stores electric energy when demand for electricity is low, as at nighttime, and uses this stored energy for peak hours; thus it can adjust the demand-supply balance and reduce the gap between the peak and off-peak hour's demand (Figure 2.8). That is, the PSPP plays a role of leveling the ever-changing electric power consumption and can be regarded as a kind of Demand Side Management (DSM).

Owing to this PSPP's role of load leveling, the other power sources which frequently start up and shut down or adjustment of output can operate continuously for long time at stable output, so their fuel efficiency can increase. Moreover, the share of base power sources with low generation unit costs can be increased; thus the overall generation cost of the power system becomes lower, and economic efficiency increases.

- Pump-up using surplus supply

  Some power sources, such as nuclear power plants and run-of-river hydro power plants, are to keep their output constant for economic and efficient operation. In some cases, surplus power supply from these power plants has to be compensated for by the pumping-up operation of PSPP. For this function, a PSPP would be necessary for demand supply control during off-peak hours in the case that share of these power plants increases.

- Pump-up for economic operation of base supply

  In order to reduce the overall fuel cost and improve the generation efficiency, the pumping-up operation is implemented in nighttime by utilizing efficient and low-cost power sources and reducing less efficient power plants' operations in daytime.

- Pump-up for lowering lower reservoir's water level

  When it is necessary to suppress the downstream flow in the case that the river flows into the lower reservoir, pumping-up generation can be operated so as not to raise the lower reservoir level and prevent un-generated water in the lower reservoir from discharging.

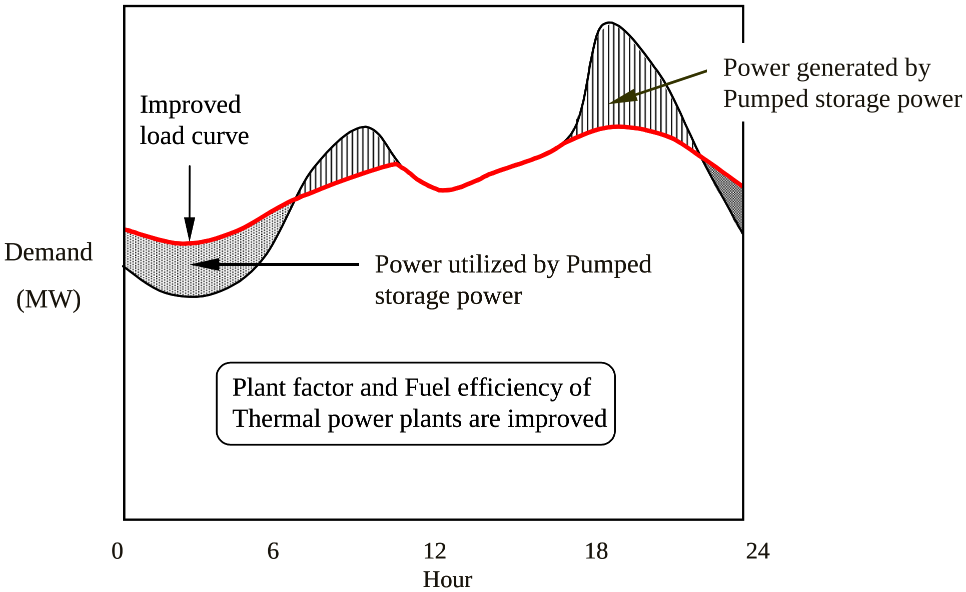


Figure 2.8 Leveling Load Curve by Pumped Storage Power Plant

(c) Ancillary Services

Since PSPP has an excellent adjustment capability like conventional hydro power plants, PSPP can provide the following ancillary services, which are indispensable to ensure the reliability of the power system:

- Frequency control capability

  In order to control the system frequency and adjust the demand supply unbalances in real time, it is required to reserve the necessary amount of reserves depending upon demand fluctuation periods, such as spinning reserve for some seconds of to per-minute fluctuations and the operational reserve for per-minute to some minutes of fluctuations. PSPP has the characteristics of flywheel effect to deal with fluctuations at periods of some seconds, the capability of governor control to deal with fluctuations at periods of some seconds to a minute, and the capability of load frequency control to deal with fluctuations at periods of a minute to some minutes (Figure 2.9).

- Power flow control in transmission network

  When network fault or unscheduled power outage leads to an overload of some part of the network or transient instability of the overall network, pumping-up or generating operation of PSPP is quickly shed or PSPP output is quickly controlled in order to relieve overload or prevent instability of the network.

- Voltage control in transmission network

  It is necessary to keep voltage of the network to appropriate ranges in order to transmit electricity stably and efficiently. PSPP can control the voltage of the network not only by controlling AVR like other power plants but also by supplying reactive power continuously in its “phase control operation” mode.

- “Black start” capability

  In the case of a wide-area blackout, power supply can be started from PSPP by its self-energizing capability.

- Pumping up as test load

  When a network test such as a large-capacity generator’s shedding test is conducted using a part of commercial power network, pumping-up operation of PSPP can be used as a test load.

- Backup of thermal power plant in case of environmental restriction alert

  For an example of Japan, when “Air Pollution Alert” is issued and output control of thermal power stations is restricted in that area, PSPPs are used for demand supply control as their backup.

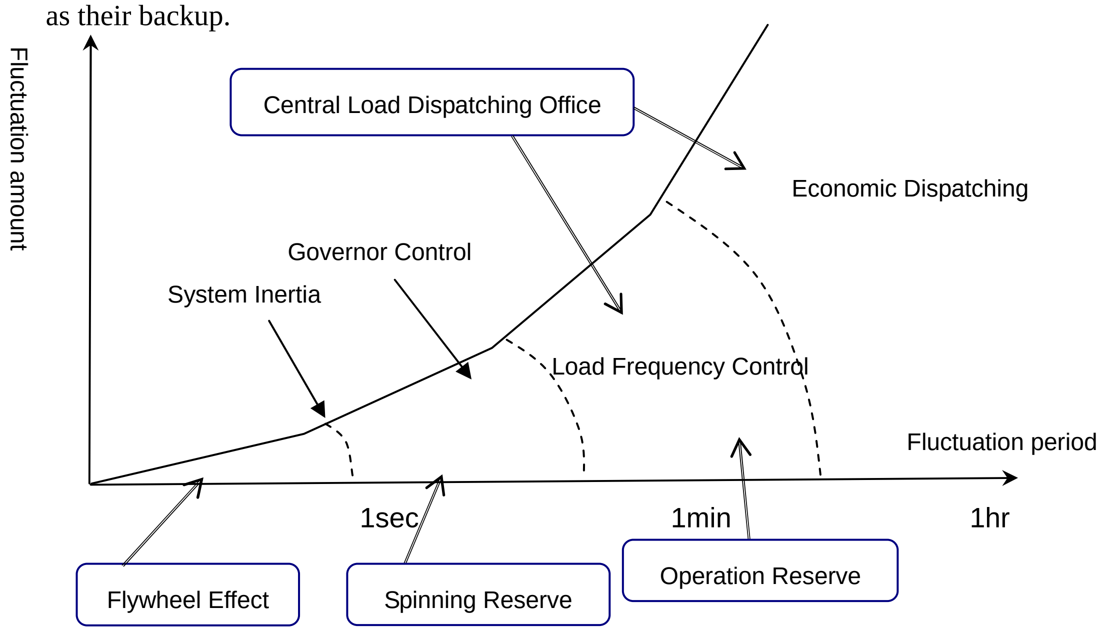


Figure 2.9 Outline of Demand Supply Control

In the normal demand-supply control and power system operation, PSPP is mainly operated for following purposes.

- From the function of storing energy, by pumping-up at the off-peak hours in the nighttime and generating at the peak hours in the daytime, it is used as the peak supply capability, and also used for economical demand-supply operation for overall power sources.
- From the feature of high output change rate, it is used as quick supply power control, by starting generation in the morning, when the demand continuously increases for several hours, and issuing output instruction as the demand changes.
- To keep the frequency of the network at the rated value, PSPP is started generation as needed, for securing the reserves for such as the load frequency control, to control demand change of a few minutes or less, and the governor control, to control demand fluctuation of one minute or less.

Since ASPS has the capability of controlling the input power in pumping-up operation, it is used as the control in off-peak hours for demand-supply control and power system operation. Operation of ASPS is stated in the following section.

2.2.3 Operation of Adjustable Speed Pumped Storage in Demand-Supply Control

In Japan, ASPS is operated as the reserve for adjustment in the nighttime, in addition to the roles of PSPP, as follows.

- Reserve for adjustment in off-peak hours

  In order to keep the frequency of the network to the rated value, electric power companies makes the rules to prepare necessary reserves (spinning reserve, operational reserve). Supposing that the reserve required for load frequency control, out of operational reserve, is called LFC reserve, specified generators for LFC reserve keep their operation with controlling outputs in accordance with the command from Central Load Dispatching Office, within their output change ranges.

  If the daytime load of 50,000MW and nighttime load of 20,000MW, and LFC reserve has to be 1% of the demand, the required LFC reserves are 500MW in the daytime and 200MW in the nighttime.

  Since conventional PSPP (Constant Speed) is not able to control the input power for pumping-up, the reserve in the nighttime has to be prepared by thermal power plants, which have 5% of control capability. In this case, 20 thermal power plants are required as follows.

  200MW (Output in the nighttime) * 5% (Control range) * 20 (# of operation) ＝200MW

If two ASPS with 50MW of output change rate are available, required capacity of 200MW is reserved by two ASPS and 10 thermal power plants.

Hence, the number of thermal power plants for LFC reserve can be reduced by operating ASPS, which means that the thermal power plants can be operated at more efficient output, comparing with pumping-up by conventional PSPP.

In addition, since the control speed by the load frequency control of hydro power plant is much higher than that of thermal power plant, it is confirmed that the frequency following capability becomes much better when ASPS is operated than the case that frequency control is conducted by thermal power plants only. Frequency fluctuation against the load change becomes larger in the light load hours. Therefore, ASPS plays the important role to increase the precision of frequency control.

Table 2.7 Output Control Capability

Power Source	Output Change Rate	Output Change Range
ASPS (400MW)	50～60% / min	±50MW
Thermal (Combined Cycle)	5% / min	5%

- Control of pumping input

While constant speed system is able to operate at fixed speed in pumping-up operation, ASPS is operable at several steps of input, such as 250MW, 300MW, and 350MW. Therefore, input of pumping-up can be set at the efficient point considering available generation capacity and demand.

2.2.4 Conditions in Demand-Supply Operation for considering ASPS

Considering the characteristics of ASPS, it is expected to be the role of a power source for load frequency control, as well as the peak supply power source like conventional PSPP. Therefore, it is important to grasp the needs of power sources for load control, in considering the introduction of ASPS.

(a) Change of Power Source Composition

Power sources with low variable cost and less output control capability, such as nuclear power plant and coal fired power plant, are operated as the base load supply. When the ratio of these types of power plants increases, there would be difficult to stabilize the frequency of the network in the nighttime when demand becomes low, due to insufficient response to the demand change. If thermal power plants are operated to control frequency to stabilize the network, they have to be operated at low efficiency output, which cause the economical inefficiency.

In Europe, development and installation of renewable energy sources are being implemented based upon ”EU20-20-20”, as in 3.1.3, and issues of demand-supply control and securing network stability become great problems when large amount of renewable energy sources, with less capability of output control such as wind and solar power plants, are introduced.

(b) Demand for Quality of Electricity

As the development of industry and economy, the demand for quality for electricity rises. In general, after the power sources to meet the demand are prepared to some extent, it is required to stably supply the electricity with quality. For this purpose, facilities such as power sources with quick response for load frequency control, power sources with quick start-up to be used as reserve, and voltage control equipment, have to be installed appropriately, in proportion as the electricity demand.

In Asian countries, power sources have been developed as the growth of economy. However, PSPP has not been much developed so far. In years to come, requirement of large capability of output control shall increase, when high quality and stable electricity supply is demanded for such as manufacturing precision equipment as highly and sophisticated development, or for the use of peak supply in order to efficiently operate base supply power sources, such as nuclear power plants.

Chapter 3 Current Situation and Issues of PSPP and Renewable Energy in European International Interconnected Power Systems

3.1 Situation of the European Interconnected System

3.1.1 Outline of situation of electric power in Europe

European electric power sector has promoted unbundling, i.e., separation of generation, transmission and distribution to aim for fair competition, liberalization and integration of electricity markets, based upon the third liberalization package put into force by European Union in September 2009.

Each regional TSO (Transmission System Operator) has conducted power system planning and system operation. Transmission systems of each TSO are interconnected, and the electric power is traded through the market. To coordinate among TSOs, the European Network of Transmission System Operators (ENTSO-E) has been organized, consisting of 42 TSOs from 34 countries.

The EU has established the energy policy named “EU20-20-20” to set the targets for renewable energy development. The member countries are required for the execution of its renewable energy goals.

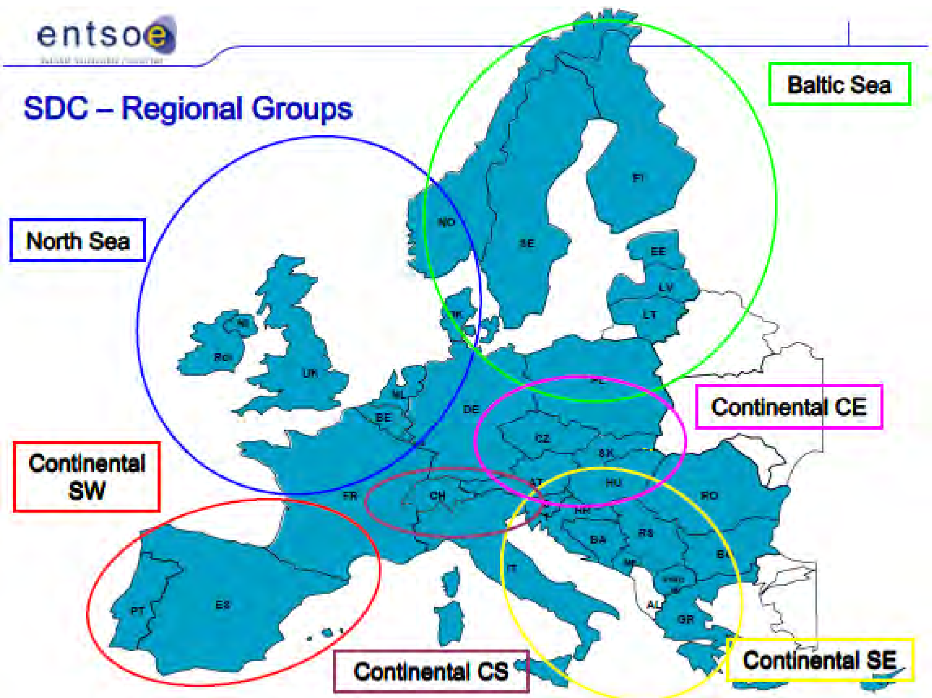


Figure 3.1 ENTSO-E Members and Area Group

3.1.2 Situation of international interconnected transmission line

International power system interconnection in Europe has been developed to pursuit economic benefits from improvement of system reliability and operational efficiency, starting from the utilization of hydroelectric power in Switzerland in 1920s. At present, the interconnected transmission lines of around 300 circuits are operated in the voltage levels from 110kV to 750kV. In the Barcelona EU Summit in 2002, the target was set stating "Each country shall prepare international interconnection capacity of 10% of the country's generation capacity by 2005." The network development of each EU country is planned by the TSO in each country and is submitted to the regulating authority of each country, as the plan with legal binding force.

European power system is operating as a system interconnected in a mesh, connected at multiple transmission lines between countries. As a characteristic of a meshed power network, the wide area blackouts were caused by single transmission line fault, which were occurred in 2003 and 2006, and this is recognized as one of the important issues to be resolved immediately. To deal with this, as one of the means of strengthening regional interconnection, "The revised EU rules for international electricity trade" was enacted in July 2009, and the ENTSO-E was established as reconstructed international network in EU countries.

In ENTSO-E, 10-year network development plan (TYNDP) was publicized in March 2010, in which the network plans of each area group for seven regions were discussed and determined. According to the TYNDP, approximately 500 projects are planned including 32,500km of AC interconnection and 9,600km of DC interconnection, by 2020. Out of them, nine (9) projects have been selected to be high priority and the financial support from EU was determined.

3.1.3 Situation and issues of renewable energy penetration in Europe

EU has drawn up an energy policy including renewable energy penetration target, named "EU 20-20-20". The targets by 2020 in the EU 20-20-20 are summarized as follows.

- A 20% reduction of green house gas emissions compared to 1990 levels
- A 20% share of energy consumption originating renewable energy sources
- A 20% reduction in primary energy use, based on projected levels, through improved energy efficiency

EU countries have been facilitating renewable energy development through such policies as Feed-in Tariff, Green Certificate, and tax benefits. "EU 20-20-20" strategy is targeted for the whole energy sector including electricity sector, and is not obliged to achieve. However, an increment of wind power penetration is the most promising measure to increase renewable energy share to 20% of whole energy consumption. At 2008, the proportion of renewable energy generation is approximately 8.5% and most of them are assumed to be the wind power. A projection indicates that 85GW capacity of wind power in 2008 will become 140GW to 210GW in 2020. Also, ENTSO-E indicated the probability that the wind power could share 30-35% of electricity generation in the future.

As the intermittent power source, massive introduction of renewable energy caused issues to deal with, such as change of operation of base supply power sources, reserve of supply capability for adjustment, congestion of international interconnection, negative price in power market, required ancillary service for system stability, and so on.

There occurred an event in Spain, as one of the events of apparent impact on the network, that the wind power plants without the function of sustainable operation have been tripped concurrently by the voltage drop due to network fault, which causes the system-wide frequency drop (Figure 3.2). The frequency drop was recovered by the power import through the interconnection with the French network. There are cases that half of electricity demand is supplied by wind power in Spain. At certain hour on November 9, 2010, 54% of power consumption was generated by wind power. It is concerned that the wide area blackout would occur by blocking interconnection, in the similar situation when spinning reserve is short due to the massive penetration of wind power.

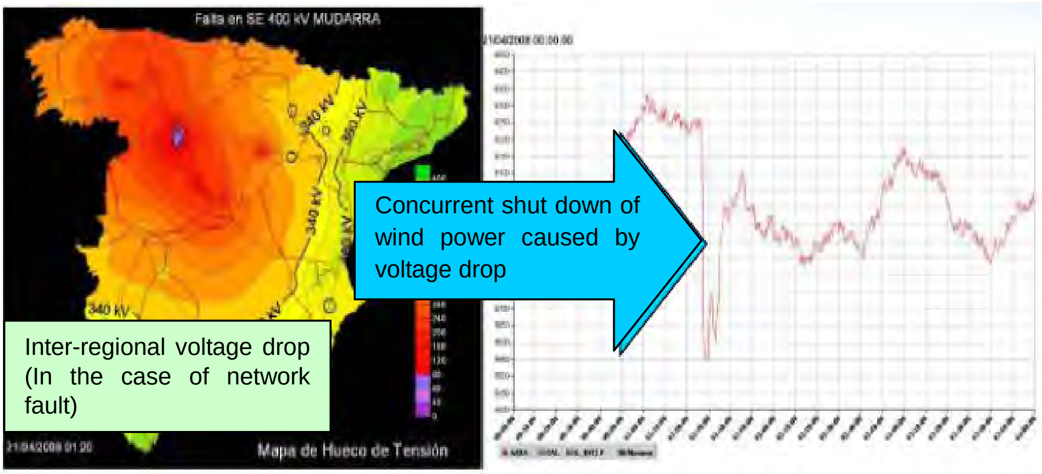


Figure 3.2 System frequency drop in Spain

As a countermeasure, a wind power plant was obliged to equip the FRT (Fault Ride Through) function to continue its operation in the case of network fault. So far, 97.5% equipped this function. In addition, REE, the Spanish TSO, was established the Renewable Energy Control Center (CECRE) to monitor the outputs of wind power plants over 10MW and to restrict their outputs within reserve margin capacity which they can secure. So far, REE can monitor 98.6% of wind power plants and 96% out of them can be controlled. Moreover, capacity of the interconnection with France is being increased. The Spanish government aims to penetrate more wind power. In order to do, it is considered that additional measures such as further reinforcement of interconnection with France, introduction of PSPP, obligation of primary reserve for wind power producers.

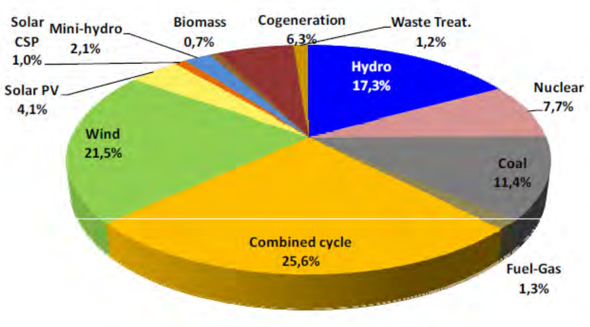
3.2 Situation of the Spanish Wind Power Penetration and System Stabilization

3.2.1 Situation of the Spanish wind power penetration and securing reserves

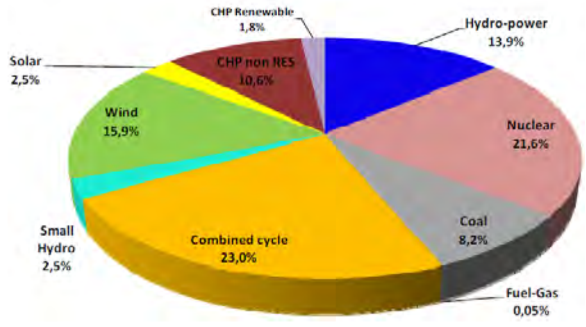
(1) Situation of wind power penetration

In accordance with the EU energy strategy, Spanish government has been implemented the policies for dissemination of renewable energy, including the introduction of feed-in tariff in 1994, raise of purchase price in 2007. As a result, wind power takes the second share of installed capacity in 2010, following the gas combined cycle. As of the end of 2010, solar power is second in the world following Germany, and wind power is fourth in the world. Although the purchase price has been lowered in recent year due to the criticism of cost burden, the government has set a target of wind power installed capacity 35,000MW in 2020.

In 2010, the wind power capacity has around 20,000MW, accounting for 21% of whole generation capacity in Spain. Generated energy by wind power has 3,000GWh, accounted for 15% of whole Spanish generated energy. The wind power generation has affected to system operation, especially in off-peak hours.



Installed capacity



Generating Energy

Figure 3.3 Generation Capacity in October 2011

(Source: REE)

The capacity of installed wind power plants in Spain is 19,976MW in the end of 2010. Most of them are located in the northern seashore area and the southeast area. (Figure 3.4)

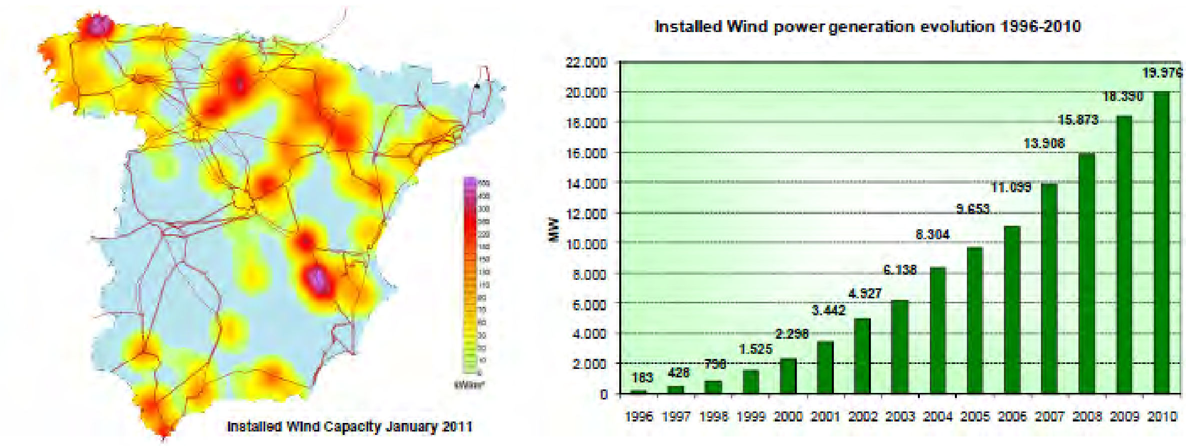


Figure 3.4 Wind power plant capacity growth in Spain （Source: REE）

(2) Situation of securing reserve

REE has to secure necessary reserve for demand supply control and keeping frequency appropriately[2]. ENTSO-E determines the necessary amount of primary reserve and it is divided in each region. The amount for REE is 400MW. The amounts of secondary and tertiary reserves are determined by considering the drop of the largest capacity unit. These reserves are prepared from the market, and in many cases they are obtained through interconnection with France as the result.

In this situation, power development of PSPP is planned as a measure of securing reserves in response to the increase of renewable energies.

3.2.2 Situation of Eurus Energy

(1) Outline of Eurus Energy

Wind power plant capacity in Spain has 20,676MW in 2011. Eurus has 553MW of wind power plants in Spain. Most of them is located in the northeast area in Spain (Figure 3.5).

Wind power IPP in Spain can select annual basis whether a contract of regulatory fixed tariff based on the PPA or trading in the market, which effects within 20 years as the PPA contract period. The wind power IPP can make contract with lower tariff after 20 years by the regulation in Spain. Wind power generation energy has traded in the market at present, due to the good market conditions.

Regulatory fixed tariff after 2013 has not determined yet, which has become a risk for the management of wind power IPP.

2 www.esios.ree.es

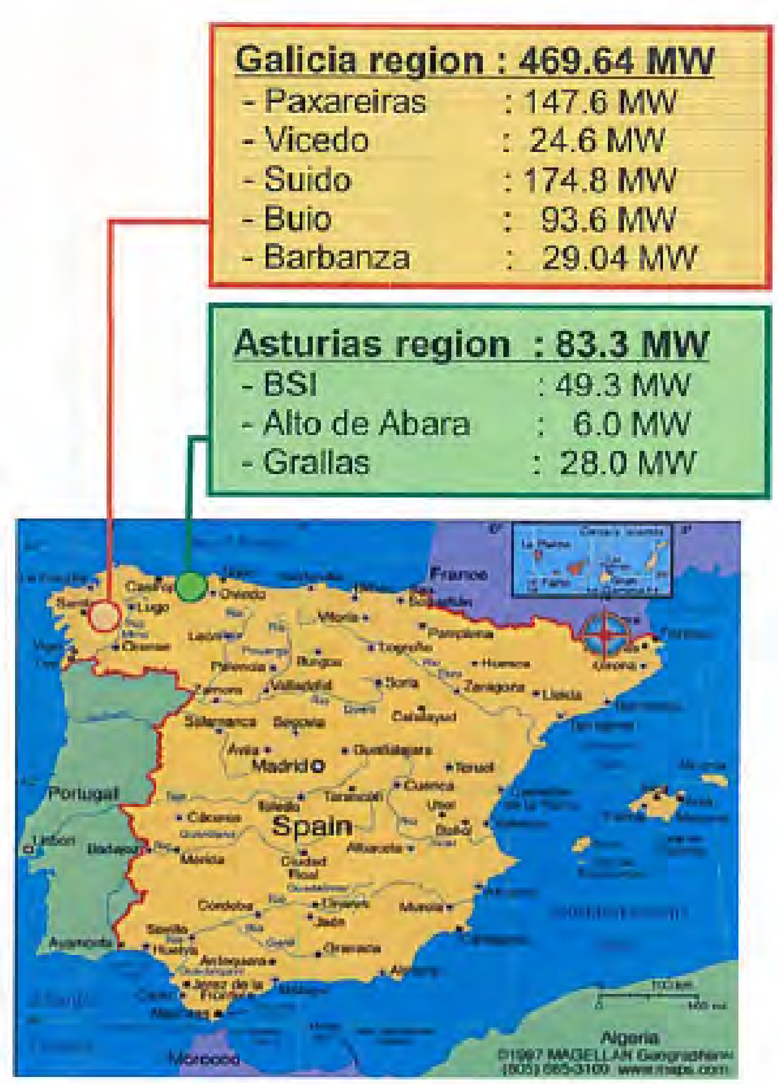


Figure 3.5 Eurus Wind power（Source: Eurus energy）

(2) Bid in power exchange market

Bidding prices are determined considering meteorological data and historical price data. Imbalance penalty that is a fine of discrepancy between plan and actual outputs is 10% of total revenue. Although the imbalance penalty is not small amount for IPP management, the generation amount estimation at bidding would not be intentionally reduced because the lost revenue is grater than the penalty. An instruction for output restriction likely to receive from the dispatch center of TSO is not incorporated into the generation plan.

Penalty of unachieved from the supply plan after closing bid should be borne by a distribution company as a buyer. The distribution company could not reflect it to the retail tariff.

(3) Output restriction to secure system frequency and voltage

There are cases of output restriction instructions to be obeyed for several times. Although the output restriction causes the revenue loss, it is mandatory by a law and its impact to IPP management is limited because the loss of output restriction is less than 1% of total revenue. Output restriction is conducted by one wind turbine unit rather than by a node of wind farm. The regional control centers operate the output restriction.

Since many of the wind power IPPs have owned and operated other generating facilities such as hydro power, they can prepare (secondary) reserves by such generation so that wind power can be operated with less restriction.

Unlike the cases in Germany, the output restriction instructions are not caused by exceeding the whole wind output over the whole system demand. Most of them are caused by exceeding the transformer capacity at the substation connecting to the system. For this reason, there occurred no negative price case in the market even though there was the zero price case.

3.2.3 Situation of system stability and adaption to the new regulation

In response to the experience of consecutive shutdown of wind power plants due to the voltage drop, REE has the capability of suppressing the wind power output, and REE monitors the output of wind power plants with certain scale of output in order to do it. When certain level of reserve cannot be secured considering the wind power output estimation and reserve situation, outputs of wind power plants are restricted. There is no compensation obligation for the un-generated power.

Currently, ENTSO-E studies new rules of frequency stabilization and voltage stabilization for wind power plant, REE also studies the measures for equipment in accordance with it.

Regarding a new regulation, when LVRT (Low Voltage Ride Through, the function to keep operation in the case of voltage drop, same as FRT) was adopted, existing wind power plants were not obliged to equip in the initial stage, but the regulation was changed later, to include existing plants. It is estimated that the new rules will include existing wind power plants in the end. Since the time-limited scheme of additional premium was adopted to compensate the initial cost for the function in the case of LVRT, it is expected that the some compensation scheme could also be adopted for the new functions.

3.3 Situation of Power Market and PSPP Operation in Germany

3.3.1 Situation of Power Market and PSPP Operation in Germany

(a) Situation of Power Market

The European Energy Exchange (EEX) operates energy markets for electricity, natural gas, coal and CO2 emission right, mainly in Germany. By joining a TSO in Austria in December 2010, its participant consists of 20 power generation companies in Germany and Austria, and 5 TSOs, that is, 50 Hertz Transmission GmbH, Amprion GmbH, EnBW Transportnetze AG, TenneT TSO GmbH and Austrian Power Grid[3].

Figure 3.6 Power Plants of EEX Participant Companies

In the power market, the supply is prepared to meet the demand in the Wholesale Market, and the reserve for the demand fluctuation is prepared in the Reserve Market. In the Wholesale Market, supply power is traded for long term (from 3 months to 3 years), short term (from following day to 3 months) and intraday. In the Reserve Market, reserve power is traded for primary reserve (available in around 30 seconds), secondary reserve (available within around 15 minutes), and minute reserve (or tertiary reserve, available in more than around 15 minutes)[4].

Primary reserves are allocated for the designated power plants with their own capability of frequency control, while secondary and minute (tertiary) reserves are instructed by TSO to each generation company for controlling the output of each generator.

In the German market, the power producers have to prepare the operation reserves as the back

[3] www.eex.com
[4] www.regelleistung.net

up to secure the N-1 criterion. In order to do this, they prepare the back up power sources a) by making some of their power units hold standby status, b) by purchasing from Reserve Market, and so on. Other than that, it is possible to purchase an option of purchasing the secondary reserve of future fixed timeframe at a fixed price, through bidding from other power producers.

Total primary reserve to be prepared is determined by the K-Factor of the network, and it has to be maintained at all time. For this purpose, TSO requests power producers to submit the generation plan and the primary reserve plan for the following day in each power plant at 14:00 every day, to confirm the reserve.

In the secondary Reserve Market, TSO purchases the option of operation rights to use the secondary reserve for the following week, in the unit of generation capacity (MW), to keep the necessary amount of secondary reserve. Power producer bids the outputs and prices to use as secondary reserve, and the reserves (operation right) are determined by the order of price in capacity (MW) for a week. After the reserve is determined, its option can be traded between power producers. At the time of operation, power producer has to follow the output control instruction from TSO for the determined option for reserve, since TSO has the right of operation for that amount.

(b) Situation of PSPP operation

Operation plan of PSPP is determined by the trade strategy considering the market price. In the past, supply capacity in daytime is comparatively short for the demand and vice versa in the nighttime. Therefore, at that time, pumping electricity is purchased at the relatively low price in the nighttime and generated electricity is sold at high price in the daytime, in the Wholesale Market. After the significant development of wind and solar power plants, since the price differences between daytime and nighttime became small in the Wholesale Market, it became difficult to make profit from the Wholesale Market.

On the other hand, from its capability of secondary reserve, PSPP has advantage when it is used in the Reserve Market, especially in the secondary reserve market in Germany. Currently, it is considered to be profitable for PSPP to use it in the secondary market, power producers make profit by selling the operation right to TSO in the Reserve Market. Therefore, typical operation pattern of PSPP became disappeared. In this situation, as well, it is the advantage of Adjustable Speed PSPP which can control the input for pumping, while the input of pumping of conventional PSPP has to be constant.

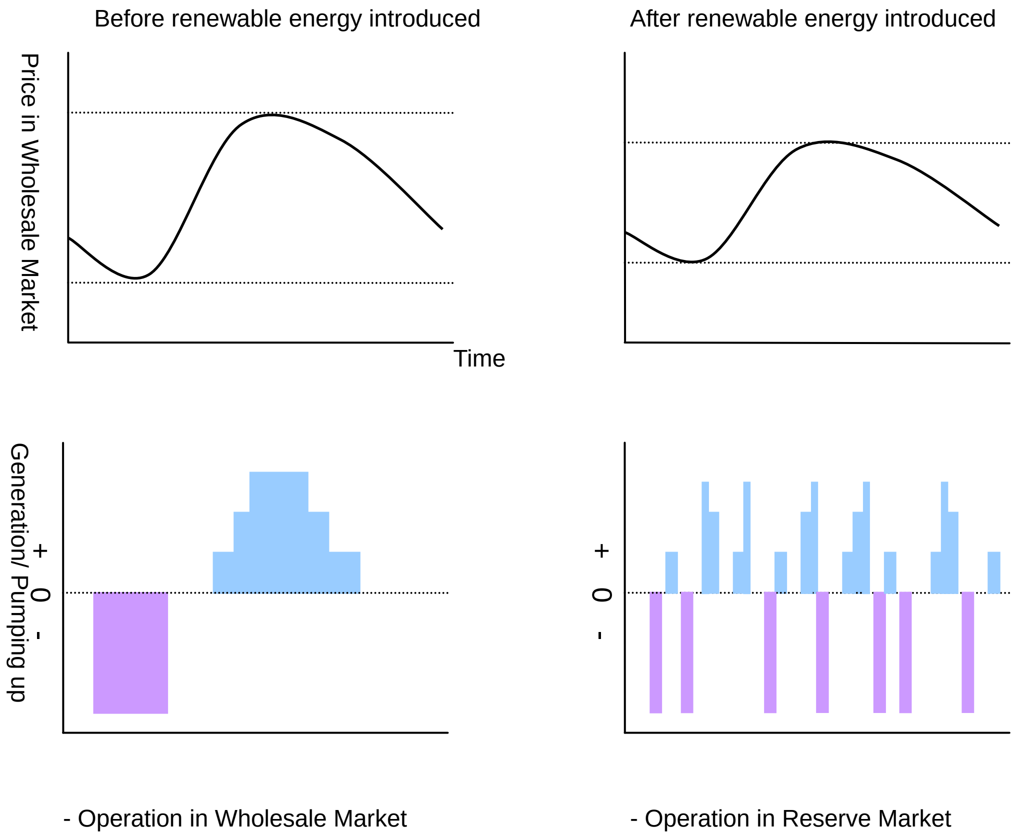


Figure 3.7 PSPP Operation before and after Renewable Energy Penetration

When TSO implements the option of secondary reserve for a power producer, TSO sends the required output change to the power producer, which is transmitted in every 3 seconds, and it is sent to each designated power plant. Each power producer determines the allocation of the transmitted output change by such means as computer programs, and sends them to each power plant.

While each power plant operates as the operation plan determined by the trade of such as Wholesale Market, its output is changed in accordance with the output change instruction for adjustment by TSO. As the result of this operation, the price for traded generation amount in the Wholesale Market, the price for option that TSO reserved in the secondary reserve market, and the price for the amount that is actually controlled as the secondary reserve, will be paid.

For example, when secondary reserve of -50MW is requested in operating at 500MW in accordance with the determined output in the Wholesale Market, output becomes 450MW but the profit is the summation of 500MW*(bid price in Wholesale Market) and 50MW*(bid price in Reserve Market).

In the secondary market, options for operation as the reserve are determined for a week. In addition, the price for the generated amount (MWh) is also paid when the option for the reserve is implemented. Since this price is also bid, the priority of implementation becomes low if its price is high. Its price is usually close to the actual cost for operation.

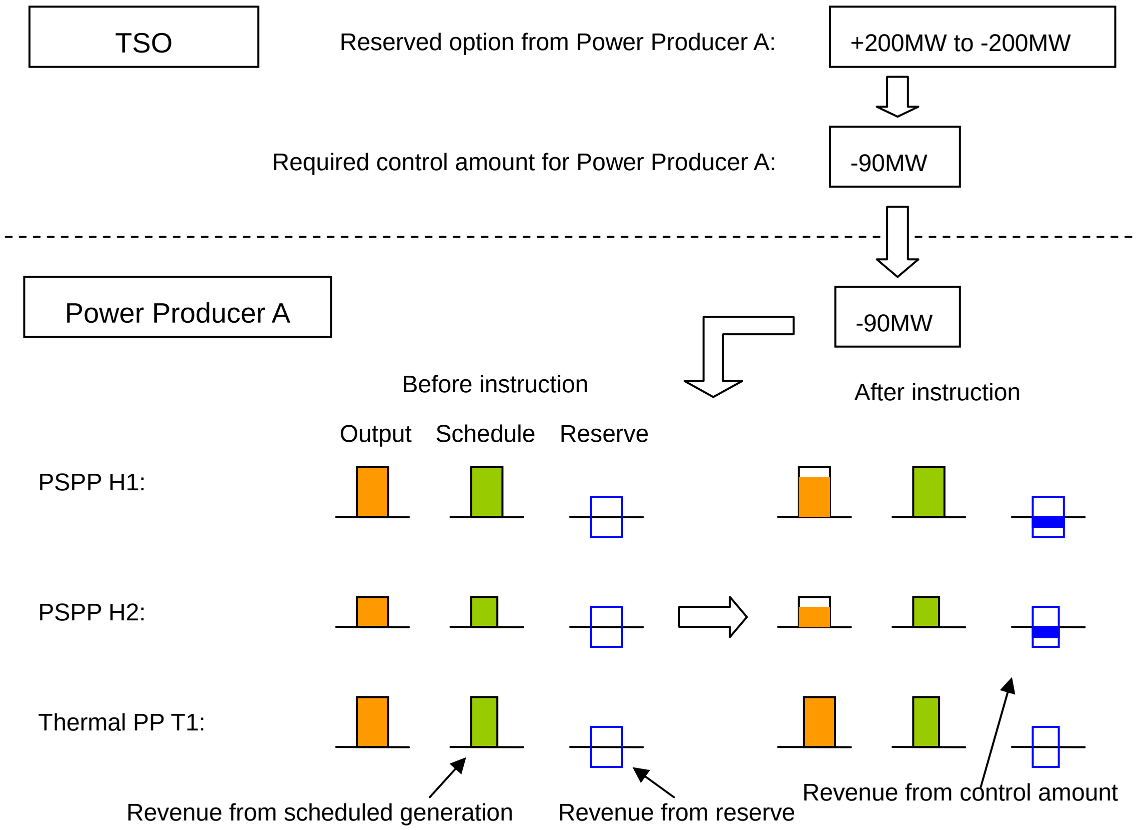


Figure 3.8 Concept of Reserve Operation and Profit of Power Producer

Maintenance plan of PSPP is determined by the power producer, considering operation plans of other power plants, fuel plan, electricity sales and trade plan, and so on. Depending upon the power producers, fuel plan of their thermal power plants or situations of derivative trade, such as future options, are also considered.

(c) Penetration of renewable energy and PSPP operation

In Germany, the policy of renewable energy penetration has been implementing, by The German Renewable Energy Sources Act in 2000 including feed-in tariff, and purchase price has been raised in 2004 and 2009. As the result, 27GW of wind power is installed, which is No.1 in the world, and with recent growing development, 17GW of solar power is installed, which is No.3 in the world. Figure 3.9 shows the trend of the generation capacity of the renewable energy and the ratio of generated power by renewable energy against total generated power. In 2010, generated power by renewable energy amounts to 103TWh, which takes 17% of total electricity consumption. In this situation, when outputs from renewable energy power plants are high while the electricity demand is low in holidays, there occurs surplus of electric power, which causes the negative price in the market of EEX. In these cases, PSPP can be beneficial by pumping up with obtaining revenue.

On the other hand, old nuclear power plants are forced to shut down by the Government order after the Fukushima Accident, and the power source composition will likely change by shutting down all nuclear power plants[5]. From these backgrounds, the role of PSPP has been shifting from the peak demand supply to the reserve supply for the whole network.

However, as in the case in Spain, purchase price has been lowered recently, in response to the criticism for the cost burden. Currently, since the scope of future situation of electric power market is not clear, market value of PSPP is also not clear. Hence, many power producers are reluctant to invest on the new project of PSPP. Although there are some PSPP projects in Germany, location is limited due to objection from the residents. For this reason, there are plans to construct or upgrade PSPP in the countries adjacent countries, such as Switzerland, Austria, Luxembourg, and so on, to supply reserve power to Germany.

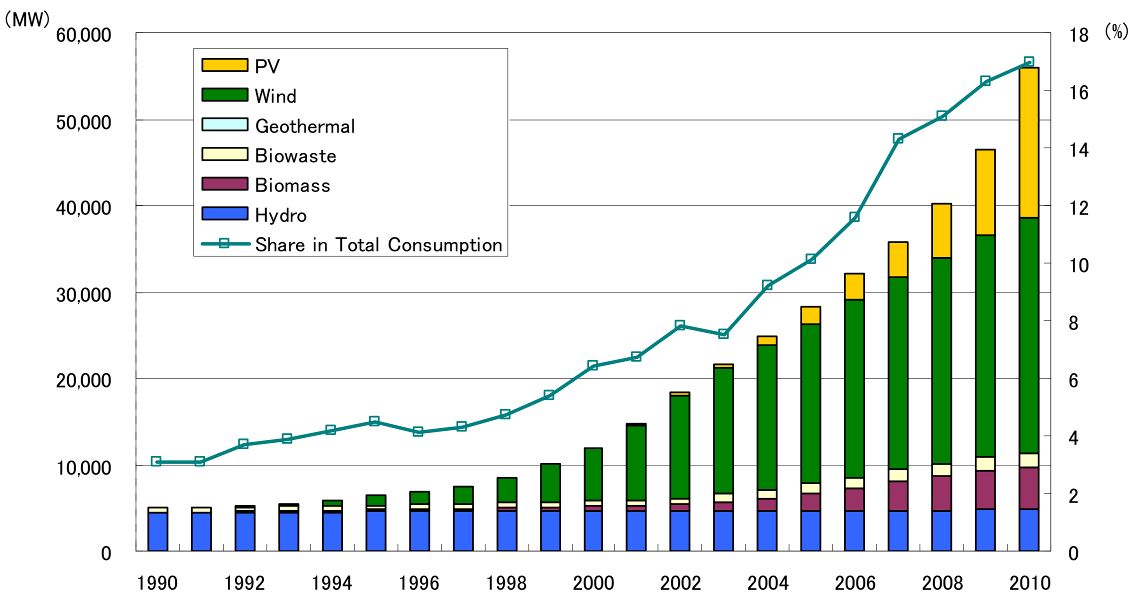


Figure 3.9 Penetration of Renewable Energy in Germany
(Left: Capacity, Right: Ratio of generated power)

(Source: Working Group on Renewable Energy Statistics)

[5] According to the quick estimation of ratio of power source in electricity consumption in Germany in 2011 by BDEW, lignite 24.6%, renewable energy 19.9% (from 16.4% in 2010), coal 18.7%, and nuclear 17.7% (from 22.4% in 2010)

3.3.2 Kops II PSPP (Austria)

(1) Outline of power plant

Kop II PSPP is located in Vorarlberg State, the west of Austria. The construction started in 1994 and all the 3 units with total capacity of 450MW are commissioned in June 2008. Total construction cost is approximately 400 million Euro. Kops II uses the existing Kops Reservoir as upper reservoir and the existing balancing reservoir Rifa as lower reservoir.

The main unit of Kops II PSPP is tandem type which has a turbine runner for generating and a pump runner for pumping and they are coupled with generator-motor on the same shaft (Figure 3.10). This system allows the plant adjusting input power in pumping mode by supplying a part of pumped water to turbine runner at the same time, which enables the full range of control ability of +/- 100 % in turbine operation and in pump mode with "hydraulic short-circuit".

Each unit consists of Generator (manufactured by Andritz), Pelton turbine (manufactured by Andritz, 175 MW), and 3-stage Pump (with clutch manufactured by Voith Siemens, 150MW)

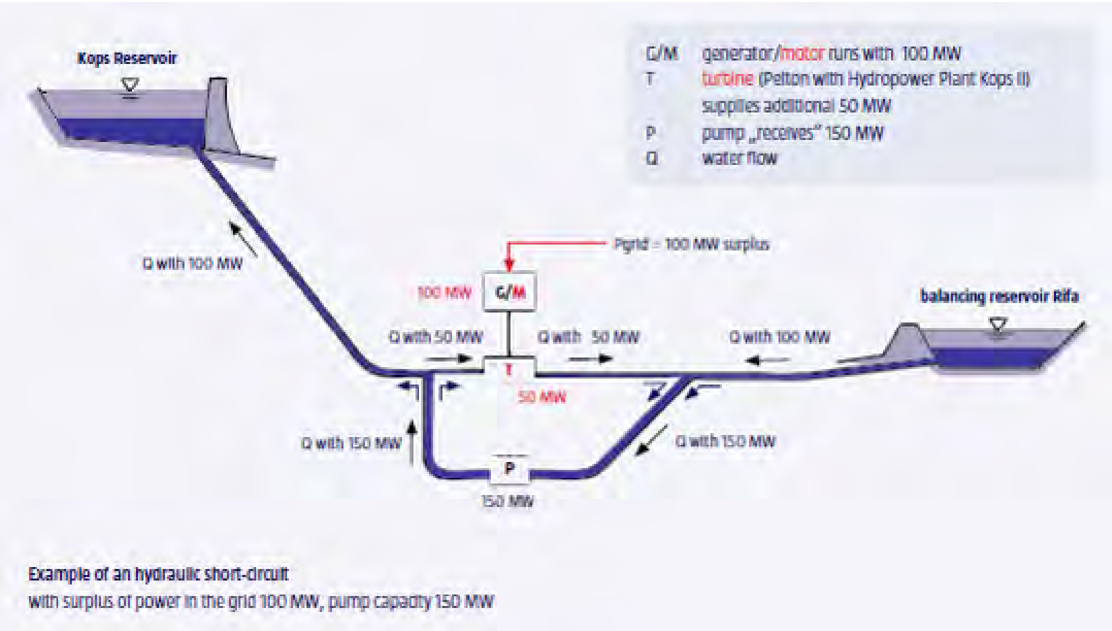


Figure 3.10 Overview of Kops II PSPP

(2) Comparison with Adjustable Speed PSPP

Kops II PSPP is able to adjust the input power in pumping mode like the Adjustable Speed system. While the adjustable input range of the Adjustable Speed system is from -100% to -70%, that of Kops II is from -100% to 0%. However, Kops II requires more time to pump up water to the upper dam than the Adjustable Speed system because Kops II supplies a part of water pumped to turbine runner in order to adjust input power.

In addition, comparing to the Adjustable Speed system, it is considered that the water way of Kops II is so complicated that energy loss is large, and that the length of the machine axis is so long that mechanical vibration is also large.

In terms of construction cost, the Adjustable Speed system has advantages over Kops II because Kops II system needs not only a turbine runner and a pump runner respectively, but also a mechanical clutch for separating pump in generating mode.

(3) Power plant operation

Operation right of Kops II is owned by Illwerke (Austria) and EnBW (Germany), and the power plant is operated based upon the operation plans of both companies. As the result, annual generation amount is split by these companies.

When it is fine whether in Germany, since solar power plant generates electricity, Kops II operates in pumping mode at daytime. By these effects, switchover between generation mode and pumping mode occurs more than ten times in a day in recent yeas.

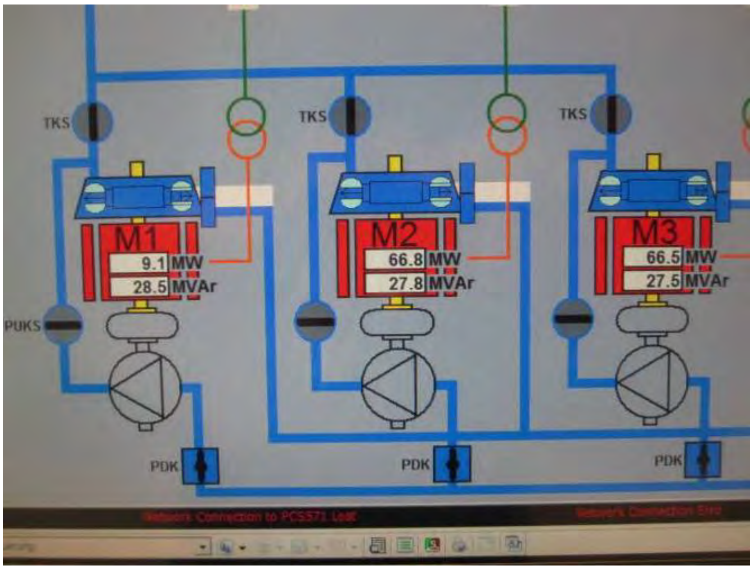


Figure 3.11 Operation Monitoring Panel

(4) Other Information

Illwerke started the new PSPP project of Obervermuntwerk II, which is the similar type to the Kops II system. The capacity will be 2 x 180 MW and the turbine and pump will be the horizontal Francis type.

Figure 3.12 Obervermuntwerk II Project

3.4 Power Market and PSPP Operation in Italy

3.4.1 Situation of power market in Italy and its effects to PSPP operation

(1) Situation of power market in Italy

In the Italian power market, there are an Energy Market which is operated by power marketers to trade electric power and a Balancing Market which is operated by Terna as the TSO. Power producers should secure 1.5% of their generation capacities as primary reserve. In 2010, from the records of power trade the average price in the Energy Market was 70 Euro/MWh, with 90 Euro/MWh of peak price and 40 Euro/MWh of off peak price. Prices in the Balancing Market were twice as the price in the Energy Market. The prices in the Balancing Market were 120 – 140 Euro/MWh. In 2011, the average price in the Energy Market was 70 Euro/MWh from the records of power trade, while the average price in the Balancing Market was 100 Euro/MWh.

Operation of PSPP is composed of pumping up by purchasing from the Energy Market and generation for selling in the Balancing Market. From the energy trade records of PSPP in 2008 and 2009 (Figure 3.13), there are 74% of generating energy trading in the Energy Market, 26% of generation trading in the Balancing Market and there are 52% of pumping energy trading in the Energy Market, 48% of pumping in the Balancing Market.

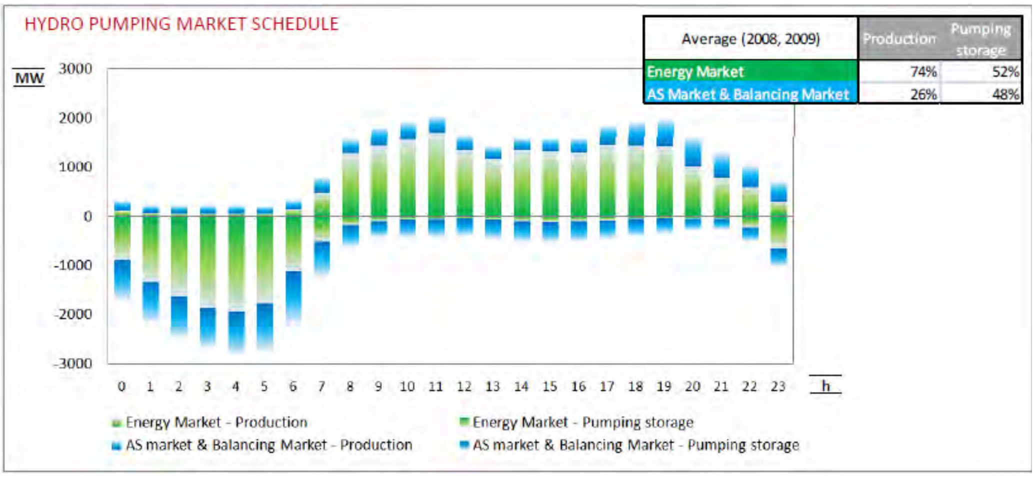


Figure 3.13 Records of Power Trade of PSPP

(Source: Terna)

(2) Penetration of renewable energy and its effects of network operation and PSPP operation

In Italy, renewable energy capacity increase to meet with the EU energy strategy. As shown in Figure 3.14, installed capacity became 10 times for 6 years. Especially, capacity of photovoltaic cell (PV) generation was greatly increased from 2010 to 2011.

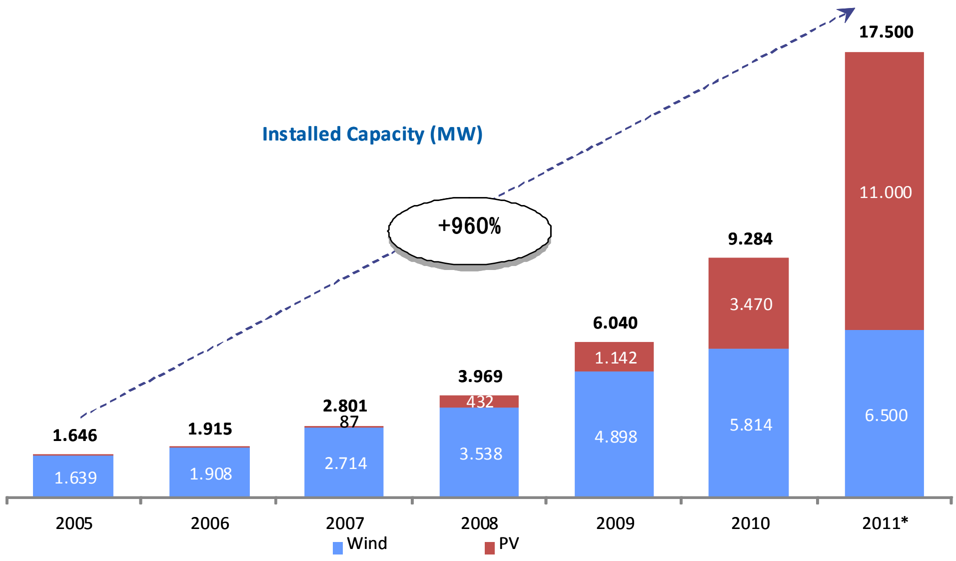


Figure 3.14 Installed Capacity of Wind and PV Power in Italy

(Source: Terna)

Large amount of solar power is affected system in the sharp decline in demand during the sunny day.

Figure 3.15 shows the relation of power demand, PV and wind power output, and base supply output in August of 2011. Generated power from PV is supplied to the distribution network and that from wind power is mainly supplied to the transmission network. Terna has to control other supply capability, to meet the demand in the dotted line in the figure. It is shown that the minimum demand was recorded at 14 in the afternoon and the peak demand was recorded at 19 in the evening. For some times at the time of minimum demand, the demand became lower than the base supply power after secondary and tertiary reserve margins that are purchased from the market are used. In this situation, Terna stopped the import power from neighboring countries based on the emergency operation agreement with neighboring TSOs. However, the supply power still exceeded to the demand, surplus power was exported to the neighboring countries, and furthermore, wind power outputs were suppressed.

TSO have to compensate lost revenue of wind power producers when they ordered to suppress the wind power outputs for the reason of system operation, according to the Italian regulation. Hence, increase of renewable energy causes more cases of wind power output suppress, which puts pressure on the profit of Terna.

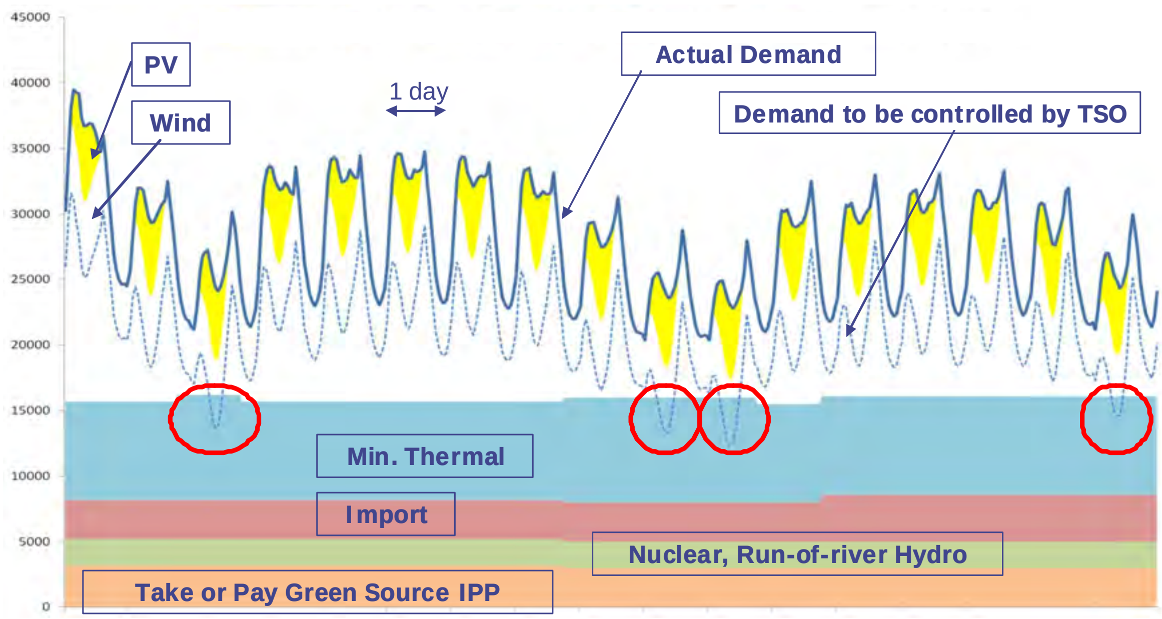


Figure 3.15 Demand and Base Supply in Italian System（August 2011）

(Source: Terna)

Since solar power is mainly installed on the roof of the residential house and is connected to the distribution system, TSO is difficult to monitor and control its output. From Terna, the demand to be controlled suddenly drops when solar power generates. Difficulty of output forecast of renewable energy, especially due to the inaccurate estimation of PV output, causes the hardship of scheduled and accurate demand supply operation.

In this situation, Terna has to instruct unscheduled decrease of thermal power and pumping up of PSPP besides the operation of reserve margin purchased in the market, and additional pumping operation of PSPP during the night peak hours. Figure 3.16 shows the unscheduled generation and pumping of Thermal PP and PSPP, caused by the renewable energy output.

System operation in the summer was affected by the large penetration of renewable energy especially by PV power plant. PSPP operation was also affected, with pumping up operation in the off-peak hours in summer, and generating operation in the nighttime.

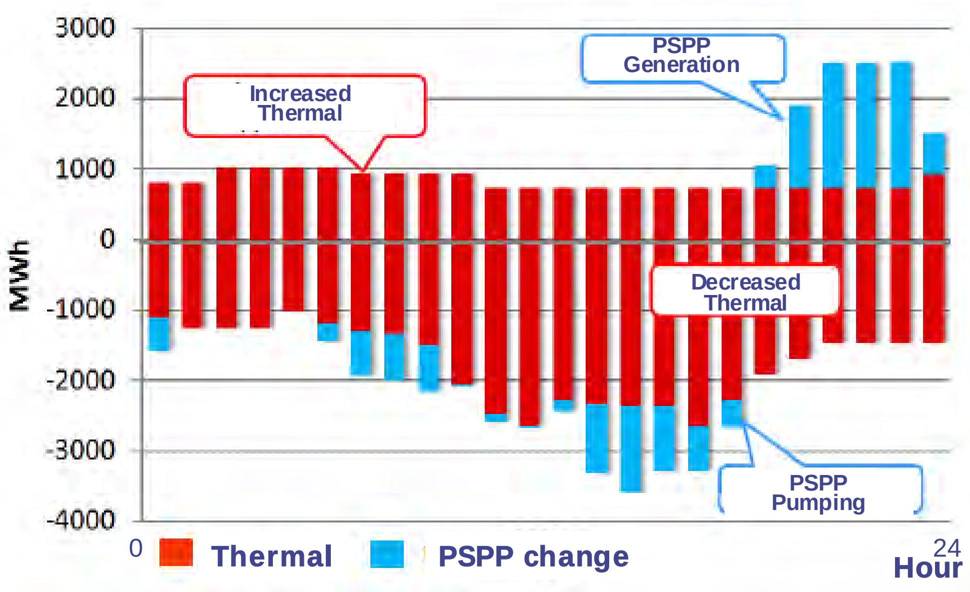


Figure 3.16 Effects to Demand Supply Control by Renewable Energy Penetration

(Source: Terna)

(3) Measures to the fluctuation by renewable energy penetration

In Italy, large amount of power demand and PSPP is located in the north region, while PV and wind power plants are concentrated in the south region. Since there is limitation in the capacity of the transmission lines between north region and south region, intermitted power generated in the south is not completely absorbed by the PSPP in the north, which causes the limitation of wind power output (Figure 3.17). To deal with it, Terna is considering three measures against the fluctuation due to massive penetration of solar power.

First item is the installation of the distributed power storage facility, such as battery or flywheel, in the distribution network to absorb the surplus power from PV and wind power. Second item is the installation of PSPP in the regional transmission network as a system stabilizing system, to secure the demand supply balance within the region. Third item is the reinforcement of bulk transmission lines between north and south regions. There are suitable locations for renewable energy in the south and islet area, while demand centers are located in the north area.

These measures are under discussion with the government as of 2011.

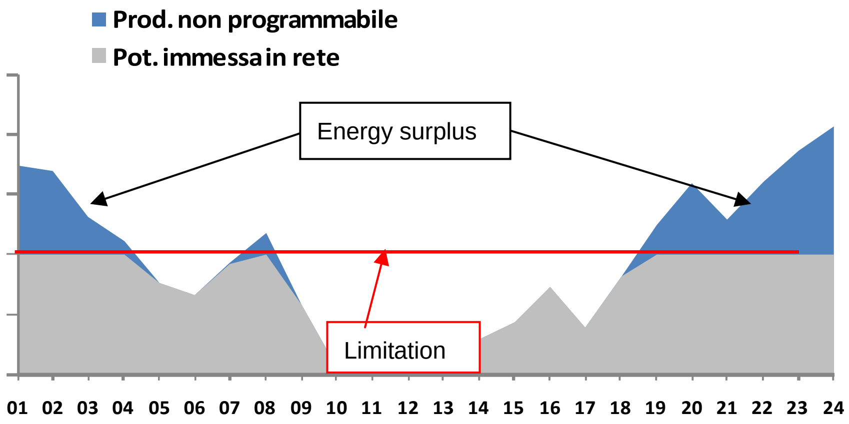


Figure 3.17 System limitation and renewable energy surplus outputs

(Source: Terna)

3.4.2 Entracque PSPP (Italy)

(a) Facility Outline

Entracque PSPP, owned by Enel Production, has the capacity of 1,190MW for total 9 units. The construction started in 1960s and the operation started from 1980 to 1984. Out of 9 units, bi-directional pump/turbine is used for Unit 1 to Unit 8, and the tandem system is used for Unit 9.

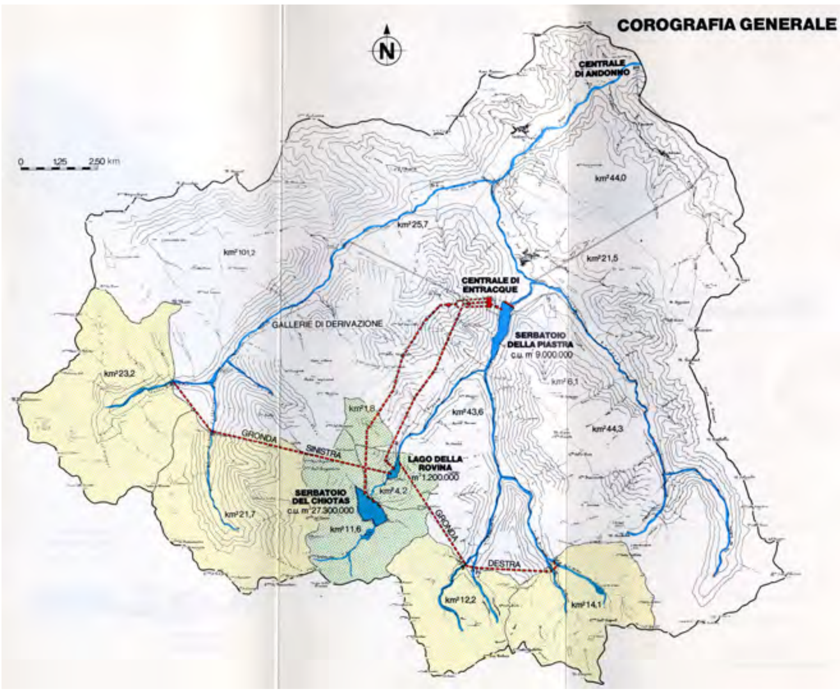


Figure 3.18 Configuration of Entracque PSPP and Dam

There are two upper reservoirs, Chiotas for Units 1 to 8, and Rovina for Unit 9, and lower reservoir, Piastra is common. Heads are 1,050m for Chiotas and 600m for Rovina. Capacities are 27.3 million m^3 for Chiotas and 1.2million m^3 for Rovina.

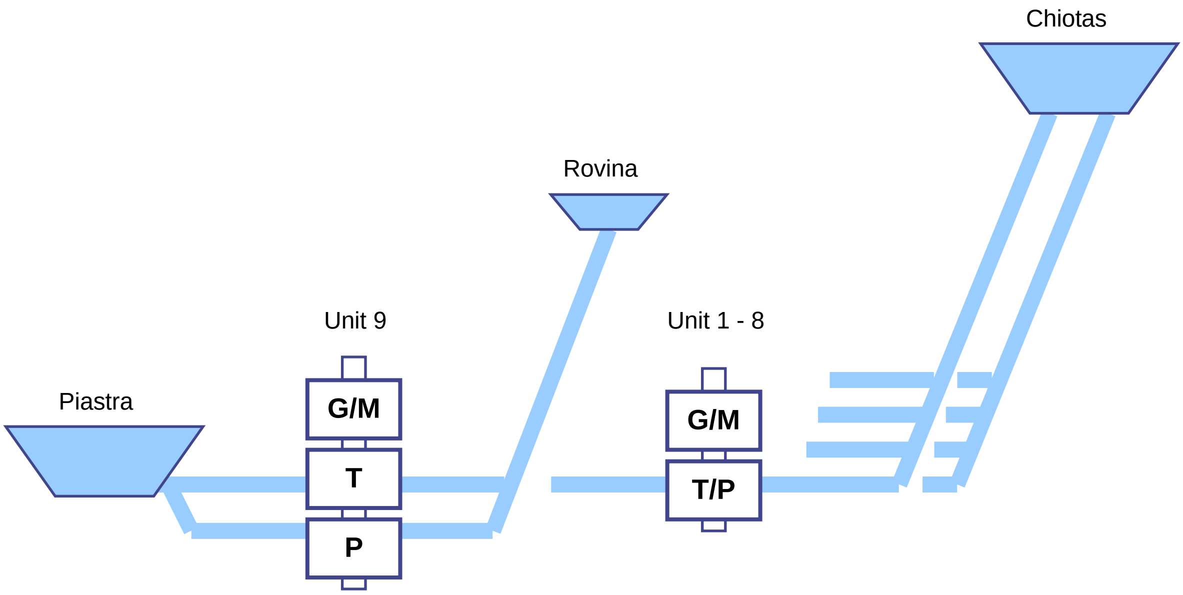


Figure 3.19 Outline of Facility of Entracque PSPP

There are 4 stages for the turbine/pump of each Unit 1 to 8, 1 stage for the turbine of Unit 9, and 2 stages for the pump of Unit 9. From the top of Unit 9, equipment is arranged in the order of generator/motor, turbine, and pump. In the generation operation, the clutch between pump and turbine is disconnected.

When starting pumping operation of the Units 1 to 8, “Back-to-Back” startup (pump is started in the water) is available from the group of Unit 1 to 4 to the group of 5 to 8, and vice versa. From Unit 9, “Back-to-Back” startup is available for each of Unit 1 to 8, and Unit 9 is also able to start the pump by itself.

Time from startup (No.1 switch start) to parallel in is around 2.5 minutes for generation, around 3.5 minutes for pumping, and time from parallel in to the rated output is around 1 minute.

(b) Situation of PSPP Operation

Entracque PSPP is controlled from one of 5 control centers in Italy, located in Piemont. From the control center, approx. 100 hydro power plants, including 26 of Enel Production and approx. 75 of Enel Greenpower, are monitored and controlled.

Unit 1 to 8 of Entracque PSPP operate only at their rated output for generation and rated input for pumping, which means that their outputs are not controlled. For Unit 9, generation output is controllable in the range of 40% to 100%, while pumping is constant input. Hence, this power plant is not used for frequency control, and its operation pattern is pumping in the nighttime and generating in the daytime for each unit.

Generation plan of each unit is determined by Enel OPR in Rome. Operation instruction is given from Terna, through Enel OPR, and transmitted to the control center in Piemont. For this purpose, availability of each unit has to be reported everyday.

Two to three weeks of maintenance is conducted annually for each unit. Besides, once in 10 years, dam is maintenanced with all units shut down. This was conducted in September 2011, for a month.

(c) Others

Market prices for peak hours tend to decrease, while those for off-peak hours tend to rise, which is similar to the trend in Germany.

 Entrance of PSPP and Lower Reservoir Dam	 Switchyard
 Top of Generators	

Figure 3.20 Entracque PSPP (Pictures)

東京電力 TEPSCO

3.4.3 Avce PSPP (Slovenia)

(a) Outline of Slovenian electric power situation

While Electric Utilities are horizontally-divided in Slovenia, most of them are almost monopolized by the state owned electric utility company, unlike other western European countries. There is no privatization plan such as power station sellout in the near future. Demand supply balance of the country is negative, which means that electricity is imported from neighboring countries like Italy. The capacity of the network is relatively small, approx. 2,000MW, and the back up power source for country's nuclear power plant (348MW) in one of the most concerned issues.

Ratio of power sources in generation amount is 40% for hydro power, 40% for thermal power, and 20% for nuclear power. The capacity of the nuclear power plant is 700MW and its output is shared with Croatia.

SENG is one of the hydro power producers under HSE, which is a state owned electric utility holding company having 25 hydro power plants at Soca River and its tributaries. Besides, HSE owns thermal and hydro power producers, coal mine, and so on. HSE also owns power trade companies outside of Slovenia, and their main purpose is the import (trade) of electricity.

After former Yugoslavia was divided, there was no PSPP in Slovenia, until SENG developed Avce PSPP in 2010 as the first PSPP in the country. Considering the effect of frequency control and economic efficiency (decrease in civil work cost and increase in equipment cost), installation of Adjustable Speed PSPP was determined. Necessity for additional PSPP is recognized as power storage facility, and there is a plan of another PSPP project at Kozjak.

Figure 3.21 Upper Reservoir of Avce PSPP

(b) Facility Outline

Commercial operation was started on April 1, 2010. It is one unit configuration with capacity of 185MW for generation and 180MW for pumping. Manufacturers are Mitsubishi Heavy Industry for pump/turbine (vertical shaft single stage Francis turbine), Mitsubishi Electric Corporation for generator/motor and control panel for adjustable speed, ABB for excitation system and PG panel, and domestic companies of ISKRA and KORONA for control and protection panel of generator. Total efficiency of pump/turbine and generator/motor is 77%.

Capacity of upper reservoir is 2.17 million m^3, that of lower reservoir is 0.42 million m^3, along Soca River, and effective head is from 500.2 m to 528.8 m.

In starting the pumping operation, self starting method is taken, with short circuit of main circuit, applying adjustable frequency from secondary excitation equipment through step-up transformer. Time for operation switches are 161 seconds from shutdown to generation, 241 seconds from generation to shutdown, 454 seconds from shutdown to pumping up, 211 seconds from pumping up to shutdown, 228 seconds from shutdown to phase control generation, and 360 seconds from shutdown to phase control pumping up.

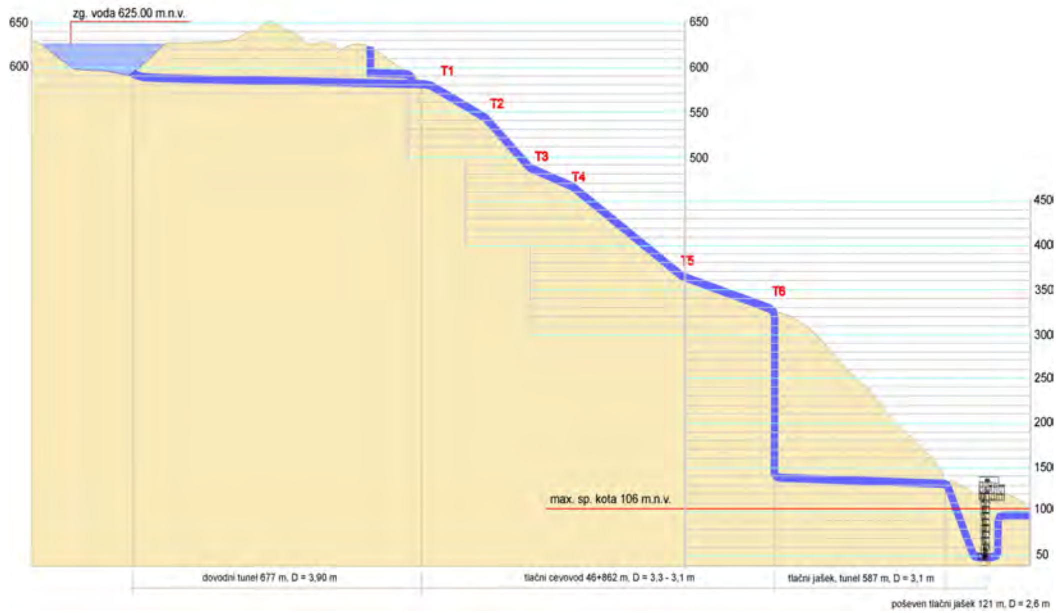


Figure 3.22 Outline of Penstock

(c) Situation of Operation

ELES, TSO of Slovenia, takes charge of demand supply control. Output instruction is issued from ELES, through SENG, transmitted to Avce PSPP.

Avce PSPP is operated for the purpose of supplying peak supply, with generation in the daytime and pumping up in the nighttime. In addition, it is used for secondary reserve to control frequency in the daytime and nighttime. Typical operation patterns in the weekday and weekend are shown in Figure 3.23.

Other than the operations of generation and pumping up, Avce PSPP has the operation modes of phase control generation and phase control pumping up, which are occasionally used for voltage control at the interconnection point with Italy. Currently, secondary reserve is not supplied between Slovenia and Italy in principle, there is the possibility to do in the future, provided that the necessary conditions are prepared.

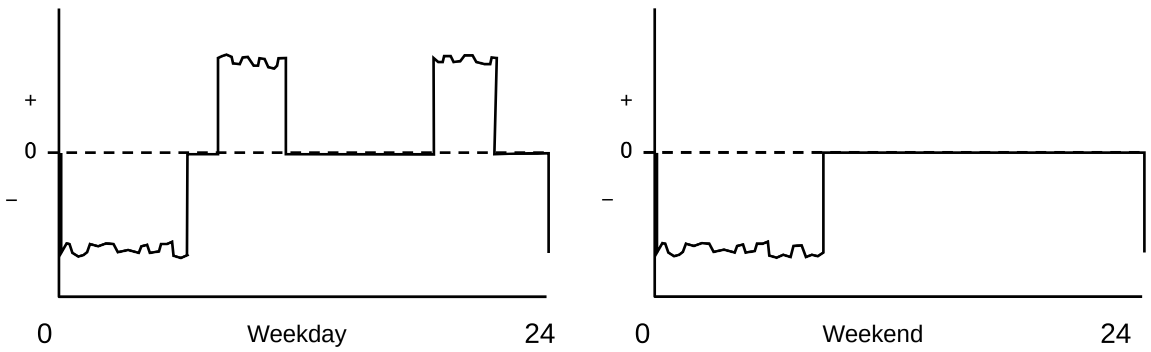


Figure 3.23 Operation Pattern of Avce PSPP

(d) Outline of power market and demand supply control

Power trade is conducted among power producers, power traders, and power suppliers, by means of bilateral contract and through the market. More trades are determined by the bilateral contracts than through the market, and generation plans are determined considering the situation of power trade.

Basically, demand supply plan is coordinated by the end of the Day Ahead Market, and the reserves for adjustment, such as primary and secondary reserves, are prepared from the Balancing Market.

It is required that power producer reserves 2% of its generation capacity as primary reserve. More reserves are prepared by the bilateral contract than from the market, and as a result, secondary reserves are prepared for the next 1 to 2 years.

3.5 Summary of Situation and Issues of PSPP in Europe

European countries have conducted aggressive renewable energy penetration based on the EU energy policy. As the result, effects of renewable energy penetration are appeared in the stage of system operation. From the cases of Germany, Spain and Italy, measures of system stabilization such as limiting output of the renewable energy and equipping additional functions are required, when renewable energy sources, especially hardly controllable power plants such as wind and PV power plants, are massively installed, exceeding 10% of the whole generated energy. In addition, the institution and the market to secure necessary ancillary service, including reserve capacity, are also required.

Even if the market is established, it is difficult to secure appropriate reserve capacity without proper incentive scheme. It is desirable that the institution, including investment scheme, is designed so that TSO who has the responsible for network operation can take necessary measures for system stabilization when necessary. At present, power storage technologies for the use of adjustment power sources with economically feasible are limited, including PSPP and NaS battery. When these technologies are kept available to utilize by TSO as appropriate, hardly controllable and hardly predictable renewable energy sources can be operated at their maximum availability.

Concerning the operation of PSPP, due to the increase of renewable energy and the formation of ancillary services market, some PSPPs are used for balancing demand and supply and obtaining revenue from the ancillary services market, in addition to the operation to supply for the peak demand. In addition, as mentioned in Chapter 2, since AS-type is capable of adjusting the input-output power in both generating and pumping, it will increase in Europe in a few years. Comparing the tandem-type, adopted in Kops II, and the AS-type, although tandem type has wider range of input adjustment, its water loss is greater and its shaft is longer so that vibration influence can not be negligible. And since tandem-type has the structure of separated pump and turbine connecting by clutch, AS-type could be more economical than tandem-type.

Chapter 4 Feasibility of Introducing Adjustable Speed PSPP in Turkey

4.1 Feasibility of Introducing Adjustable Speed PSPP in Turkey

4.1.1 Current Status of PSPP Development Plan in Turkey

As of September 2009, Turkey does not have any Pumped Storage Power Plants (PSPP). According to the report, “The Study on Optimal Power Generation for Peak Demand in Turkey (2009 – 2011)”, the necessity of PSPP was agreed upon among relevant organizations in Turkey, and two potential sites, Altinkaya and Gokcekaya, were selected for PSPP. The General Directorate of Electric Power Resources Survey and Development Administration (EIE), which conducted feasibility studies of planned power plants, started the site survey for the development of PSPP. Taking the implementation schedule into consideration, the commissioning of the first unit will be in 2023.

The required function of PSPP is not only power generation for peak demand but also the off-peak frequency adjustment function to improve power quality.

Therefore, the report advocates that it is essential to introduce an Adjustable Speed Pumped Storage (ASPS) Power Plant, input of which is variable during off-peak periods.

4.1.2 Issues on Introduction of PSPP in Turkey

From the recent requirement for power quality in Turkey, it is necessary to properly evaluate the value of its ancillary service when considering the introduction of PSPP, in addition to the economic advantage of the power supply as the peak supply capacity. Considering the situation, following four items are important in studying the PSSP development.

(1) Ratio of conventional hydropower plant and development potential

Table 4.1 shows the generation capacities of each power source in Turkey as of June 2010. It is shown that the conventional hydropower makes up about one-third of the whole.

On the other hand, as of January 2010, the Energy Market Regulatory Authority (EMRA) has issued licenses for 477 hydro sites, which amount to 13.7 GW.

Table 4.1 Generation Facility Composition in Turkey as of June 2010

	Capacity	Ratio
Thermal	29.6 GW	65.1%
Geothermal	0.1 GW	0.2%
Wind	1.0 GW	2.2%
Conventional Hydro	14.8 GW	32.5%
Total	45.5 GW	100.0%

(Source: Turkish Electrical Energy 10-year Generation Capacity Projection (2009-2018), TEIAS, June 2009 and TEIAS Web Page)

Figure 4.1 shows the load curve and supplied power sources on August 23 of 2008, when the maximum demand recorded.

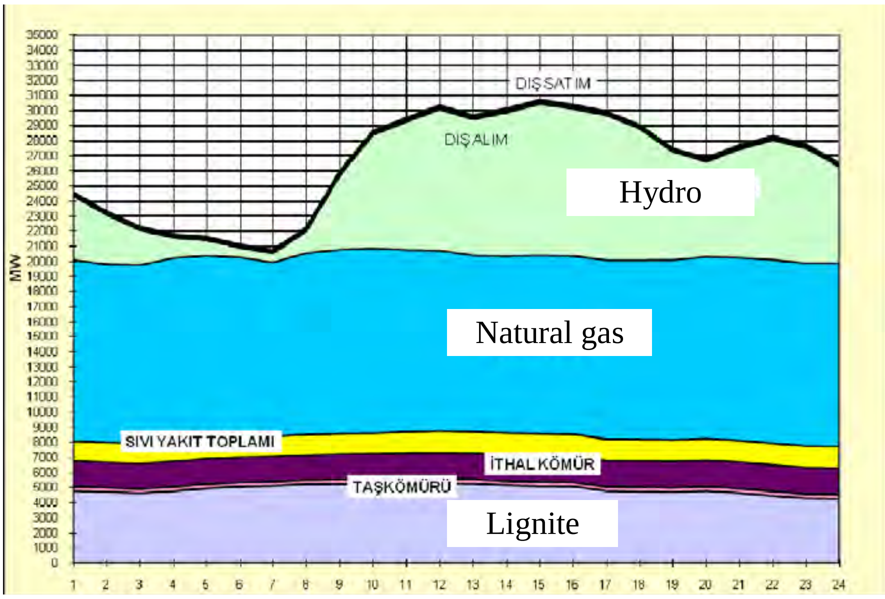


Figure 4.1 Load Curve by Power Source on August 23, 2008

(Source: Turkish Electrical Energy 10-Year Generation Capacity Projection (2009-2018))

The daily minimum demand is about 70% of the daily maximum demand. The gap between the maximum and minimum demand is not large. Basically, the gas-fired and lignite-fired thermal power plants are used as base supply and operated at constant output throughout the day, while hydropower is used to deal with the peak demand.

From this situation, hydro power plants are used for the ancillary service capacity during peak hours in the daytime, while there is the shortage of reserves for ancillary service during off-peak hours.

(2) Power trading market and demand supply control

Generation plan of the following day is determined through the Day Ahead Market by an hourly based transaction. At the Intraday Market, deviations from the generation plan are adjusted for every 15 minutes.

Out of the ancillary service to control the network frequency by adjusting generation output in response to the demand changes, primary frequency control takes the adjustment for the fluctuation from several seconds to a few minutes, and is secured by reserving 2% of the generation capacity of all generation units with 50MW and above, with the exception of the renewable energy power plants. Payments are made for the reserve as part of the fixed price in the contract.

Concerning the secondary frequency control corresponding to the fluctuation between from several minutes to 15 minutes and the tertiary frequency control corresponding to the fluctuation for more than 15 minutes, the bid will be conducted the day before, and the order of priority is determined by the merit order. The revenue is paid only if the plants are operated by the instruction from NLDC.

Hereafter, all thermal power plants will be owned by IPP in Turkey. Since IPPs earn by selling generated power to the network, they usually aim for higher operation level. Therefore, IPP thermal power plants have less incentive to suppress output even at the nighttime when the power demand is relatively low.

The primary reserve is required to have 300MW to 350MW, which corresponds to 1% of the demand, after the interconnection with European network, while it was 770MW, which was 2% of the demand before the interconnection.

The required secondary reserve was 770MW before the interconnection, and 770MW to 900MW after the interconnection, which corresponds to 5% of the generation units with 100MW and over.

Currently, daily maximum and minimum demands are 33,000MW and 18,000MW respectively. Since many of the hydro power plants are shut down in the nighttime, secondary reserve amount prepared from midnight to 6 am is around 600MW.

(3) Wind power penetration

Currently, approx. 1,500MW of wind power plants are operating, which amounts to 2% of generated energy, and 700MW are under construction. Turkey government gives priority to develop renewable energy sources, with the target of developing 20GW of wind power plants by

2023, according to the 2009 strategy paper, "Electricity Energy Market and Supply Security Strategy Paper", publicized by SPO. This policy encourages many IPPs to develop wind power plants, which leads to the 78,000MW amount of development license application to EMRA, and 7,500MW out of them are approved by October 2011. Hereinafter, there requires further screening and approval at other departments. Since it is estimated that the capacity of potential development is approx. 50GW and application of development license will be submitted aftertime, a large amount of wind power plants are likely to be introduced to the power grid in the near future.

Figure 4.2 shows the wind power generation in one week, April 01-07, 2011. The total capacity of wind power facilities is 1,415 MW at that time.

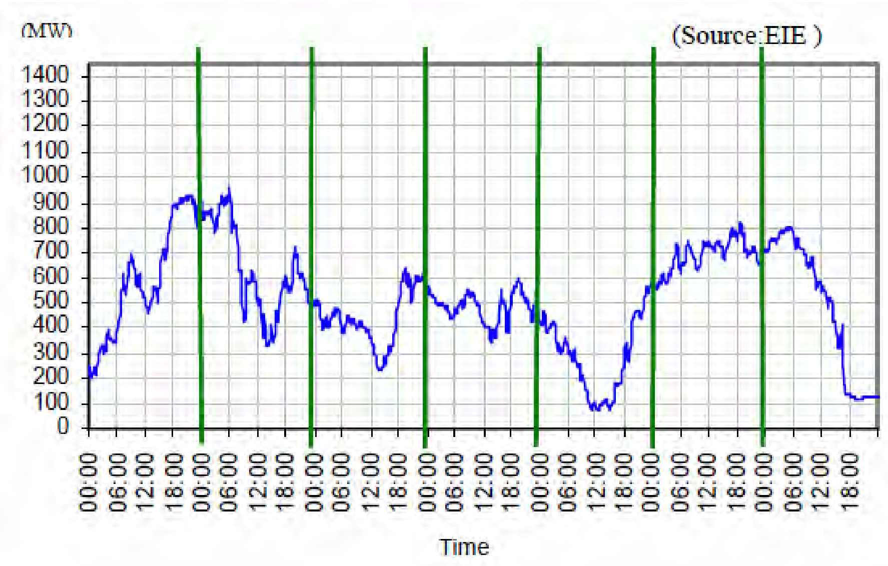


Figure 4.2 Wind Power Generation in One Week, April 01-07, 2011

As shown in Figure 4.2, fluctuation of wind power output is large. Figure 4.3 shows the assumption that the amount of the wind power facilities increases to 20,000MW. The output may change approximately 10,000MW in a day.

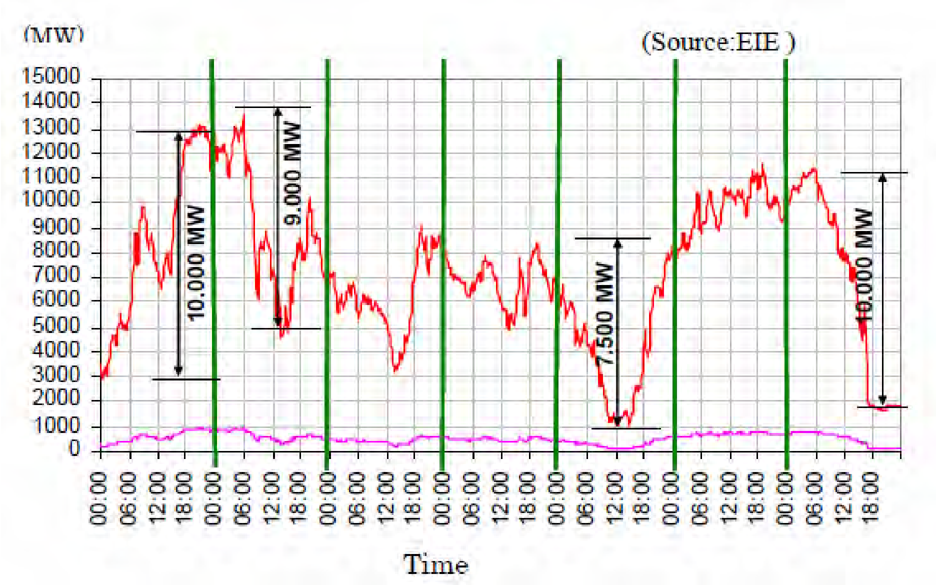
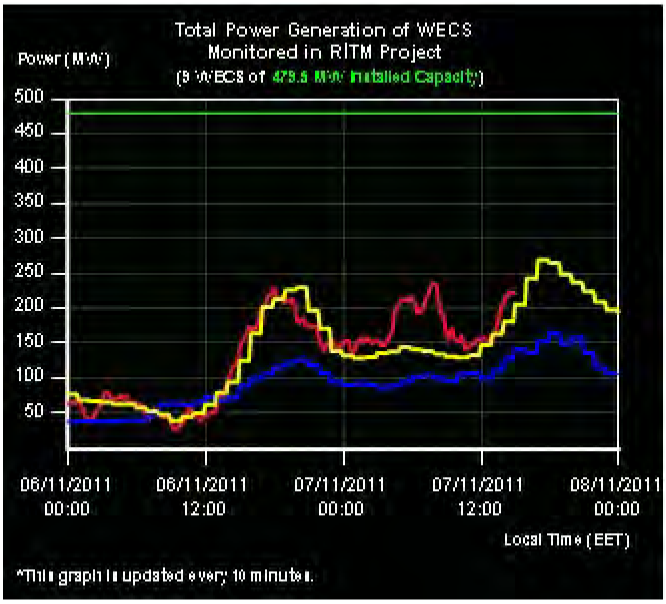


Figure 4.3 Assumption that the amount of the wind power facilities increase to 20,000MW

Since such large fluctuation of wind power output is foreseen, EIE and TUBITAK (Türkiye Bilimsel ve Teknolojik Araştırma Kurumu) have developed the software to forecast the wind power output, and publicize the forecast value (10 hours in advance) on the web site (http://www.ritm.gov.tr).

The following diagram shows example of forecast that is publicized on the web site. It is evaluated that this software does not have enough precision so far, with unforeseen output changes recorded.



(Source: http://www.ritm.gov.tr)

Figure 4.4 Example of prediction

(d) Interconnection with the EU network

Turkey has the interconnectionwith Europe via 380kV transmission lines, for two circuits with Bulgaria and for one circuit with Greece. Previously, these interconnection circuits were used to supply power making the isolated areas of the other country, On September 18, 2010, Turkey started the synchronized interconnection through these circuits. Currently, it is in test operation, with keeping 0MW at the beginning of the interconnection, and started to increase. From July 2011, they are operated at 500MW (Bulgaria to Turkey: 200MW, Greece to Turkey: 100MW, Turkey to Bulgaria: 133MW, Turkey to Greece: 67MW). It is planned to increase to 1,000MW and 1,500MW, step by step.

At the initial stage of interconnection, the power fluctuation with 0.15Hz occurred on the interconnection. It is considered to be caused by the influence of Turkey's iron factory and the long transmission line from the eastern power generation area to the western power consumption area. This problem had been solved by adjusting the PSS setting of the generations in Turkey.

In starting the synchronized interconnection, the protection system was installed in the Hamitabat Substaion near the Bulgaria border. This protection system monitors the power flow of the interconnection every two second, and operates for maintaining interconnection by shedding the generators or loads in Turkey if the power flow exceeds the setting value.

4.1.3 Economy of PSPP introduction in Turkey

(1) Effect of Introduction of PSPP

The merits of PSPP introduction are considerd as follows.

(a) Power Generation for Peak Demand

Annual fixed costs of PSPP are so cheap that PSPP is better than the other kind of power plants for peak demand while annual load factor is less than 20%.

(b) Equalization of Load Curve of Thermal Power Plant

Increasing the thermal power output with cheap fuel during off peak, pumping the water from lower reservoir to upper reservoir during off-peak and generating electricity during peak, PSPP is able to suppress the output of thermal power plant which fuel costs is expensive and equalize the Load Curve of Thermal Power Plant.

(c) Provision of Ancillary service

During operation, rapid adjustment of output (or input) can alleviate the upset of system frequency. Also, during stopping, PSPP, which has ability to start generation in about 5 minutes from the operation command, contributes to ensure tertiary reserve power, which is in preparation for large generator stopping and rapid change of load and wind power output.

(2) Economy of Power Generation for Peak Demand

A generating cost for each availability factor is calculated based on construction cost (fixed cost) and fuel cost (variable cost) of various power sources, and then which power source is optimal as peak supply capacities are examined.

(a) Annual fixed cost

By reference to the values provided from EIE, standard unit construction costs for various powers used for calculating the costs in the base case have been set, and then the annual fixed costs are calculated as shown in Table 4.2 based on the unit construction costs. Generally speaking, the annual fixed costs differ depending on the depreciation methods, and are the highest just after the start of operation rather than being constant every year. In this case, equalized costs by lifetime are shown assuming that the interest rate is 10%. Note that the calculations were made assuming that the lifetimes for generation facilities are 40 years for hydro facilities where civil engineering facilities account for a large proportion, and 20 years for thermal facilities, respectively.

Table 4.2 Annual Fixed Cost

	Unit construction cost (USD/kW)	Annual expense rate (%)			Annual expense (USD/kW/ year)
		Interest rate, depreciation	O&M costs	Total	
Natural gas-fired thermal (C/C)	700	11.75	4.5	16.25%	113.8
Natural gas-fired thermal (GT)	500	11.75	5.0	16.75%	83.8
Oil-fired thermal (ST)	800	11.75	2.5	14.25%	114.0
Lignite thermal	1,600	11.75	3.5	15.25%	244.0
Import-coal fired thermal	1,600	11.75	3.5	15.25%	244.0
Conventional hydro	1,400	10.23	0.5	10.73%	150.2
Pumped Storage Power Plant	800	10.23	1.0	11.23%	89.8

(b) Fuel cost

The fuel cost projection until 2030 published by IEA in 2009 has been used for the future fuel cost projection. Fuel costs in standard power plants in 2020 are calculated based on the price projection, as shown in Table 4.3

Table 4.3 Fuel Cost

	IEA forecast (2020)		Fuel price (USC/kcal)	Efficiency	Fuel cost (USC/kWh)
Oil ST	100.0 USD/bbl	9,600 kcal/kg	7.3	38%	16.5
Oil GT	Ditto	Ditto	Ditto	29%	21.6
Gas C/C	12.10 USD/Mbtu	4.0 kcal/Btu	4.8	55%	7.5
Gas GT	Ditto	Ditto	Ditto	29%	14.2
Coal ST	104.16 USD/tonne	6,000 kcal/kg	1.7	41%	3.6

(c) Generating cost

Standard generating costs for various power sources in 2020 are calculated as shown in Table 4.4 based on the above-described projections of the unit construction costs and fuel costs. Note that the fuel cost for PSPP is based on the assumption that water is pumped by coal-fired thermal power and pumping efficiency is 70%.

Table 4.4 Generating Cost for various power sources

	Const. cost (USD/kW)	Annual fixed cost (USD/kW/yr)	Fuel cost (USC/kWh)	Generating cost (USC/kWh)		
				L.F=10%	L.F=40%	L.F=80%
Hydro	1400	150.2	0.0	---	4.3	---
PSPP	800	89.8	5.2	15.5	---	---
Gas CC	700	113.8	7.5	20.5	10.7	9.1
Gas GT	500	83.8	14.2	23.8	16.6	15.4
Oil ST	800	114.0	16.5	29.5	19.8	18.1
Oil GT	500	83.8	21.6	31.2	24.0	22.8
Import Coal	1600	244.0	3.6	31.5	10.6	7.1

In the peak supply capacity region (i.e., the range where the availability factor is 20% or less), Facilities with lower annual fixed unit prices are economically advantageous. Because Gas Turbine which annual fixed cost is the lowest is very high fuel cost, PSPP which annual fixed cost is relatively low has become the most economic power supply for peak.

(3) Values of Ancillary service

(a) Needs of Ancillary service

In the last section, the comparison was made about the only sum of fixed and variable (fuel) costs by focusing on the economics. In other words, benefits deriving from the ability to provide ancillary service, which is one of the major features of various peaking power plants, are not incorporated. Whether ancillary service is available or not is a factor which has an important impact on the level of power quality. For Turkey, which is required to raise its power quality, it will be essential to appropriately evaluate the value of ancillary service.

The availability of various ancillary service for a variety of peaking power plants is described below.

Table 4.5 Ancillary Service of Various Peaking Power Plants

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">Frequency Control (Primary & Secondary reserve)</th><th rowspan="2">Stand-by operation (Tertiary reserve)</th></tr>
<tr><th>Peak period</th><th>Off-peak period</th></tr>
<tr><td colspan="2">Pumped storage power plant</td><td>♦ Possible</td><td>♦ Possible via pumping operation （in a case of adopting variable-speed pump）</td><td>♦ Possible</td></tr>
<tr><td colspan="2">Reservoir type hydro</td><td>♦ Possible</td><td>♦ Possible but very uneconomical during hours with low marginal cost</td><td>♦ Possible</td></tr>
<tr><td colspan="2">Gas turbine （GT）</td><td>♦ Possible</td><td>♦ Possible but very uneconomical during hours with low marginal cost</td><td>♦ Possible （slower than hydro）</td></tr>
<tr><td colspan="2">Buying power from other countries</td><td>♦ Possible</td><td>♦ Possible</td><td>♦ Possible （dependent on other countries）</td></tr>
<tr><td rowspan="2">Refer</td><td>Combined （C/C） thermal</td><td colspan="2">♦ Possible by adding adjustment equipment, but need to lower output to operate and somewhat uneconomical.</td><td>♦ Possible （slower than GT）</td></tr>
<tr><td>Coal-fired thermal</td><td colspan="2">♦ Possible by adding adjustment equipment, but need to lower output to operate and considerably uneconomical.</td><td>♦ Impossible</td></tr>
</table>

Different peaking power plants have very similar ancillary functions, but only PSPP and system to buy power from other countries have frequency control function during off-peak periods. During off-peak period, if there are conditions under which conventional hydropower plants and combined-cycle thermal power plants can make frequency adjustments, the off-peak frequency adjustment functions that PSPPs have cannot be seen as greatly valuable. However, looking at the current status and future of Turkey, the country will face the following challenges, and TSO will likely to have considerable difficulty in adjusting frequencies during off-peak hours. This means frequency adjustment function during off-peak hours will be of high value.

- Issues in power plants to supply frequency adjustment function
  - A majority of conventional hydropower plants of large and medium capacity (50 MW or larger) are shut down during off-peak hours.
  - Combined-cycle thermal power plants owned by private companies aim to operate at the maximum output as much as possible rather than making output adjustment.
- Increasing needs of frequency adjustment
  - Large-scale introduction of wind turbines whose output largely fluctuate during short duration.
  - The introduction of nuclear power plants which constantly operate at the maximum

output is planned.

(b) Needs of Ancillary service

The breakdown of the transmission tariffs of different European countries described in “ENTSO-E Overview of Transmission Tariffs in Europe: Synthesis 2010” (September 2010) is shown in Figure 4.5.

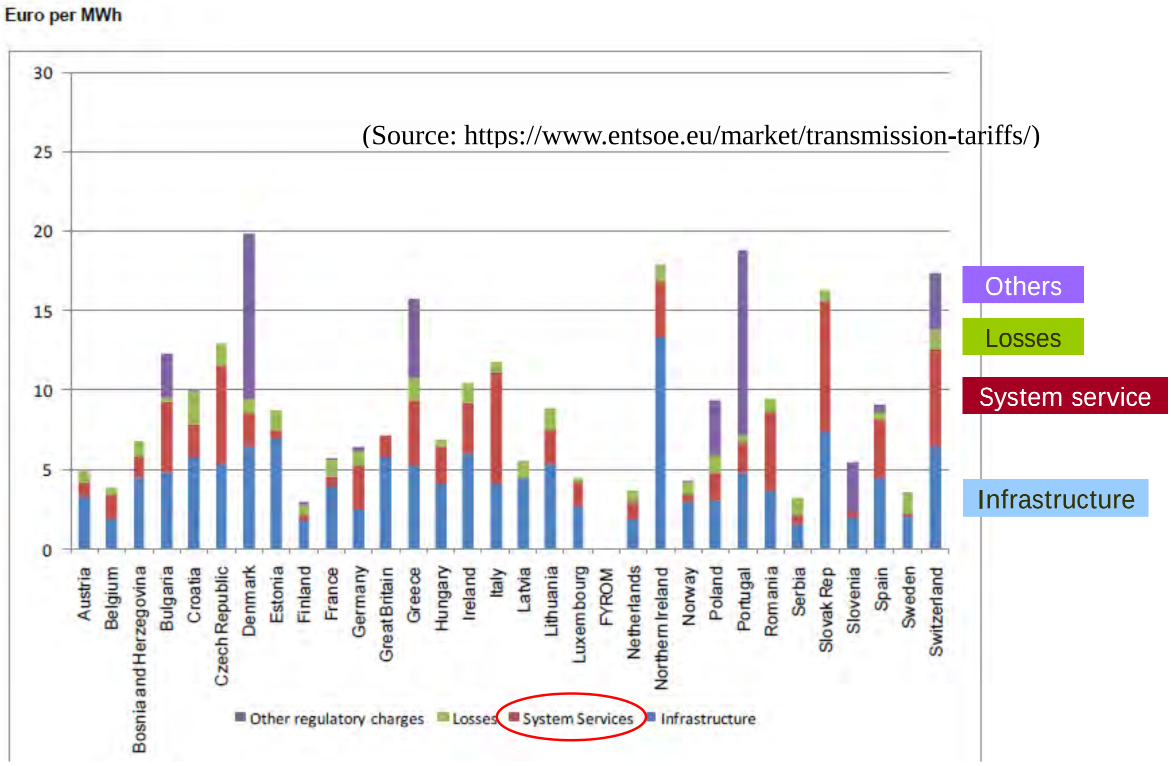


Figure 4.5 Transmission Tariffs of European countries

This cost is considered necessary expenses in order that each TSO operates domestic electricity system stably. Although prices for system service including primary reserve, secondary reserve, tertiary reserve, voltage control, and so on, vary from country to country, the average is around 3 Euro/MWh (4 USD/MWh). By using this figure, the value of frequency adjustment function was calculated and the result is shown below:

- Off-peak power demand in 2020 : 40,000 MW
- System service charge necessary for implementation: 40,000 MW × 4USD/MWh = 160,000 USD/hour
- Frequency adjustment capacity necessary to implement the system (2% of demand): 40,000 MW × 0.02 = 800 MW
- Frequency adjustment capacity per 300 MW pump: 50 MW (equivalent of 6.25% of

required amount)

operating at about 250MW and varying input according to the system frequency in the range of 200MW-300MW.

- This means frequency adjustment function per pump of 300 MW is equivalent of 10,000USD/hr.
- Assuming that annual off-peak operation time is 500 hours, the value is equivalent of 5 million USD a year.

(4) Comprehensive Evaluation

The comparison of annual expense in case that 300MW PSPP is introduced to the power system in Turkey was conducted. In this comparison, economic values on overall of Turkey were evaluated.

(a) Power Generation for Peak Demand

If PSPP was developed for peak demand, the development of other power supply such as gas turbine, etc. for can be omitted for the same amount of PSPP devolopment.

1) Additional Cost for PSPP (construction cost: 800 USD/kW)

- 300MW x 800USD/kW = 240 million USD
- Annual Additional Cost : 240 million USD x 11.28% = 27.1 million USD/year

2) Value by Omitting Gas Turbine Development

Regarding omitted gas turbine, its unit construction cost is 500 USD/kW, annual expense ratio is 16.75%, and fuel cost is 14.2 USC/kWh. In addition, variable cost of PSPP is considered in the condition of pumping by coal-fired power plant during off-peak, fuel cost 3.6 USC/kWh, and pumping efficiency 70%.

- Annual Fixed Cost of Gas Turbine : 500 million USD x 300MW x 16.75% = 25.1 million USD/year
- Reduction of fuel cost : (14.2 USC/kWh – 3.6/0.7) x 300MW x 500hr =13.5 million USD/year

3) Benefit (Value - Cost) : 11.5 million USD/year

(b) Ancillary Service during off-peak

If AS-PSPP is introduced, It can provide Ancillary service during off-peak. In this section, economic evaluation of ancillary service was conducted.

1) Additional Cost for AS-PSPP

Regarding the construction cost of AS-PSPP, the cost of mechanical and electrical equipments of AS-PSPP is about 30% higher than of PSPP. According to the report,

"REPUBLIC OF TURKEY THE STUDY ON OPTIMAL POWER GENERATION FOR PEAK DEMAND IN TURKEY", conducted from 2009 to 2010, the percentage of mechanical and electrical equipments cost is assumed 30% in overall construction cost.

Therefore, if AS-PSPP was adopted, the mechanical and electrical equipments cost would be 240USD/kW because PSPP which unit construction cost is 800USD/kW. As a result, the additional cost is 72USD/kW.

- Additional Cost for 300MW PSPP : 300MW x 72 USD/kW = 21.6 million USD
- Additional Annual Cost : 21.6 million USD x 11.28% = 2.4 million USD/year
- Value of Ancillary service
- In case of 500hr operation : 5 million USD/year

2) Benefit (Value - Cost) : 2.6 million USD/year

4.1.4 Comparison of AS-PSPP and Tandem-Type PSPP

Conventional constant-speed machine is not able to provide ancillary service basically when pumping due to inability to change the input. To cover this weakness, Kops II of Austria (refer 3.3.2) generates electricity power by flowing some part of pumped water to the generator waterwheel, and change the total input power by changing the amount of its generation, and provide ancillary service. (Pump and generation wheel of Kops II are placed in same shaft, so it is called tandem-type PSPP.)

Both of Tandem type-PSPP and AS-PSPP are able to provide ancillary service basically. Thus, They are expected same benefit in terms of ancillary service function, but are different in terms of original operation of PSPP. In light of this, economc comparison was conducted.

(1) Difference in Operational Characteristics

The difference in operational characteristics of the both is shown as follows.

Table 4.6 Difference in Operation Characteristics

	Tandem Type (Kops II)	Ajustable Speed Type
Switching from generation to pumping-up	Almost 1 minutes The rotating direction of Generator/Motor is same.	More than 10 minutes The rotating direction of Generator/Motor is reverse, it is necessary to stop once.
Stable operation range	Generation : 5% ～ 100% Pumping : 0% ～ -95%	Generation : 50% ～ 100% Pumping : -70% ～ -100%
Efficiency	Almost same (maximum efficiency) Higher than Adjustable Speed Type at partial load	Almost same (maximum efficiency)
Water flow at pumping	To secure same generation output, additional pumping required	Pumping-up water is bigger than that of Tandum Type

Water operational method during generation and pumping of both types is shown as follows.

There is no difference of water operation of both types during generating and 100% pumping operation. However, during input adjustment, the amount of pumped water of Tandem type-PSPP is smaller than of AS-PSPP at same input. This trend becomes noticeable when input is low. This is due to necessary for tandem type-PSPP to increase the amount of generation in order to decrease input during pumping operation.

Because six Pelton water wheels are used in Kops II, the lowest load factor is very low. But if Francis water wheels are used, the minimum output is about 40%.

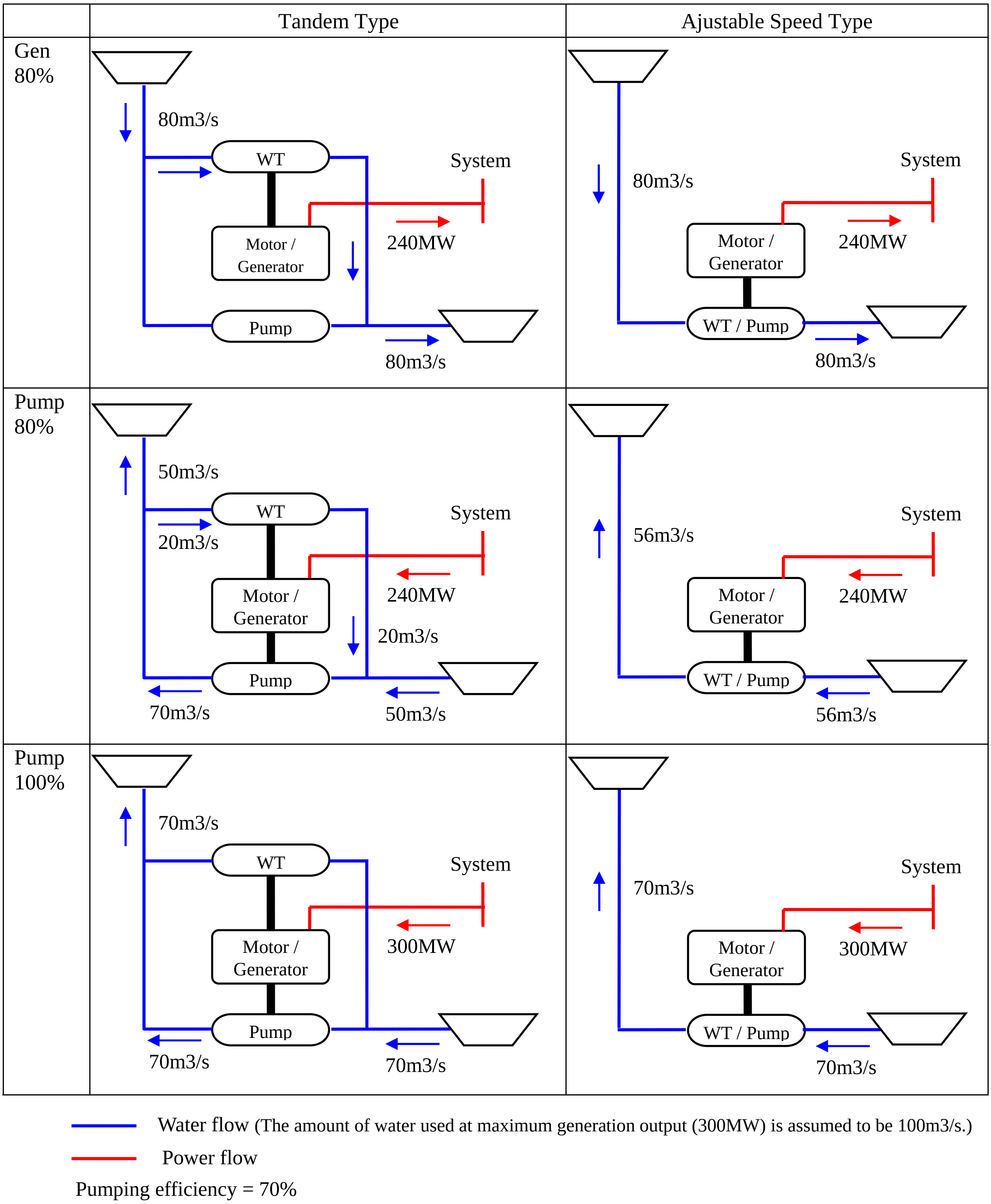


Figure 4.6 Water operational method during generation and pumping of both types

(2) Economic Comparison

(a) Calculation Condition

Economic comparison of AS-PSPP and Tandem type PSPP is conducted in the condition as follows.

- Owner of PSPP conducts electricity transaction in the market.
- Selling price of generation : 12 cent/kWh
- Buying price for pumping : 2 cent/kWh
- Price of ancillary service : 4 cent/kWh (both direction : Up/Down)
- Ancillary service : 45MW (15% of 300MW)
- Pumping efficiency : 70%
- Operation range : 85% +/- 15% (from 70% to 100%)

(b) Calculation Result

Relation between the time to provide ancillary service during pumping operation and income is shown as follows.

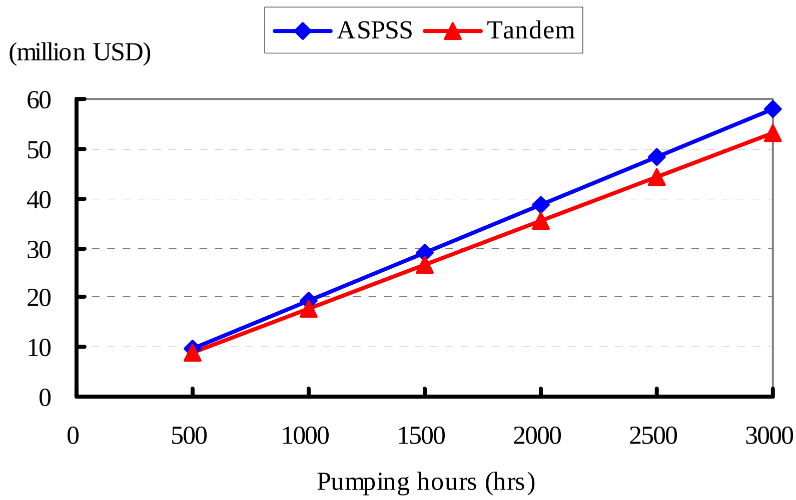


Figure 4.7 Relation between the time to provide ancillary service during pumping operation and income

If unit construction cost of PSPP was 800USD/kW, the additional cost would be 27.1 million USD per year for 300MW PSPP introduction. Therefore, in case that pumping operating hours are not more than 1500 hours, both types of PSPP is no economic advantage at the above condition.

In case that pumping operation time is 500 hours which is relatively little, there is not a large difference about income from power generation between tandem type-PSPP and AS-PSPP.

However, if the pumping operation time becomes longer, AS-PSPP can pump more water than Tandem type-PSPP, and can earn more income than tandem type-PSPP. Therefore, economical dvantage of AS-PSPP becomes remarkable.

4.2 Design for ASPS System in Gokcekaya PSPP

Based on the plant design condition of Gokcekaya PSPP in the report, "The Study on Optimal Power Generation for Peak Demand in Turkey (2009 – 2011)", the pump characteristics of the pumpturbine are designed as shown in Figure 4.8.

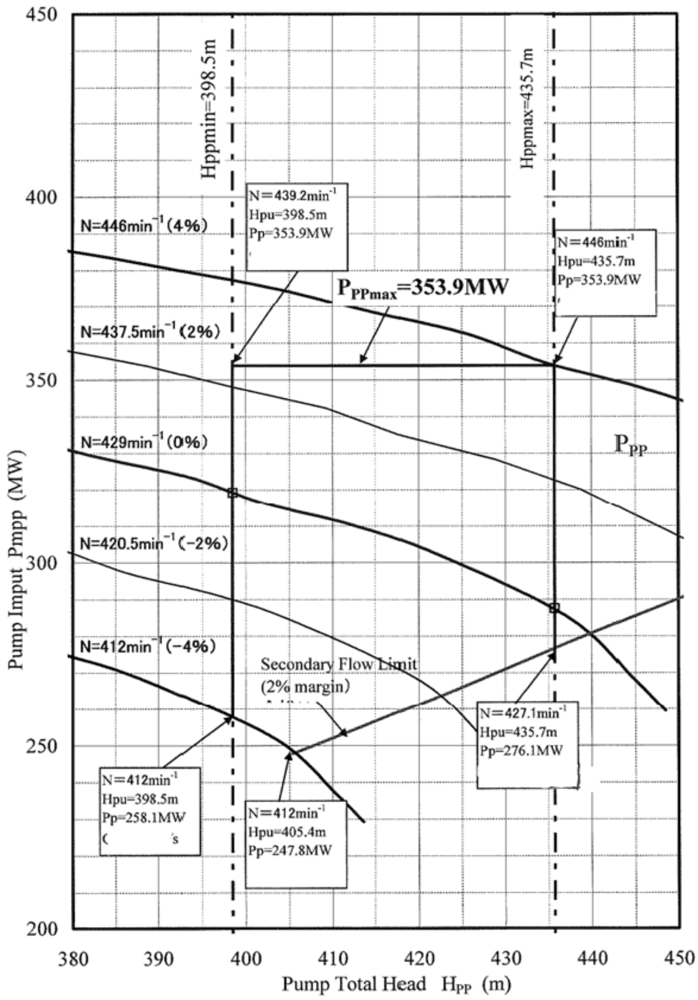


Figure 4.8 Pump Characteristics

According to this characteristic diagram, maximum pumping head is 435.7 m, minimum pumping head is 398.5 m, and maximum pump input is 353.9 MW. Adjustable speed range is designed as ± 4% to the rated rotation speed of 429 min^{-1}. This speed range is minimum value necessary for starting the unit in pumping mode by the excitation system.

Rated capacity of generator-motor is 412 MVA considering plant power factor of 0.9. Adjustable range of pump input at minimum pumping head is from 258.1 MW to 353.9 MW. Expected minimum partial load in generating mode is 35% for all head with this pumpturbine.

4.3 Workshop on Introducing AS-PSPP

4.3.1 Purpose

EIE hosted the workshop of AS-PSPP inviting related organizations in Turkey, for the purpose of publicizing the technology and advantages of AS-PSPP and further understanding the application of it in Turkey.

4.3.2 Outline

Date and time: Wednesday, October 26, 2011, 10:00-15:00

Venue: EIE

Attendants: EIE Mr. Maksut SARAC, et. al.
TEIAS, EUAS, EMRA, JICA, and other related organizations,
Approx. 60 attendants

Presenter: JICA Study Team

Contents:

- Situations in Europe - Power Market, Renewable Energy and PSPP -
- Adjustable Speed Pumped Storage System
- Economical Evaluation of PSPP
- Operation of PSPP and Adjustable Speed PSPP in TEPCO

In the workshop, situation of power market and renewable energy development in Europe, operation of PSPP in Europe based upon the situation, outline of Adjustable Speed PSPP technology, characteristics and advantages, economic evaluation in introducing Adjustable Speed PSPP in Turkey, and operational issues of PSPP and Adjustable Speed PSPP in Japan, are reported.

Following the presentation, lively discussions and questioning are held on the following topics.

- Application of flywheel for power system stabilization
- Costs of installation of Adjustable Speed PSPP
- Maintenance of Adjustable Speed PSPP
- Replacing existing hydro power plant with adjustable speed system (generation only)
- Experience of Adjustable Speed PSPP in Japan

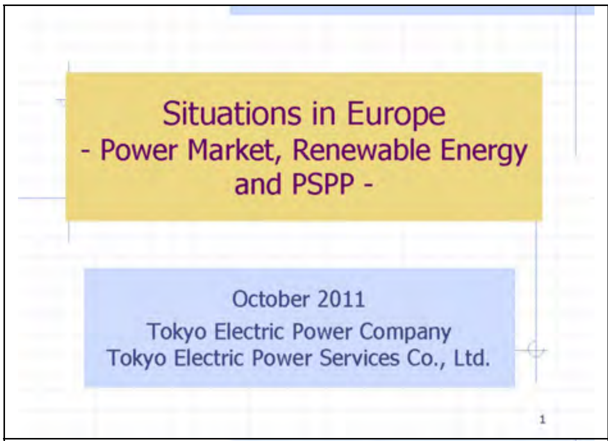
The workshop was wrapped up by the closing remarks by Maksut SARAC as a representative of the host. "In Turkey, development of nuclear power plant and increase of wind power plants are seen hereafter, and PSPP is required for balancing demand and supply and for securing the necessary reserves in response to this situation. We are currently studying to introduce PSPP at

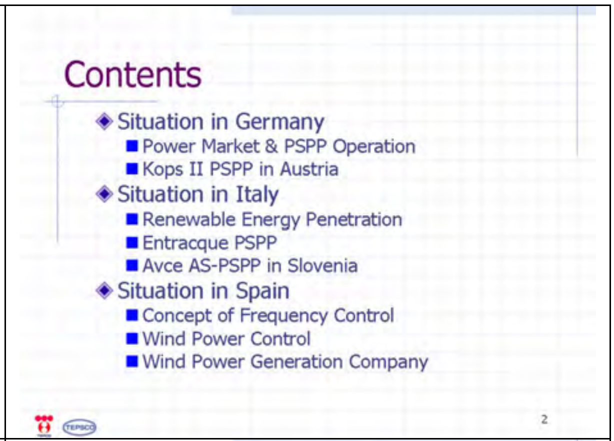
Gokcekaya. Thanks to the presentation today, advantages of Adjustable Speed PSPP ware clarified and we recognized that this is what we need. It is also clarified that this technology can be applied to conventional hydro power plants as well as for PSPP. We would like to advance toward the installation of this facility for the sake of Turkey, with the cooperation of Japan, hereafter as well."

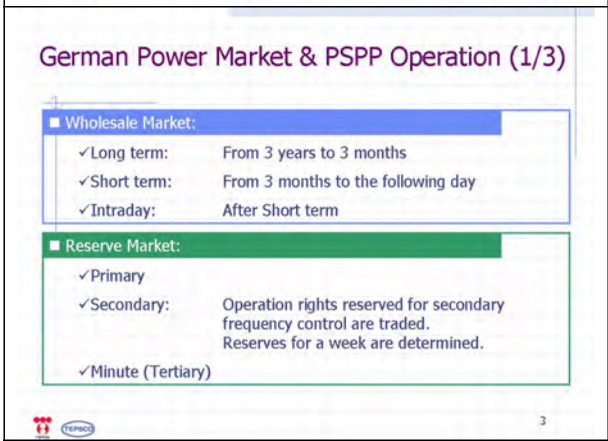
Figure 4.9 Workshop at EIE

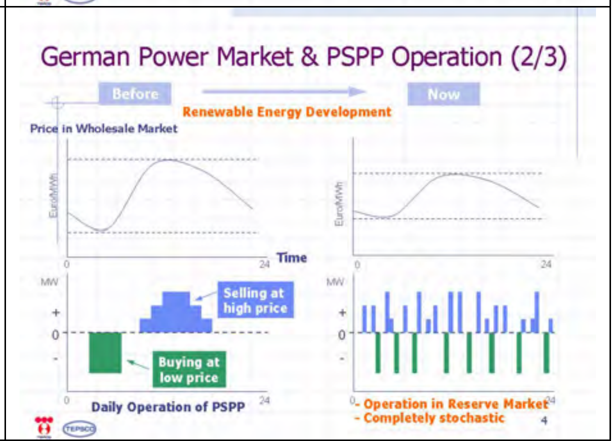
4.3.3 Contents of Workshop

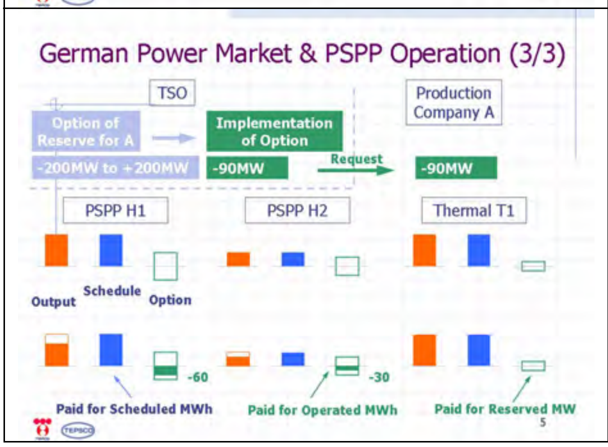
(a) Situations in Europe - Power Market, Renewable Energy and PSPP -

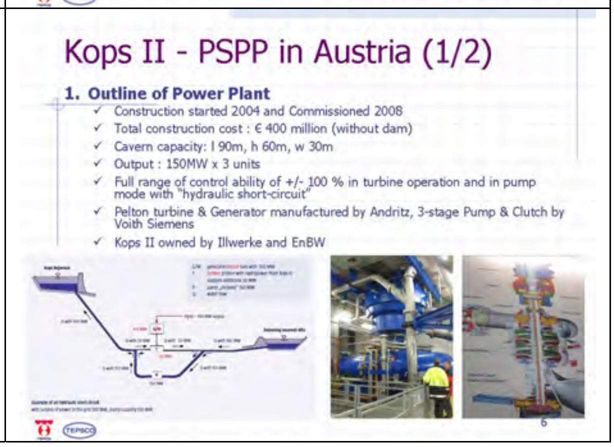












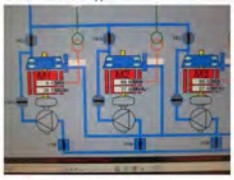
Kops II - PSPP in Austria (2/2)

2. Plant Operation

- ✓ Generating/pumping mode is changed 14 times per unit per day.
- ✓ Plant operation is instructed by Illwerke and EnBW and the share of annual energy production is almost even.
- ✓ When the whether in Germany is good, photovoltaic power plant generates electricity a lot. Therefore, Kops II is operated in pumping mode at noon.

3. Other Information

- ✓ Illwerke will start a project Obervermuntwerk II, the new PSPP similar to Kops II system. The capacity is 2x180MW and the turbine and pump are horizontal Francis type.



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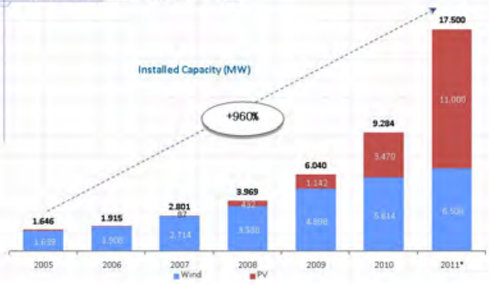
Italian Case of Renewable Energy Penetration (1/4)

- Increase of Renewable Energy



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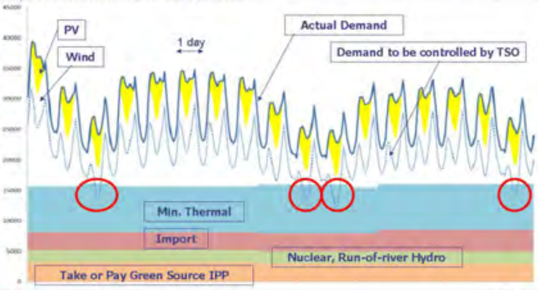
Italian Case of Renewable Energy Penetration (2/4)

- Case of 2011 Summer - 17 days sample: Weekend demands became below minimum supply level



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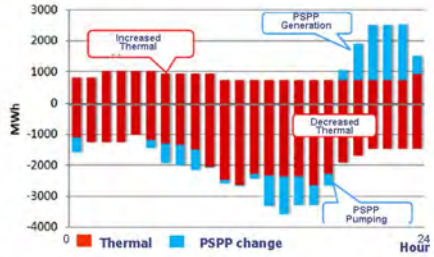
Italian Case of Renewable Energy Penetration (3/4)

- Amount of changes from operation plan, due to PV/Wind power output fluctuation on Sunday. 19/6/2011



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Italian Case of Renewable Energy Penetration (4/4)

- 64% of PSPP are in north region.
- Many PV and wind power are located in south region.
- Interconnection between north and south is limited.
- Wind Power Control
  - Terna can monitor, forecast and control wind power output.
  - When reserves for balancing are shortened due to the increase of wind power,
    - Reduce the thermal power plant outputs depended on the price list of Secondary and Tertiary market
    - Stop the import from neighboring countries
    - Limit the wind power outputs
  - When the wind power outputs are controlled, Terna has to compensate for the "un-served energy."
- Development of power storage plant in south region (PSPP, NAS battery)
- Enhancement of interconnection

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Entracque - PSPP in Italy (1/2)

1. Outline of Power Plant

- ✓ Commissioned in 1980
- ✓ Total output : 1,190MW
- ✓ Chiotas : 8 Reversible units, 1,065MW in total
- ✓ Rovina : 1 Ternary (Generator-Turbine-Pump) unit of 125MW
- ✓ Effective head : 1,050m for Chiotas, 600m for Rovina
- ✓ Penstock : 2 for Chiotas, 1 for Rovina

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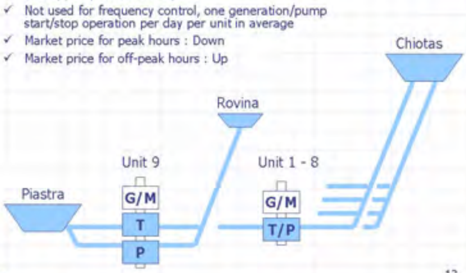
Entracque - PSPP in Italy (2/2)

2. Plant Operation

- ✓ Units 1 to 8 : No output control, Rated output only
- ✓ Unit 9: Generation output is controllable from 40% to 100%, pump is constant speed
- ✓ Not used for frequency control, one generation/pump start/stop operation per day per unit in average
- ✓ Market price for peak hours : Down
- ✓ Market price for off-peak hours : Up



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Avce - AS PSPP in Slovenia (1/2)

1. Outline of Power Plant

- ✓ Commercial operation : April, 2010
- ✓ Number of unit : 1
- ✓ Output : 185MW/turbine, 180MW/pump
- ✓ Pump/turbine type : Francis turbine, vertical
- ✓ Average net head : 498m
- ✓ Efficiency : 0.77

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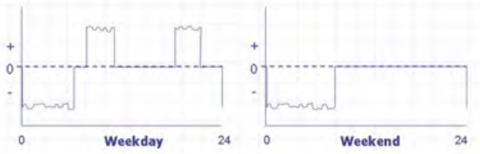
Avce - AS PSPP in Slovenia (2/2)

2. Plant Operation
- ✓ Operation schedule determined day ahead : Generating in daytime of weekday, Pumping in nighttime
- ✓ Secondary frequency control in Slovenia : Generating/pumping
- ✓ Phase control operation mode : To be used for voltage control



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Spanish Concept of System Frequency Control

- Primary 400MW in Spanish System
- Secondary and Tertiary are purchasing from Market
- Results of bidding, Majority of Secondary and Tertiary reserves are from French
- Wind outputs are limited when wind outputs are estimated over reserve capacities based on the law

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Wind Power Control in Spain

- Wind firms over 1MW are monitored.
- REE can monitor, forecast and control wind power output.
- When wind power output forecast exceeds reserve capacity, REE orders a power reduction to thermal power plants from the price list of Tertiary market
- When primary and secondary reserves can not be prepared, wind power outputs are limited.

- ENTSO-E has drafted a new common regulation of grid code including renewable energy
- The Draft includes Voltage and Frequency control duty of renewable energy
- REE is preparing the draft law of renewable energy grid code in following the draft of ENTSO-E regulation

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EURUS - Wind Power Generation Company

Eurus Energy

- FACT: Wind Power (WP) in SPAIN
  - YR 2010: 20,676 MW installed.
    - Eurus: 553MW in Spain.
  - Plan: 35,000 MW in YR2020.
- ISSUE: Dispatch Order to lower the output
  - Ruled by Law.
  - No compensation for the opportunity revenue.
  - Obey the order, because of small financial damage so far.
- Future: WP needs to add Frequency Control function.
  - Under study by REE.
  - Regulation on Power factor.
  - Might be applied to existing units, while the cost would be recovered by premium on tariff.

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Thank you for your attention.

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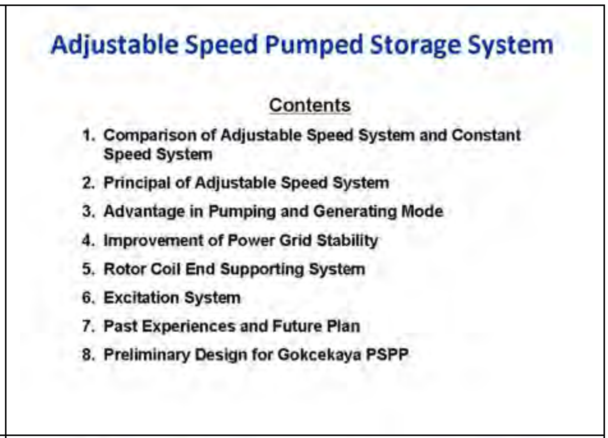
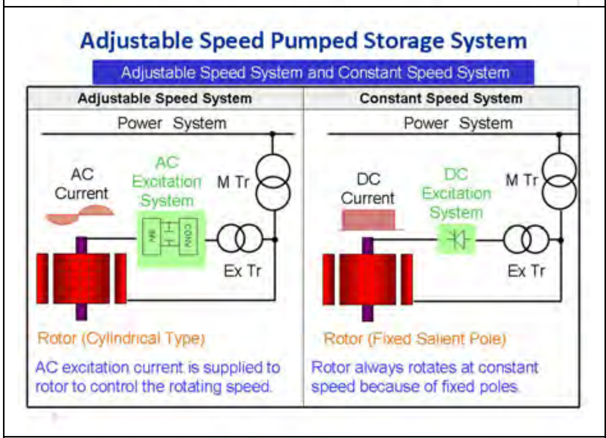
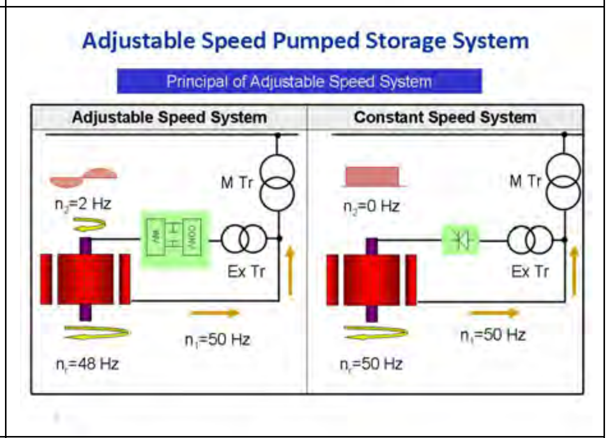
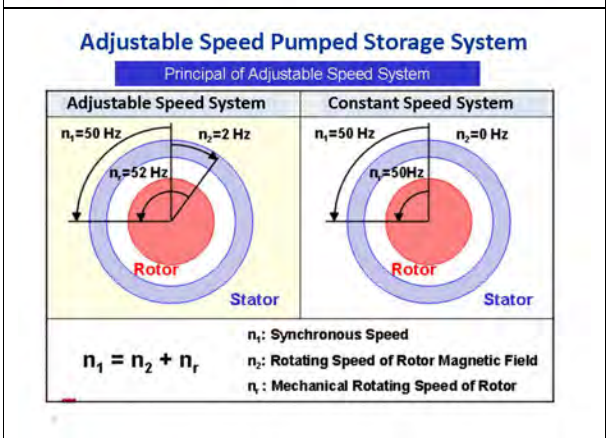
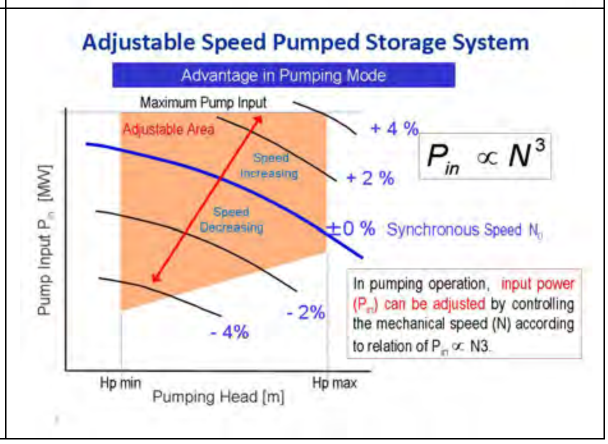
(b) Adjustable Speed Pumped Storage System





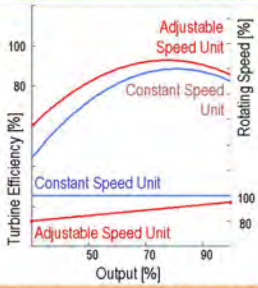






Adjustable Speed Pumped Storage System

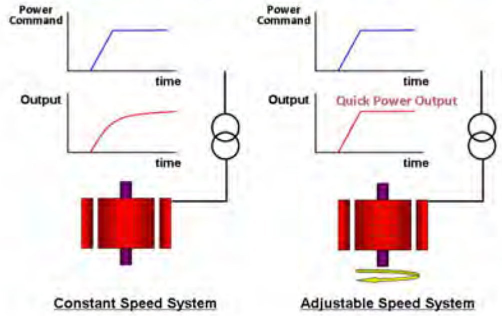
Advantage in Generating Mode



Adjustable Speed Machine can operate at the best efficiency by adjusting the mechanical rotating speed to optimum operating point

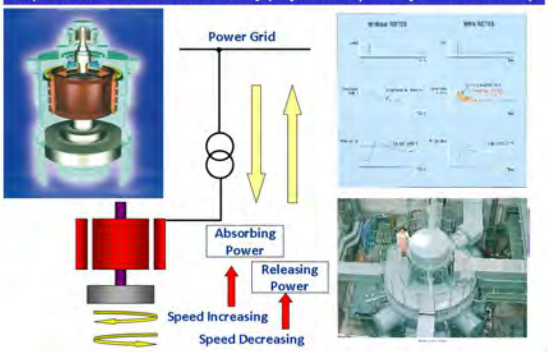
Adjustable Speed Pumped Storage System

Improvement of Power Grid Stability



Adjustable Speed Pumped Storage System

Improvement of Power Grid Stability (Adjustable Speed Flywheel Generator)



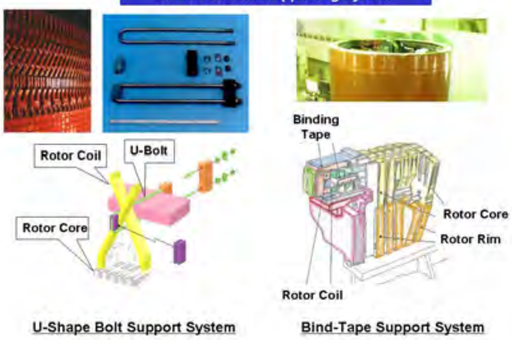
Adjustable Speed Pumped Storage System

Comparison of Adjustable Speed System and Constant Speed System

	Constant Speed	Adjustable-Speed	Remarks
Dam Volume	Almost same		Adjustable speed system can utilize water level much lower than Constant speed system.
Cavern Volume	100 %	105 %	Adjustable speed system needs additional space for Rotor and Excitation system.
Cost for Turbine & Generator including AC-Excitation System	100 %	140 %	Cost for adjustable speed system is more expensive because of special rotor design and AC-Excitation system.
Turbine Efficiency in generating mode	100 %	0.5% improvement for Max output, much (more) improved 2.5% at partial load	In Generating mode, Adjustable speed system can operate at optimum speed for improved efficiency
Operation range in generating mode	50 – 100 %	30 – 100 %	In adjustable speed system, Improvement of turbine efficiency can extend operation range.
Operation range in pumping mode	Constant	70 – 100 %	Adjustable speed system can adjust pump input. (Input power changes in proportion to the cube of rotating speed)
Response time of output/input	0 -100% / 60sec	20MW / 0.1sec	Adjustable realize fast power control by absorbing/releasing flywheel energy to power grid.

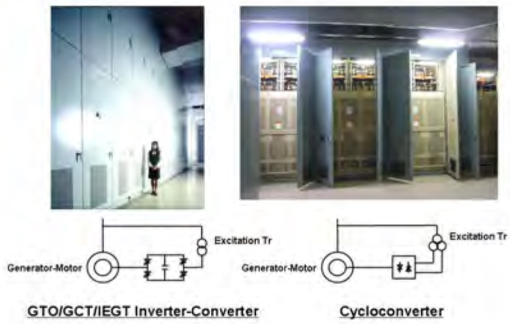
Adjustable Speed Pumped Storage System

Rotor Coil End Supporting System



Adjustable Speed Pumped Storage System

Excitation System



Adjustable Speed Pumped Storage System

Commissioned Projects in the World

Owner (Country)	Power Station	Capacity * unit	Main Manufacturer	Operation in
Tokyo Electric Power Co.	Yagisawa	80MW * 1	Toshiba	1990
Hokkaido Electric Power Co.	Takami	100MW * 1	Mitsubishi	1993
Kansai Electric Power Co.	Okawachi	320MW * 2	Hitachi	1995
Tokyo Electric Power Co.	Shiobara	300MW * 1	Toshiba	1995
EPDC	Okukiyotsu No.2	300MW * 1	Toshiba	1995
EPDC	Yambaru sea water	30MW * 1	Toshiba	1999
Germany	Goldisthal	300MW * 2	ANDRIZ	2003
Kyushu Electric Po. Co.	Omarugawa	300MW * 4	Hitachi/Mitsubishi	2007
Slovenia	AVCE	200MW * 1	Mitsubishi	2010

TEPCO YAGISAWA 80MW-1 Unit TEPCO SABIGAWA 300MW-1 Unit KEPCO OHKAWACHI 320MW-2 Units KYUSHU OMARUGAWA 300MW-4 Units

Adjustable Speed Pumped Storage System

Planned Projects in Future

Owner (Country)	Power Station	Capacity * unit	Main Manufacturer	Operation in
Kansai Electric Power Co.	Okutataragi	320MW * 2	Hitachi	2014
Hokkaido Electric Power Co.	Kyogoku	200MW * 1	Toshiba	2015
Switzerland	Nant de Drance	250MW * 4	ALSTOM	2015
Switzerland	Linth-Limmern	250MW * 2	ALSTOM	2015
Portugal	Vende Nova Ⅲ	400MW * 2	SIEMENS	2015
India	Tehri	250MW * 4	ALSTOM	
Tokyo Electric Power Co.	Kazunogawa	400MW * 2	Toshiba	2020

TEPCO KAZUNOGAWA 400MW-4 Units

Adjustable Speed Pumped Storage System

Preliminary Design for Gokcekaya PSPP

Pumping Operation

Max. Pumping Head	435.7 m
Min. Pumping Head	398.5 m
Max. Pumping Input	353.9 MW
Speed Range	429 min^{-1} ± 4%

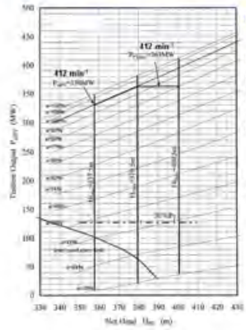
Rated Capacity of Generator-Motor (Plant Power Factor of 0.9 Lagging) 412 MVA

Remarks:

1. Speed range of 4% is minimum value for self-starting operation.
2. Adjustable input range can be increased by wider speed range design.

Adjustable Speed Pumped Storage System

Preliminary Design for Gokcekaya PSPP



Generating Operation

Max. Net Head	400.5 m
Rated net Head	379.5 m
Min. Net Head	357.5 m
Max. Output	363.0 MW

Remarks:

1. Expected minimum partial load is 35% for all head.

Adjustable Speed Pumped Storage System

Summary

Advantages

1. Adjustable Input in Pumping Operation
2. Improved Efficiency in Generating Operation
3. Wider Operating Range of Partial Load
4. Improvement of Power Grid Stability
5. Rapid Output/Input using Flywheel Energy
6. Efficient Utilization of Dam Water

Adjustable Speed Pumped Storage System

Thanks for Your Kind Attention

(c) Economical Evaluation of PSPP

Economical Evaluation of Pumped Storage Power Plant (PSPP)

October 2011
Tokyo Electric Power Company
Tokyo Electric Power Services Co., Ltd.

1

Benefit of PSPP

- Peak supply
  - Operation at peak time (load factor is less than 20%)
- Levelization of demand
  - To utilize cheap power plant and to reduce expensive power plant operation
- Ancillary service
  - To control frequency
  - Reserve capacity (tertiary reserve)

2

Characteristics of Various Peak-Response Power Plants

	Frequency Control (Primary & Secondary reserve)		Stand-by operation (Tertiary reserve)
	Peak period	Off-peak period	
Pumped storage power plant	• Possible	• Possible via pumping operation (in a case of adopting variable-speed pump)	• Possible
Reservoir type hydro	• Possible	• Possible but very uneconomical during hours with low marginal cost	• Possible
Gas turbine (GT)	• Possible	• Possible but very uneconomical during hours with low marginal cost	• Possible (slower than hydro)
Buying power from other countries	• Possible	• Possible	• Possible (dependent on other countries)

3

Generating Cost

	Const. cost (USD/kW)	Fuel cost (USC/kWh)	Generating cost (USC/kWh)		
			L.F=10%	L.F=40%	L.F=80%
Hydro	1400	0.0	---	4.3	---
PSPP	800	5.2	15.5	---	---
Gas CC	700	7.5	20.5	10.7	9.1
Gas GT	500	14.2	23.8	16.6	15.4
Oil ST	800	16.5	29.5	19.8	18.1
Oil GT	500	21.6	31.2	24.0	22.8
Import Coal	1600	3.6	31.5	10.6	7.1
Nuclear	2400	1.0	41.4	11.1	6.1

4

Needs of Ancillary Service in Turkey

5

Policy & Action Plan for Power Development Planning

- Numerical targets for Power Development Planning
  - "Electricity Energy Market and Supply Security Strategy Paper" (May 2009)
- Target of the share of nuclear power plants
  - To install total capacity of 5000MW, by 2020
- Target of the share of renewable resources
  - Installed capacity of wind energy power is targeted to increase to 20,000MW by 2023

6

Considerations - 1

- Interconnection with EU system
  - Needs to improve quality of electricity
- No measure to supply/demand fluctuation at night
  - Difficulty of frequency control at night
  - Private company (thermal) does not have a tendency to reduce output

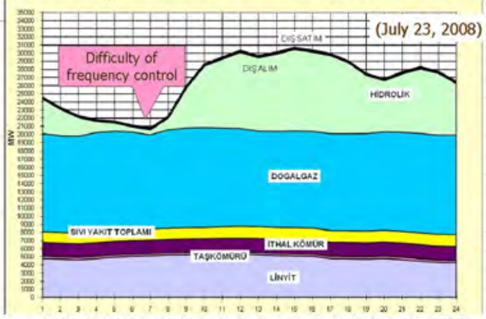
7

Considerations - 2

- Ancillary market: already established
- Primary reserve
  - Obligation to secure 2% of output for ancillary service (TEIAS pays the money)
  - No obligation rule for wind power company to prepare ancillary service
- Secondary (tertiary) reserve
  - To procure power based on the price at day ahead market or current day market

8

Loading Order of Power Plants



(Source: Turkish Electrical Energy 10-year Generation Capacity Projection, June 2009)

9

Required Ancillary Service

- Unforeseen sudden change in supply power
  - Forced outage in power plant
    → Maximum unit capacity: 1,200MW (Nuclear)
  - Drastic change in output from Wind power plant → Target capacity 20,000MW (2023)
- Unforeseen change in demand
  - Forced outage in big substation, big factory

10

Change in Wind Velocity (sample)

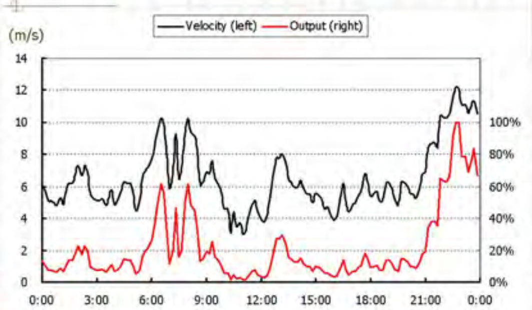
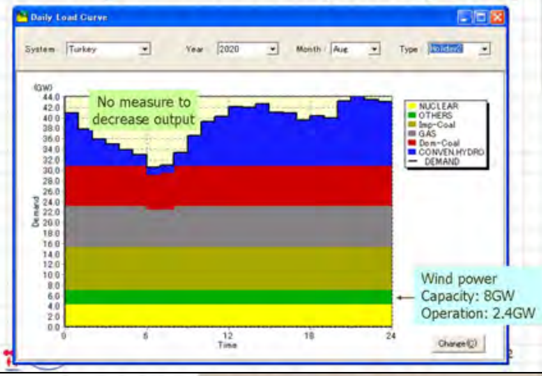


Image of Load Dispatch (2020)



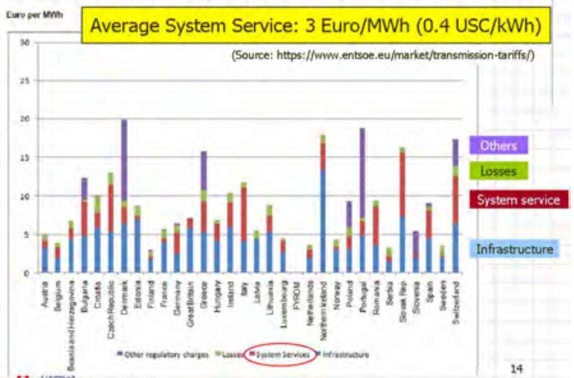
Economical Evaluation of Ancillary Service Equipment

13

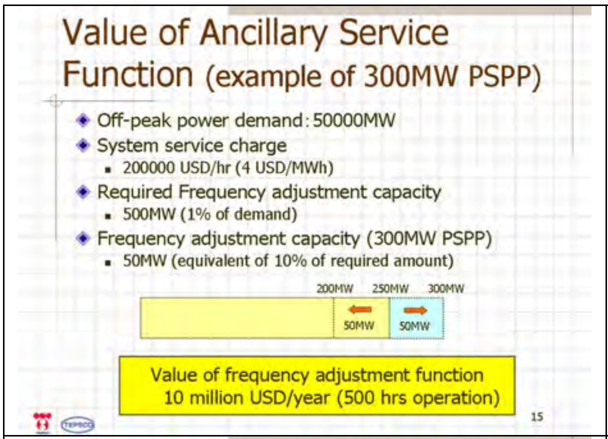
Transmission Tariffs of EU

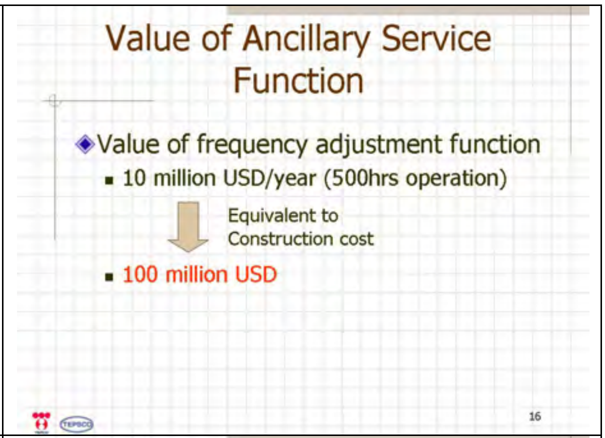
Average System Service: 3 Euro/MWh (0.4 USC/kWh)

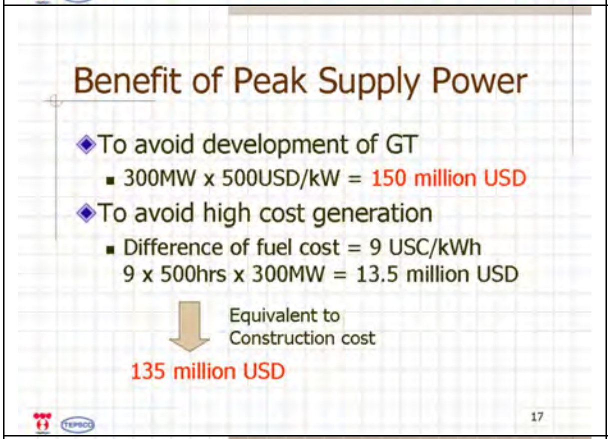
(Source: https://www.entsoe.eu/market/transmission-tariffs/)

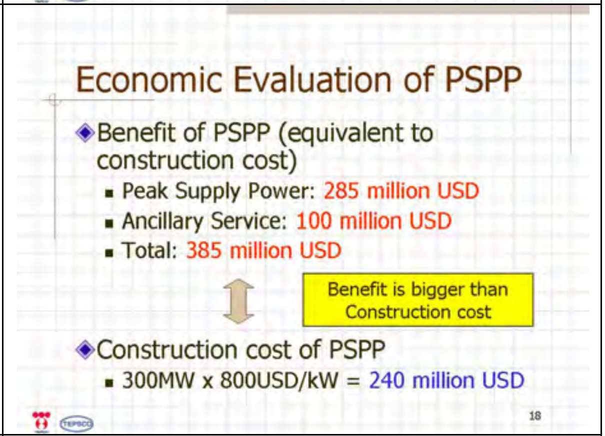


14


Value of Ancillary Service Function (example of 300MW PSPP)
Off-peak power demand: 50000MW
System service charge
200000 USD/hr (4 USD/MWh)
Required Frequency adjustment capacity
500MW (1% of demand)
Frequency adjustment capacity (300MW PSPP)
50MW (equivalent of 10% of required amount)
200MW
250MW
300MW
50MW
50MW
Value of frequency adjustment function
10 million USD/year (500 hrs operation)
15


Value of Ancillary Service Function
Value of frequency adjustment function
10 million USD/year (500hrs operation)
Equivalent to Construction cost
100 million USD
16


Benefit of Peak Supply Power
To avoid development of GT
300MW x 500USD/kW = 150 million USD
To avoid high cost generation
Difference of fuel cost = 9 USC/kWh
9 x 500hrs x 300MW = 13.5 million USD
Equivalent to Construction cost
135 million USD
17


Economic Evaluation of PSPP
Benefit of PSPP (equivalent to construction cost)
Peak Supply Power: 285 million USD
Ancillary Service: 100 million USD
Total: 385 million USD
Benefit is bigger than Construction cost
Construction cost of PSPP
300MW x 800USD/kW = 240 million USD
18


Thank you for your kind attention
19

(d) Operation of PSPP and AS-PSPP in TEPCO

Operation of PSPP and Adjustable Speed Pumped Storage System in TEPCO

October 2011

TOKYO ELECTRIC POWER COMPANY

Pumped Storage Power Plant of TEPCO

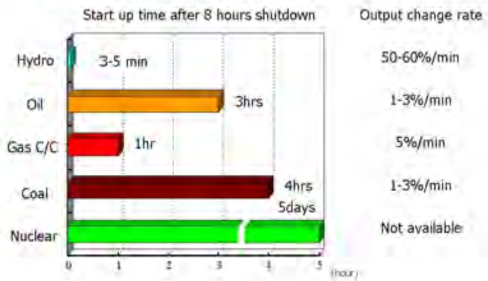
Name	Capacity (MW)	Effective Head (m)	Number of Unit	Commissioning Year
Yagisawa	240	93.5	3	1965
Azumi	623	135.8	6	1969
Midono	245	79.8	4	1969
Shin-Takasegawa	1,280	229	4	1979
Tamahara	1,200	518	4	1982
Imaichi	1,050	524	3	1988
Shiobara	900	338	3	1994
Kazunogawa	800 (to be 1,600)	714	2 (to be 4)	1999
Kannagawa	470 (to be 2,820)	653	1 (to be 6)	2005

Adjustable Speed Machines in TEPCO

Item	Yagisawa Unit 2	Shiobara Unit 3
Generator-Motor Capacity (MVA)	85	360
Speed Range (min^{-1})	130-156	345-390
Excitation System	Cyclo-converter	Cyclo-converter
Manufacturer	Toshiba	Toshiba
Commissioning	1990	1995

Shiobara Pumped Storage Power Plant

Adjustability of each power sources



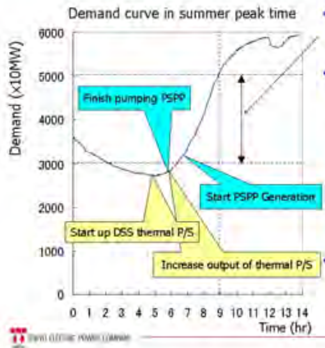
Roles of PSPP - 1. Demand supply control

a. Supply for peak demand
   - ✓ Store water for the reserve in peak demand supply

b. Supply for unscheduled power source outages
   - ✓ Back up by generating operation or pump up shedding

c. Supply for large demand fluctuation
   - ✓ Control quick demand changes

Demand supply control in demand rising hours



- Demand change from 7 to 9 am is approx. 20,000MW, and its rate is 500MW/min
- For this period, following has to be considered
  - Control generation output to meet demand
  - Reserve supply capability of approx 2,000MW at any time, in case of sudden power source down
  - Prepare for peak supply in the afternoon
- PSPP is suitable for frequency control in the steep demand change

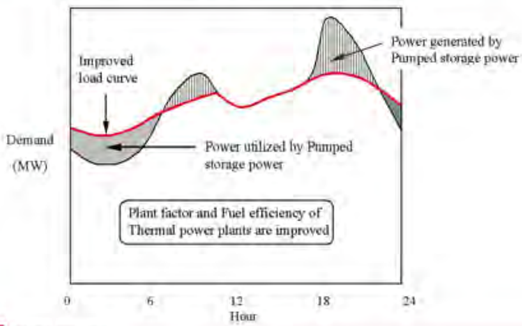
Roles of PSPP - 2. Economic dispatching

a. Pump up using surplus supply
   - ✓ To maintain constant output power sources

b. Pump up for economic operation of base supply
   - ✓ Utilize efficient power sources as much as possible

c. Pump up for lowering lower reservoir's water level
   - ✓ To prevent ungenerated water discharge in the lower reservoir

Leveling load curve and efficient power supply



Roles of PSPP – 3. Ancillary service

a. Frequency control capability
   - ✓ Flywheel effect, Spinning reserve, Hot reserve

b. Power flow control in transmission network
   - ✓ To prevent overload or instability in the network

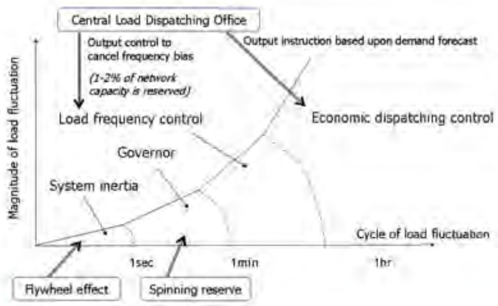
c. Voltage control in transmission network
   - ✓ "Phase control operation" for continuous reactive power supply

d. "Black start" capability
   - ✓ Start energizing from PSPP in the case of wide area blackout

e. Pumping up as test load
   - ✓ In the case of shedding test of large capacity generator

f. Back up of thermal power plant in case of environmental restriction alert
   - ✓ In the case that "Air Pollution Alert" is issued

Demand supply control scheme



Operation of ASPS in TEPCO

- Reserve for frequency control in off-peak hours
  - ✓ Reserve for LFC is available in pumping up operation, with its control speed higher than that of thermal PP

50MW LFC reserve

Thermal		ASPS
5units x 200MW x 5% 5% per minute	⇨	1unit of 300MW = +/-50MW 50-60% per minute

- Control of pumping input
  - ✓ Since pumping input is controllable, efficient power source can be used flexibly.

Constant Speed PSPP		ASPS
300MW	⇨	250MW, 300MW, 350MW

東京電力 TEPCO

4.4 Criteria of Introduction of AS-PSPP

Pumped-storage hydro Features including variable speed machines is described in detail in Chapter 2. In conclusion, Pumped-Storage Power Plant features can be aggregated into the following three points.

1) Economic advantages as peak supply compared with other power generation facilities.

   Peak supply includes the waiting power generation facilities which are not operated during normal peak hours.

2) Capability to store large power.

   Large power storage enable the cost reduction of power supply by storing power when marginal cost is low and by generating power when marginal cost is high.(In the case that private company operates PSPP as a business, differences between on-peak unit price and off-peak unit price becomes revenue.

3) Superior Response to the change of demand and supply in short time.

   In the case that response capability to the demand and supply change in seconds is needed, response capability is actualized by the running facilities.

Regarding (1) or (2), there is little difference between constant machine and adjustable speed machine. On the other hand, regarding (3), constant speed machine can quickly change power output in response to changes in the power demand during only generating operation. But, adjustable speed machine can quickly change input-output power in reponse to changes in the demand during both generation / pumping operation

(1) Feasibility of AS-PSPP as Peak Supply

Other than PSPP, Gas Turbine is the best for peak supply due to its low construction costs. Because of this, by comparing cost of GT and PSPP, Criteria of PSPP introduction for peak supply was calculated. The result are shown below. The calculation condition is used the value in section 4.1.3.

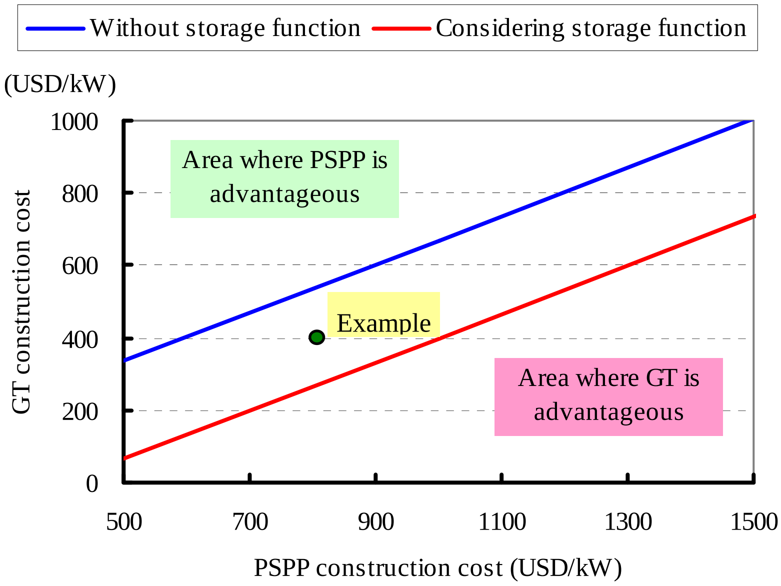


Figure 4.10 Cost Comparison of PSPP and GT

Without considering storage function, and in the case that PSPP is simply considered peak supply (without considering fuel cost cut effect), PSPP development is more advantageous than GT while the construction cost relation of PSPP and GT is above the blue line in the Figure 4.10.

In addition to the above, in the case that PSPP is operated about 500 hours in using storage capability, break-even line lowers to the red line due to the fuel cost cut effect (approx. 9USC/kWh).

For example, if construction unit price of PSPP is 800 USD/kW and it of GT is 400 USD/kW, the construction cost relation of PSPP and GT is under the blue line, but above the red line. In this case, GT is more advantageous if storage function is not considered, but PSPP is more advantageous if fuel cost-cut-effect by generating operation of 500 hours is considered.

For utilization of this graph, the following 2 conditions must be satisfied.

- ■PSPP can generate power continuously during on-peak time, and the water of upper reservoir is not run out during on-peak time. (GT can generate power continuously)
- ■In the case that the effect by storage function is expected, it is possible to obtain the low marginal cost power generation during off-peak.

Furthermore, in the case that PSPP is considered as peak supply, both constant and variable speed machine obtain similar benefit. Therefore, there is no need to introduction of PSPP.

(2) Feasibility Study on PSPP as Ancillary Services

If the ancillary services by adjusting input power during pumping operation is added to PSPP (for example Adjustable Speed Machine), its benefits differ by the situations of Ancillary Services Market development.

(a) In case of complete developed ancillary service market

If complete ancillary service has been developed, TSO procures all ancillary service from the market. In this situation, private company develops PSPP, they sell ancillary service function with market price, and

If ancillary service market is fully developed, system operator procures all ancillary service from the market. In this situation, private company develops PSPP, they sell ancillary service function by market price, and its sales become revenue. From the additional construction cost in the case of AS-PSPP development and the trading price of ancillary services, the criteria were calculated. The results are shown below. The amount of adjustable input power during pumping operation is 15% of the total facility input power.

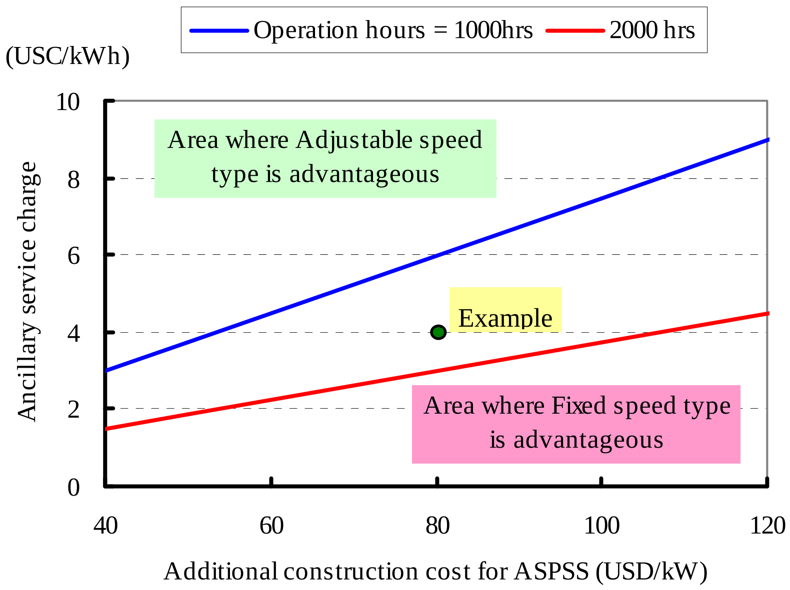


Figure 4.11 Comparison of Ancillary service charge and Additional Construction Cost

The higher the trading price of ancillary service is, and the longer the time of pumping operation is, the more merit the introduction of PSPP produces.

For example, if the additional construction unit price in the case of AS-PSPP is 80 USD/kW and the trading price of ancillary service is 4USC/kWh (40 USD/MWh), the cross point of ancillary service charge and additional cost for AS-PSPP is below the blue line, but above the redline. In this case, if the pumping operation time is about 1000 hours, there is no merit of ASPSS. But if the pumping operation time is about 2000 hours, AS-PSPP is more advantageous than Constant Speed PSPP.

(b) PSPP introduction for stable system operation.

TSO conducts various measures for stable system operation. In the case that AS-PSPP is considered for stable system operation. The case of AS-PSPP for stable system operation is considered. The criteria were calculated by the additional construction cost for AS-PSPP and System service tariff. The result is shown the below. In addition, the frequency adjustment function for stable system operation is 2% of demand, and the amount of adjustable input power during pumping operation is 15% of the total facility input power.

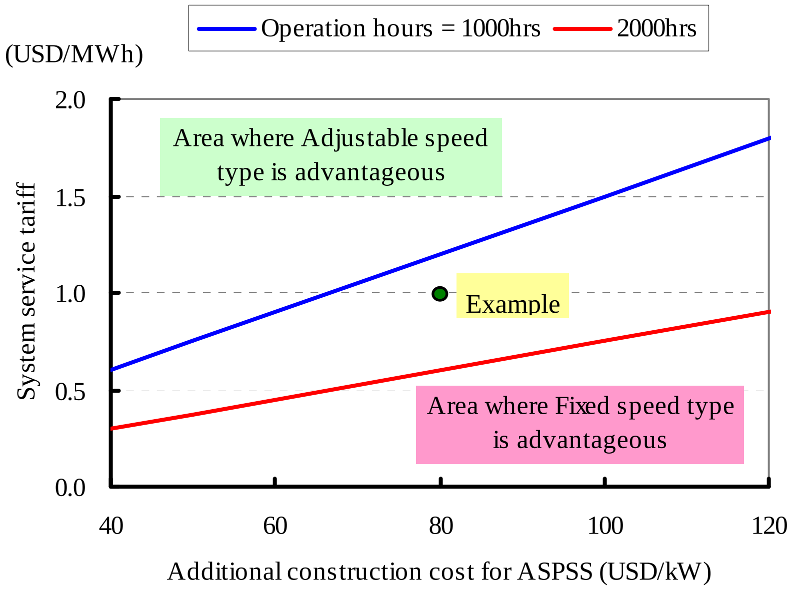


Figure 4.12 Comparison of System service tariff and Additional Construction Cost

For example, if the additional construction unit price in the case of AS-PSPP is 80 USD/kW and the cost for stable system operation is 1 USD/MWh, the cross point of GT construction cost and additional cost for AS-PSPP is below the blue line, but above the redline. In this case, if the pumping operation time is about 1000 hours, there is no merit of AS-PSPP. But if the pumping operation time is about 2000 hours, AS-PSPP is more advantageous than Constant Speed PSPP.

In addition, there is also tandem-type PSPP which provides ancillary service during pumping operation (Kops II etc.). In terms of ancillary service function, there is little difference between tandem-type PSPP and AS-PSPP, and Tandem-type PSPP is slightly more advantageous than AS-PSPP from only the viewpoint of the adjustable range. However, Judging comprehensively from peak supply and storage function, AS-type is slightly more advantageous as shown in Figure 4.7. In addition to this, considering the difference in the machine structure as mentioned in section 3.3.2, AS-type is more economical than tandem-type.

Chapter 5 Study on the Introduction of AS-PSPP Technology in Asian Countries

5.1 Feasible Countries for Introducing AS-PSPP

5.1.1 Current sitation of PSPP in Asia

There have been few pumped storage power plants (PSPPs) including adjustable speed type PSPP (AS-PSPP) in Asian countries, except Japan, South Korea, and P.R. China. There are some PSPPs in India, Thailand, and Philippines, though they do not play significant roles in their power systems. For planned PSPPs, Indonesia and Vietnam have their development plans to install PSPPs in near future.

Table 5.1 Major Existing and Planned Pumped Storage Power Plants in Asian Region

Country	Plant Name	Installed Capacity [MW]	Year	Owner
< Existing >				
Thailand	Lam Ta Khong	500	2002	EGAT
Philippines	Kalayaan	336 348.6	2002 2004	CBK Power Company Ltd.
India	Purulia, and others	900	2008	West Bengal State Electricity Distribution Company
P.R. China	Tianhuangping, and others	1,836	2004	
Japan	Shin-Takasegawa, and others	1,280	1979	TEPCO
< Planned >	a.			
Vietnam	Bac Ai Ham Thuan Bac	1,200 1,200	2021 2025	EVN EVN
Indonesia	Upper Cisokan	1,000		PLN

SOURCE: Japan Commission on Large Dams, Thailand Power Development Plan, JICA reports, et. al.

5.1.2 Issues to the Introduction of PSPPs in Asia

As mentioned above, the introduction of PSPP including AS-PSPP has been slow in Asian region. The following analyzes its reasons and barriers

(1) Needs toward "Quality" of Electricity

Firstly, there are still little requirement for the quality of electricity from demand side in those countries. One of the major advantages of PSPP, including Adjustable Speed System, is its function to control frequency of power grid, though the function has not caught much attention in those Asian nations. The stage of economic growth would be one of the reasons. GDP per capita of most Asian nations is below one tenth of that of Japan (Table 5.2). For example, Japan in its high-economic-growth-ear in 1960s, demand side needs toward the "amount" of electricity was high, as the share of elelctricity-inteinsive industry in the manufacturing industry was about twice as large as that of now. After her economy has shifted, as the share of electricity-save-industry like semi-conductor industry growth, the needs toward “quality” of electricity instead of “quantity” have risen from demand side, resulted in the rise of value using PSPP as the measure to control grid’s frequency. It is expected that the requirement for PSPP in Asian nations would increase when their economies experience the transition to the stage where people require the “quality” of electricity.

Table 5.2 Major Indices related to Electricity Business in Asia

	Japan	China	Malaysia	Thailand	Philippines	Indonesia	Vietnam	India
GDP per capita (USD/capita)	39,746	3,590	6,759	3,938	1,745	2,590	1,068	1,088
Eletrification [%]	100.0	99.4	93.5	85.8	73.0	65.8	95.0	90.4
Instaled Capacity [MW]	237,153	874,100	24,634	30,607	15,609	30,355	17,669	156,784
Share of Hydro power plants [%]	19.1	22.5	8.5	11.4	21.1	12.1	38.4	23.5
Share of Thermal power plants [%]	60.1	74.5	91.0	80.1	66.0	84.3	61.6	64.0
Share of Nuclear power plants [%]	20.6	1.0	0.0	0.0	0.0	0.0	0.0	2.6
Installed Capacity per capita [%]	1.87	0.65	0.90	0.45	0.17	0.13	0.21	0.13
Maximum Power generation [%]	155,166	541,140	15,960	22,025	9,472	23,438	15,560	101,609
Growth rate compared to the previsou year [%]	▲ 11.5	14.3	2.7	▲ 2.3	4.6	11.0	16.5	1.0

SOURCE: “Electricity in Asian Countries YR2009,” JEPIC

(2) Composition of Power Generation Source

The second reason of the slow penetration of PSPPs in Asian nations would be the fact that there are few gap of power generation cost between power plants for peak load and those for base load. Considering the fact that the average power generation efficiency of PSPP is approximately 70%, there would not be much economic impact of introducing PSPPs unless the power generation cost for pumping water is lower than that of power plants for peak load by approximately 30 %. Coal-fueled thermal power plants and nuclear power plants would be counted as such plants in general. Some countries might have deferred the decision to introduce PSPP because alternative peaking-power generation technology is more economical than PSPP, resulting in the slow penetration. Similar situations include the case of Turkey where ample inexpensive hydropower plants meet the country’s peak demand, and the case of countries which are gifted ample and inexpensive domestic natural gas, utilized for high-efficient combined gas thermal power plants. In those countries, little economic impact installing PSPPs can be expected. Another alternative technology would be power accommodation using international interconnection transmission lines.

(3) Load curve (peaking shape)

Thirdly, the shape of daily load curve might not be sharpened enough to maximize the effect using PSPPs. Considering the fact that the climate of many Asian nations is tropical one, it is expected that the demand for the use of air-conditioning during day time would increase accompanied with the economic growth, resulted in the sharpened daily load curve.

(4) Penetration of Variable Renewable Energy

The fourth is the requirement for ancillary service. In Asian region, renewable energy, specifically variable renewable energies like wind power plants which utilize resources that fluctuate time to time have not been permeated as much as western European countries. If wind power generation plants penetrate over Asian nations, like Germany of Europe, in future and there are surplus amount of power generated by wind power plants during off-peak hours, e.g. night time, the value of AS-PSS which is capable of control frequency during its pumping mode would rise, although this scenario assumes that the rule as well as products of wholesale power exchange has been well established in the designated region.

(5) Power Supply Market Structure

The stage of power industry liberalization would also influence the requirement for PSPPs. As shown in Figure 5.1, current power supply market structure can be categorized into two types.

The structure of most Asian nations might shift to “Market base system” in future though their current structures are close to “Regulated system”. The business outlook utilizing PSPPs, or the feasibility of their development and operation would depend on the choice of the supply market structure would. In case of “Regulated System,” large-scale power utilities (generally, former state-owned enterprises) which have their own power plants would be financially able to afford PSPPs. On the other hand, in case of “Market Base System,” it might be preferable from financial reasons if large-scale power utilities would be the entity which develops and operates PSPPs, though there are additional challenges to be addressed, such as financing of the project and stable procurement of electricity for pumping water.

◎ Regulated System

Several large-scale utilities are responsible for load dispatching during peak time as well as frequency control.
For example in Japan, regional vertical integrated utilities are responsible for stable power supply, although electricity market is liberalized. Those utilities provide ancillary service like frequency control utilizing their own PSPPs

◎ Market Base System

Based on market principle, anonymous power generation market participants supply electricity including peaking time.
In reality, power trading through long-term bilateral contract surpasses the one via market exchange to secure revenue and expenditure. Market participants including large-scale utilities with reserve margin provide ancillary service.

Figure 5.1 Comparison of Power Supply Market Structure

5.1.3 Selection of prioritized countries for introducing AS-PSPP in Asian countries

As stated in the previous sections, PSPPs have not been widely used in Asian countries in the current situation. In this section, countries with high potential for introducing AS-PSPP, considering current indices such as per capita GDP, annual load factor and share of hydro power plant, are selected, as the prioritized countries for introducing AS-PSPP in the current situation (Table 5.3).

From the Table, Malaysia, Thailand, Indonesia, Vietnam, Cambodia and Sri Lanka are selected. In addition, in consideration of the condition of yen loan and screened by the electricity organizational structure, countries of which generation, transmission and distribution of electricity is completely liberalized are excluded. Furthermore, for introducing AS-PSPP in the future, countries that currently have the PSPP development plan are prioritized for the study.

As the result, in this study, feasibilities of introducing AS-PSPP in Vietnam and Indonesia are studied, since advantages of AS-PSPP would be more clear if there are needs of frequency control in pumping and/or pumping input control in these countries, in addition to the functions of power storage and frequency control in generating, when PSPP is introduced in the network as the peak supply power source in the current development plan.

Besides, preliminaly study for Malaysia is also conducted as a country of different stage of development.

Table 5.3 Selection of prioritized countries

	Japan	Malaysia	Thailand	Philippines	Indonesia
GDP per Capita (US$/person)	39,746	6,759	3,938	1,745	2,590
Annual Load Factor (%)	68 %	79 %	77 %	75 %	76 %
Share of Hydro Power Plant	8 %	6 %	5 %	16 %	7 %
PSPP	Y	N	Y	N	Planned

	Vietnam	Laos	Cambodia	Myanmar	India
GDP per Capita (US$/person)	1,068	920	678	571	1,088
Annual Load Factor (%)	62 %	-	45 %	70 %	84 %
Share of Hydro Power Plant	32 %	100 %	4 %	76 %	15 %
PSPP	Planned	N	N	N	Y

	Bangladesh	Sri Lanka	Nepal	Bhutan	Mongol
GDP per Capita (US$/person)	621	2,052	428	1,826	1,555
Annual Load Factor (%)	73 %	60 %	40 %	330 %	70 %
Share of Hydro Power Plant	2 %	40 %	100 %	100 %	0 %
PSPP	N	N	N	N	N

Legend: Pink – positive, Blue – negative

5.2 Feasibility of Introducing AS-PSPP in Vietnam

5.2.1 Electricity Supply System in Vietnam

(1) Electricity Industry

Vietnam's electricity business has been mostly run by the state-run company, Vietnam Electricity (EVN), which vertically integrate each power supply stage, generation, transmission, and distribution, over the nation under the supervision of the Ministry of Industry and Trade (MOIT). The supply system can be categorized as "Regulated System" like Japan (Figure 5.2). For the power generation/ wholesale market, the entry from private sector started since 2000, based on power purchase agreement (PPA). As of the end of year 2010, approximately 40 % of power generation in the country is by owners other than EVN. The roadmap aiming for the restructuring of the country's power sector, which was established in 2006, plans to shift the country's power supply system from the current one to the system similar to "Market base system" like western Europe in future (Figure 5.3 "Roadmap of Liberalization of Vietnam's Power Industry").

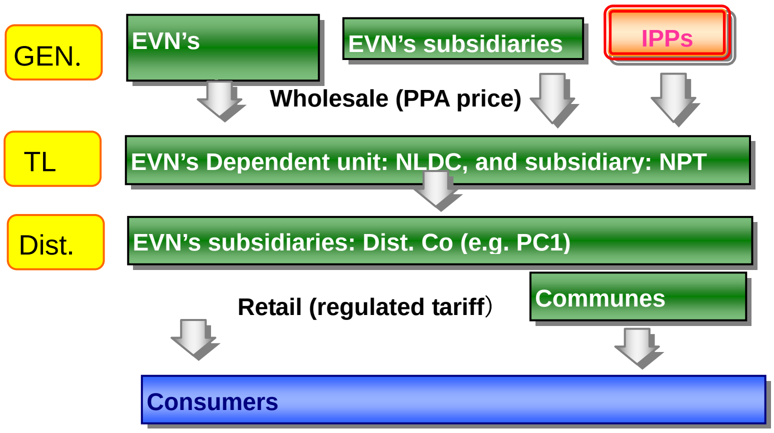


Figure 5.2 Electricity Supply System of Vietnam

MOIT supervises state-owned enterprises related to energy sector and industrial sector such as electricity, coal, and steel. Regarding matters relevant to electricity sector, the ministry supervises power utilities, develops the nation's power development plan, and establishes the electricity tariff (draft). The other government bodies related to power sector includes Ministry of Planning and Investment (MPI) which is responsible for the supervision of investment in projects and Ministry of Natural Resources and Environment (MONRE) which makes environmental regulations.

EVN is now a holding company, owning "Dependent units" which EVN owns by 100% and financially independent "Subsidiaries." The Dependent units include the National Load Dispatching Center (NLDC), major power plants, and National Power Transmission Corporation (NPT), while Subsidiaries include distribution companies.

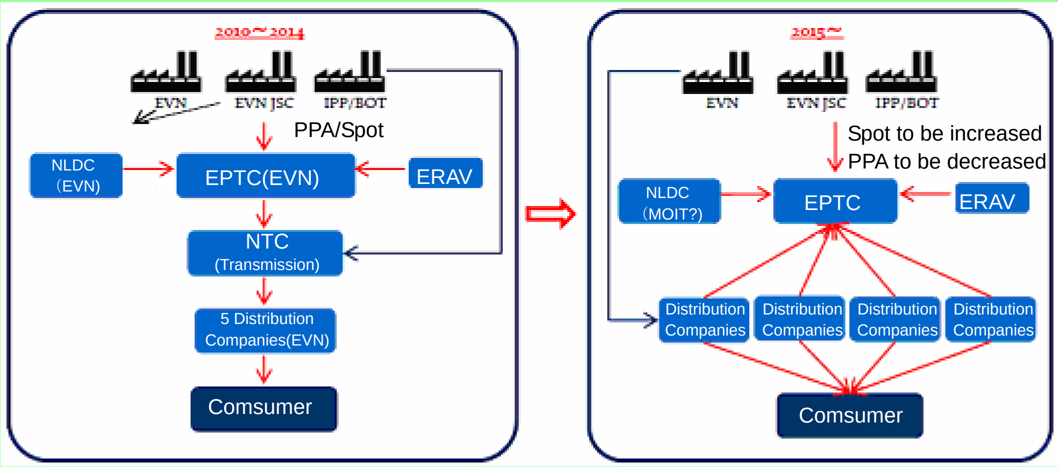
(2) Power generation/ wholesale market

Demand forecast and power development has been implemented by EVN which is also led by Institute of Energy (IE) under MOIT, finally approved by the government. The development plan of IPPs is also included in the power development plan.

For the wholesale power trading, although the country's generation market has been liberalized (the entry of private sectors is allowed), EVN purchases the electricity produced by IPP. Therefore, electricity trading through an exchange similar to the activity in the Western Europe has not been implemented. As shown in Figure 5.3, pilot project of such an activity has recently started, as the nation's wholesale market exchange, Vietnam Competitive Generation Market (VCGM), was established in July 2011.

Roadmap of Liberalization of Vietnam's Power Industry

According to the roadmap of power sector restructuring executed in January, 2006, market principle will be applied to generation, wholesale, and retail markets sequentially. Following the establishment of Vietnam Competitive Generation Market (VCGM) in July, 2011, the power trading through bidding has been implemented on a trial basis. Based on the result, the Market will provide full-scale service from next fiscal year.



SOURCE: "Study on Vietnam's Power Industry 2011 (in Japanese)," by JETRO Hanoi Center

Figure 5.3 Roadmap of Liberalization of Vietnam's Power Industry

(3) System Operation

National Load Dispatching Center (NLDC) under EVN is responsible for system operation of the Vietnam's grid. There are three hierarchies, NLDC (A0), Regional Dispatching Centers (A-1, A-2, A-3), and local Control Centers. Table 5.4 shows responsibilities of each center. NLDC is mainly in charge of network operation for 500kV, 220kV, and 110kV, and load dispatching to power stations, and each power stations on the bulk transmission lines are followed by the instructions from NLDC. NLDC under EVN is responsible for ancillary service such as daily peak load supply or frequency control.

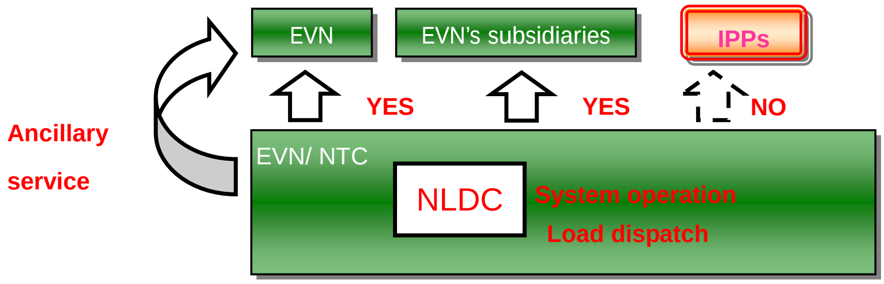


Figure 5.4 Institutional structure of Vietnam's system operation

Table 5.4 Responsibilities of Each Organization for Power System Operation

Object	Organization	Responsibilities
Bulk Transmission Network	National Load Dispatching Center (NLDC)	➢ Generators of 30MW and above, connected to the network of 110kVand above ➢ 500kV network ➢ Frequency control ➢ Voltage control at important points
Local Transmission Network	Regional Dispatching Center (North, Central, South)	➢ 220-110kV network ➢ Voltage control of generators
Distribution Network	Local Control Center	➢ Distribution network ➢ Small scale power plants

(4) Renewable energy

In Vietnam, renewable energy is mainly expected to contribute to rural electrification. As of 2008, wind power plants are installed with capacity of 800 kW. Likewise, the installed capacity of photovoltaic power is 1,150 kW, while that of biomass is 150,000kW, and of small hydropower is 64,000kW.

National Power Development Master Plan 2011-2020 (PDP7) approved on July 21, 2011, states that renewable energy should be given priority to be developed. The country's rural electrification development policy also promotes the development of renewable and new energies, and provides favorable conditions for the related investment and administration. The development policy on renewable energy in PDP7 is shown in Table 5.5.

Table 5.5 Composition of power source

	2010	2020	2030
Renewable energy Capacity base [%]	-	5.6	9.4
Generated amount base [%]	3.5	4.5	6.0
Of them, wind power [MW] (capacity base [%])	-	1,000 (0.7)	6,200 (2.4)
Of them, biomass [MW]		500	2,000
Of them, hydro power [MW]	9,200	17,400	-
Total Output [MW]	Approx. 20,000	75,000	146,800

(SOURCE: Power Development Master Plan 2011-2020)

(5) Conclusion

Table 5.6 summarizes the above result.

Table 5.6 Power supply system of Vietnam

Item	Status
Area of entry from private sector	Generation and distribution market
Status of unbundling (generation, transmission, and distribution business)	Under preparation
Power development	Implemented based on Power Development Master Plan.
Wholesale trading	Power purchase by EVN with PPA price. Power purchase by a single buyer in future.
Wholesale exchange	On a trial since July, 2011. Planned to start full-scale service from FY2012.
Ancillary service	Conducted by NLDC.
Liberalization of retail market	Under planning

(SOURCE: JEPIC)

5.2.2 Outline of power development plan

The latest government approved power development plan is the 7th national master plan (PDP). The PDP was approved by Vietnam government in 2011. The PDP consists of the power development plan and system plan from 2011 to 2020. The outline of the PDP is described in this section.

(1) General target of the power development plan

Through effective use of domestic energy resources, partial import of primary energy for power generation; sufficient electricity supply with higher quality at reasonable price for socio-economic development; the national energy security shall be assured.

(2) Demand Forecast

In order to sufficiently supply for the domestic power demand; electricity output and import shall be approx. 194-210 billion kWh by 2015; approx. 330-362 billion kWh by 2020 and approx. 695-834 billion kWh by 2030.

(3) Electrification target

Rural electrification program is promoted so that almost all rural households can access to the power grid by 2020

(4) Power utilization efficiency improvement

Electricity elasticity/GDP shall be decreased from current value of 2.0 to 1.5 by 2015, and to 1.0 by 2020.

(5) Renewable energy penetration target

Renewable energy shall be prioritized for power generation development. Accordingly power generation from renewable energy shall increase from current value of 3.5% in 2010 to 4.5% by 2020 and 6.0% by 2030, in the ratio against total power production.

Total capacity of wind power targets are 1,000MW by 2020 and 6,200MW by 2030. Power production from wind power projects shall increase to 0.7% by 2020 and to 2.4% by 2030

(6) Power Development Vision

Development of power generation projects in North, Centre and South shall be balanced, ensuring the electricity supply reliability of each regional power system and to reduce power transmission loss, sharing the reserved capacity and effectively operation of the hydropower plants in seasons.

Besides new power generation projects, the renovation of technology of existing power plants shall also be conducted; applying modern technology to satisfy environment preserve standards for new projects.

Scheme of investments to power generation projects shall be diversified to improve the competition and economic efficiency.

(7) Development of pumped storage hydropower

Pumped storage hydropower plant shall be studied to improve the availability and efficiency of the network, for further development of the network. Targets capacity of pumped storage hydropower development targets are 1,800MW by 2020 and 5,700MW by 2030.

(8) Power Development Plan

The power development plan from 2011 to 2020 is described in Table 5.7.

Pumped storage hydropower (PSPP) development plans are Bas Ai PSPP (900MW) in the southern system and Phu Yen East PSPP (900MW) in the northern system in commissioning during 2019 to 2020.

Table 5.7 Power Development Plan （Source: MOIT）

No.	Power Plant Name	Installed capacity (MW)	Owner/Developer
	Projects to be in operation in 2011	**4187**	
1	Son La HPP #2,3,4	1200	EVN
2	Nam Chien HPP #1	100	Song Da Group
3	Na Le (Bac Ha) HPP #1,2	90	LICOGI
4	Ngoi Phat HPP	72	IPP
5	A Luoi HPP #1,2	170	Central Power JSC.
6	Song Tranh 2 HPP #2	95	EVN
7	An Khe Kanak HPP	173	EVN
8	Se San 4A HPP	63	Se San 4A hydropower JSC.
9	Dak My 4 HPP	190	IDICO
10	Se Kaman 3 HPP (Laos)	250	Viet Lao JSC.
11	Dak Rtih HPP	144	Construction Corp. No.1
12	Dong Nai 3 HPP #2	90	EVN
13	Dong Nai 4 HPP #1	170	EVN
14	Uong Bi Ext. TPP #2	300	EVN
15	Cam Pha 2 TPP	300	Vinacomin
16	Nhon Trach 2 C/C GT	750	PVN
	Wind power + Renewable energy	30	
	Projects to be in operation in 2012	**2805**	
1	Son La HPP #5,6	800	EVN
2	Dong Nai 4 HPP #2	170	EVN
3	Nam Chien HPP #2	100	Song Da Group
4	Ban Chat HPP #1,2	220	EVN
5	Hua Na HPP #1,2	180	Hua Na hydropower JSC.
6	Nho Que 3 HPP #1,2	110	Bitexco JSC.
7	Khe Bo HPP #1,2	100	Electricity power JSC.
8	Ba Thuoc 2 HPP #1,2	80	IPP
9	Dong Nai 2 HPP	70	IPP
10	Dam Bri HPP	75	IPP
11	An Khanh 1 TPP #1	50	An Khanh thermal power JSC.
12	Vung Ang 1 TPP #1	600	PVN
13	Formosa TPP #2	150	Hung Nghiep Formosa Co., Ltd.
	Wind power + Renewable energy	100	
	Projects to be in operation in 2013	**2105**	
1	Nam Na 2 HPP	66	IPP
2	Dak rinh HPP #1,2	125	PVN
3	Sre Pok 4A HPP	64	Buon Don hydropower JSC.
4	Hai Phong 2 TPP #1	300	EVN
5	Mao Khe TPP #1,2	440	Vinacomin
6	An Khanh 1 TPP #2	50	An Khanh thermal power JSC.

7	Vung Ang 1 TPP #2	600	PVN
8	Nghi Son 1 TPP #1	300	EVN
9	Nong Son TPP	30	Vinacomin
	Wind power + Renewable energy	130	Hai Phong TP JSC
	Projects to be in operation in 2014	**4279**	
1	Nam Na 3 HPP	84	IPP
2	Yen Son HPP	70	Binh Minh Construction & Tourism JSC.
3	Thuong Kon Tum HPP #1,2	220	Vinh Son-Song Hinh hydropower JSC
4	Dk Re HPP	60	Thien Tan Hydropower JSC.
5	Nam Mo HPP (Laos)	95	IPP
6	Hai Phong 2 TPP #2	300	EVN
7	Nghi Son 1 TPP #2	300	EVN
8	Thai Binh 2 TPP #1	600	PVN
9	Quang Ninh 2 TPP #1	300	EVN
10	Vinh Tan 2 TPP #1,2	1200	EVN
11	O Mon 1 TPP #2	330	EVN
12	Duyen Hai 1 TPP #1	600	EVN
	Wind power + Renewable energy	120	
	Projects to be in operation in 2015	**6540**	
1	Huoi Quang HPP #1,2	520	EVN
2	Dong Nai 5 HPP	145	Vinacomin
3	Dong Nai 6 HPP	135	Duc Long Gia Lai Company
4	Se Kaman 1 HPP (Laos)	290	Viet Lao JSC.
5	Quang Ninh 2 TPP #2	300	EVN
6	Thai Binh 2 TPP #2	600	PVN
7	Mong Duong 2 TPP #1,2	1200	AES/BOT
8	Luc Nam TPP #1	50	IPP
9	Duyen Hai 3 TPP #1	600	EVN
10	Long Phu 1 TPP #1	600	PVN
11	Duyen Hai 1 TPP #2	600	EVN
12	O Mon 3 C/C GT	750	EVN
13	Cong Thanh TPP #1,2	600	Cong Thanh thermal power JSC.
	Wind power + Renewable energy	150	
	Projects to be in operation in 2016	**7136**	
1	Lai Chau HPP #1	400	EVN
2	Trung Son HPP #1,2	260	EVN
3	Song Bung 4 HPP	156	EVN
4	Song Bung 2 HPP	100	EVN
5	Dak My 2 HPP	98	IPP
6	Dong Nai 6A HPP	106	Duc Long Gia Lai Company
7	Hoi Xuan HPP	102	IPP
8	Se Kaman 4 HPP (Laos)	64	BOT
9	Ha Se San 2 HPP (50% by Cambodia)	200	EVN-BOT
10	Mong Duong 1 TPP #1	500	EVN
11	Thai Binh 1 TPP #1	300	EVN
12	Hai Duong TPP #1	600	Jak Resource-Malaysia/BOT
13	An Khanh 2 TPP #1	150	An Khanh thermal power JSC.
14	Long Phu 1 TPP #2	600	PVN
15	Vinh Tan 1 TPP #1,2	1200	CSG/BOT
16	Duyen Hai 3 TPP #2	600	EVN

17	O Mon 4 C/C GT	750	EVN
18	O Mon 2 C/C GT	750	BOT
	Wind power + Renewable energy	200	
	Projects to be in operation in 2017	**6775**	
1	Lai Chau HPP #2,3	800	EVN
2	Se Kong 3A, 3B HPP	105+100	EVN
3	Thang Long TPP #1	300	Thang Long thermal power JSC.
4	Mong Duong 1 TPP #2	500	EVN
5	Thai Binh 1 TPP #2	300	EVN
6	Hai Duong TPP #2	600	Jak Resource-Malaysia/BOT
7	Nghi Son 2 TPP #1,2	1200	BOT
8	An Khanh 2 TPP #2	150	An Khanh thermal power JSC.
9	Van Phong 1 TPP #1	660	Sumitomo-Hanoinco/BOT
10	Vinh Tan 6 TPP #1	600	EVN
11	Vinh Tan 3 TPP #1	660	Vinh Tan 3 Energy JSC.
12	Song Hau 1 TPP #1	600	PVN
	Wind power + Renewable energy	200	BOO/BOT
	Projects to be in operation in 2018	**7842**	
1	Bao Lam HPP	120	Song Da Group
2	Nam Sum 1 HPP (Laos)	90	Sai Gon Invest
3	Se Kong HPP (Laos)	192	EVN-BOT
4	Na Duong 2 TPP #1,2	100	Vinacomin
5	Luc Nam TPP #2	50	IPP
6	Vung Ang 2 TPP #1	600	VAPCO/BOT
7	Quang Trach 1 TPP #1	600	PVN
8	Nam Dinh 1 TPP #1	600	TaiKwang-Korea/BOT
9	Van Phong 1 TPP #2	660	Sumitomo-Hanoinco/BOT
10	Song Hau 1 TPP #2	600	PVN
11	Son My 1 C/C GT #1,2,3	1170	(IP-Sojizt-Pacific)/BOT
12	Duyen Hai 2 TPP #1	600	Janakuasa/BOT
13	Vinh Tan 3 TPP #2	660	Vinh Tan 3 Energy JSC.
14	Vinh Tan 6 TPP #2	600	EVN
15	Import from China	1000	Upon negotiation
	Wind power + Renewable energy	200	IPP
	Projects to be in operation in 2019	**7015**	
1	**Bac Ai PSPP #1**	**300**	EVN
2	**Phu Yen East PSPP #1**	**300**	Xuan Thien Ninh Binh Company
3	Nam Sum 3 (Laos)	200	Sai Gon Invest
4	Vinh Son 2 HPP	80	IPP
5	Vung Ang 2 TPP #2	600	VAPCO/BOT
6	Quang Trach 1 TPP #2	600	PVN
7	Nam Dinh 1 TPP #2	600	TaiKwang-Korea/BOT
8	Thang Long TPP #2	300	Thang Long thermal power JSC.
9	Quang Tri TPP #1	600	IPP/BOT
10	Duyen Hai 2 TPP #2	600	Janakuasa/BOT
11	Duyen Hai 3 TPP #3 (Extension)	600	EVN
12	Kien Luong 1 TPP #1	600	Tan Tao Company
13	Son My 1 C/C GT #4,5	780	(IP-Sojizt-Pacific)/BOT
	Hiep Phuoc TPP stopped	-375	
14	Import from China	1000	Upon negotiation

	Wind power + Renewable energy	230	IPP
	Projects to be in operation in 2020	**5610**	
1	**Phu Yen East PSPP #2,3**	**600**	Xuan Thien Ninh Binh Company
2	**Bac Ai PSPP #2,3**	**600**	EVN
3	Nam Mo 1 HPP (Nam Kan - Laos)	72	EVNI
4	Quang Tri TPP #2	600	IPP/BOT
5	C/CGT in the Center (Quang Tri or Quang Ngai)	450	
6	Ninh Thuan 1 NPP #1	1000	EVN
7	Ninh Thuan 2 NPP #1	1000	EVN
8	Vinh Tan 3 TPP #3	660	Vinh Tan 3 Energy JSC.
9	Kien Luong 1 TPP #2	600	Tan Tao Company
	Thu Duc TPP stopped	-272	
	Wind power + Renewable energy	300	IPP

Note: PSPP: Pumped Storage hydropower, HPP: Hydropower, TPP: Thermal power, C/C GT: Combined cycle thermal power

5.2.3 Outline of PSPP Project

In PDP7, which is the latest government approved power development plan, the vision of PSPP development plan is stated as follows:

- ✓ Study for putting pumped storage hydropower plant in operation in harmony with the development of power system to improve the efficiency of power system's operation. Pumped storage hydropower development targets are 1,800MW PSPP by 2020 and 5,700MW PSPP by 2030.

Table 5.8 shows the list of PSPP projects in PDP. The current status of each project is as follows:

- ✓ Of ten PHPP projects proposed in the Master Plan, Phu Yen East and Bac Ai were selected as the priority projects. Bac Ai project will be implemented by EVN and Phu Yen East will be implemented by IPP.
- ✓ The feasibility study on Bac Ai project was completed by EPDC. As of now, the results are in the process of government approval.
- ✓ Of three PSPP projects except for Phu Yen East and Bac Ai, the pre-feasible study on Ninh Son and Don Duong is being implemented by EPDC. The study will be completed by March 2012. Based on the result of the study, EVN will select a preferred project after Bac Ai.

Table 5.8 PSPP Project in Vietnam

Commssioing Year	Project Name	Installed Capacity	Number of Units
2019	Bac Ai Phu Yen East	300 MW 300 MW	1 1
2020	Bac Ai Phu Yen East	600 MW 600 MW	2 2
2021	Bac Ai Phu Yen East	300 MW 300 MW	1 1
2024	Mien Bac II Don Duong	300 MW 600 MW	1 2
2025	Mien Bac II Don Duong	300 MW 600 MW	1 2
2026	Don Duong	300 MW	1
2028	Ninh Son	300 MW	1
2029	Ninh Son	600 MW	2
2030	Ninh Son	300 MW	1

[Source：7th national master plan (PDP)]

5.2.4 Situation of power system operation

The peak demand in Vietnam increased from 2,796MW in 1995 to 15,416MW in 2010, 5.5 times in 15 years, and with annual average increase rate of 12.2% from 2001 to 2010. Electricity production in Vietnam increased from 31,137GWh in 2001 to 100,071GWh in 2010 with annual average increase rate of 14.2% (Figure 5.5). As of 2010, there are 78 power stations with total generation capacity of 19,735MW, where hydro is 38%, coal is 18% and gas combined cycle is 32% out of it.

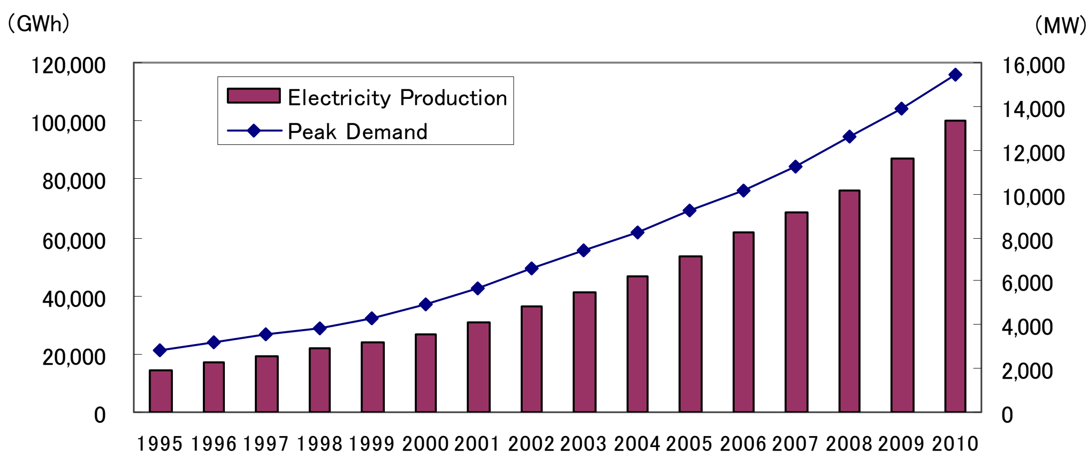


Figure 5.5 Generated Energy (left) and Maximum Demand (right)

(Source: NLDC)

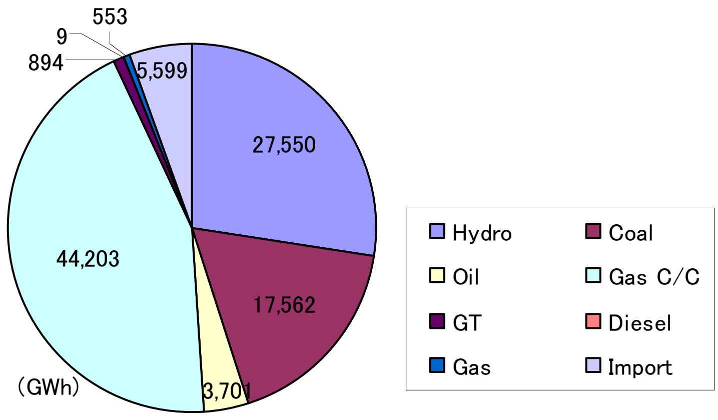


Figure 5.6 Generated Energy by Power Sources in 2010

(Source: NLDC)

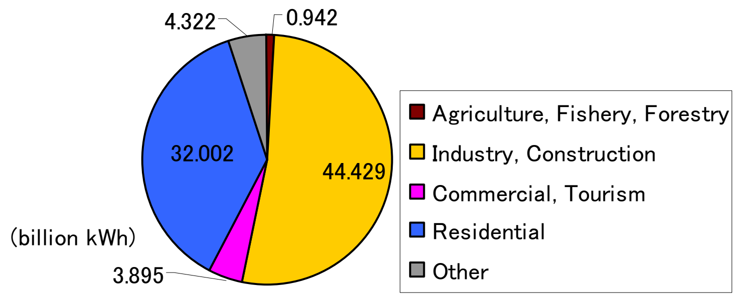


Figure 5.7 Electric Energy Consumption in 2010

(Source: NLDC)

With more than 97% of electrification rate in municipal and more than 95% of it in rural, one of the crucial issues in Vietnam is chronic shortage of electricity. To deal with this, development of major thermal power plants and electricity imports from neighboring countries are being carried out. In addition, through electricity liberalization, power plant development is accelerated by facilitating private investment.

In Vietnam, power plant development by IPP has begun from late 1990's in full-scale, which amounts to 32% of total generated energy as of 2009. As shown in Figure 5.8 and Figure 5.9, increased amount of peak demand has been supplied by the increase of IPP. Especially, power plants by IPP were installed mainly in southern region, including major combined cycle power plants, such as Phu My 3 of 720MW, which started its operation in 2004, and Phu My 2-2 of 720MW, which started its operation in 2005. This tendency has continued, as the generated power by EVN and IPP in 2008 and 2009 are shown in Table

5.9.

On the other hand, low project achievement rate is another issue, with 69.1% between 2006 to 2010, by 14,581MW of development plan and 10,081MW of actual development.

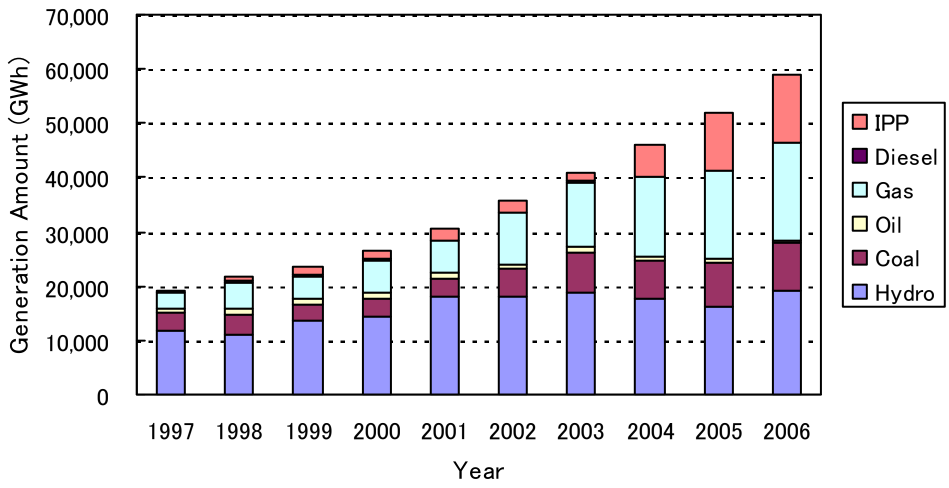


Figure 5.8 Annual Generation Amount by Power Sources (1997-2006)

Source: JEPIC, 2008

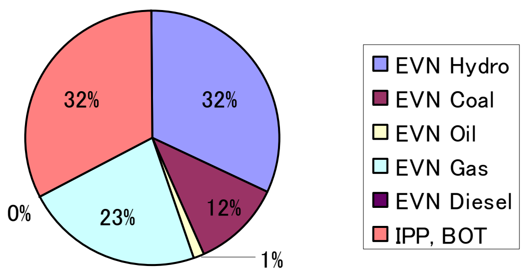


Figure 5.9 Generated Energy by Power Sources in 2009

Source: EVN Annual Report 2009-2010

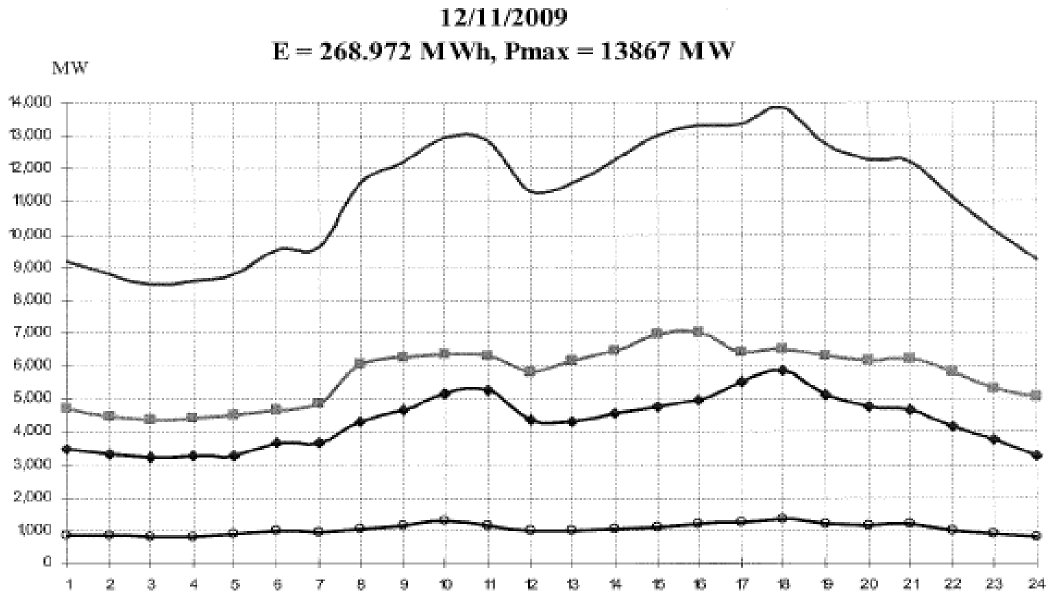
Table 5.9 Supplied Energy in 2008 and 2009

Unit: GWh

	2008	2009	Increase
EVN	53,091	57,001	7.4%
IPP, BOT	21,173	27,764	31.4%
合計	74,224	84,765	14.2%

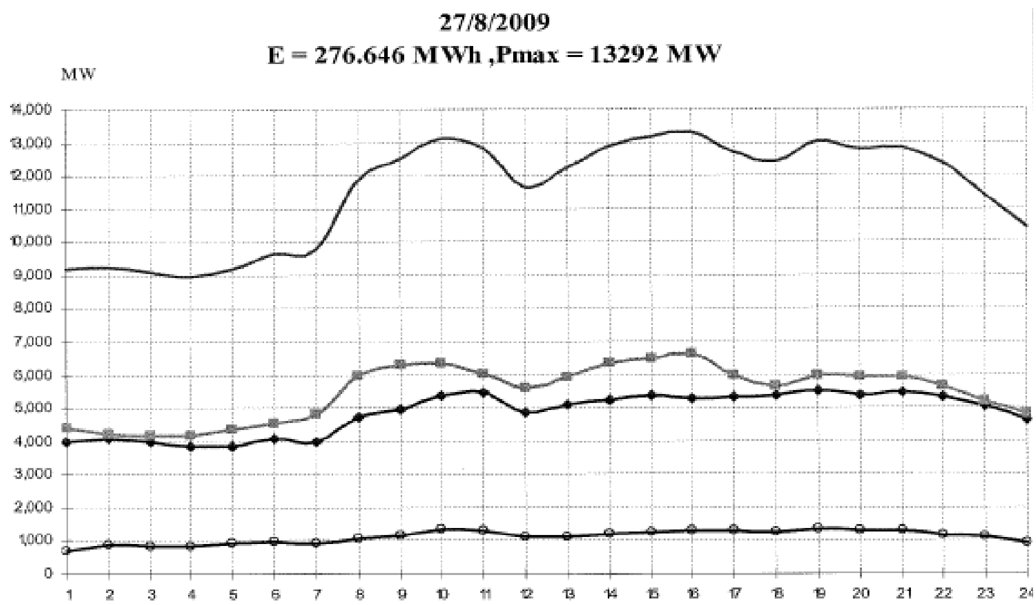
Source: EVN Annual Report 2009-2010

Daily load curves are shown in Figure 5.10 and Figure 5.11. There are two peak hours in a day, 10 to 11 in the morning and 17 to 18 in the evening. Annual peak demand occurs in November. Peak hours are different by each region, morning in summer in North Region, evening in November in North, and afternoon, around 15 to 16 in South.



Line: Total, ■: South, ◆: North, ○: Central

Figure 5.10 Daily Load Curve in November (Source: NLDC)



Line: Total, ■: South, ◆: North, ○: Central

Figure 5.11 Daily Load Curve in August (Source: NLDC)

As of October 2011, there are 78 power stations, 4,040 km of 500kV transmission lines, 10,575 km of 220kV transmission lines, 13,841 km of 110kV transmission lines, 26 500kV substations, 145 220kV substations, and 777 110kV substations in Vietnam. 8,278 MW of hydro and coal thermal power stations are located in the northern region, 3,496 MW of hydro power stations are in the central, and 9,523 MW of hydro, coal, oil, and gas thermal power stations are in the southern region. Power flows from north to south in the dry season, from January to July, and from central to north and south in the rainy season.

NLDC monitors network and gives operation instruction through SCADA/EMS system. However, frequency control is not automatic such as by LDC, it is instructed by telephone to designate power stations, usually Hoa Binh and Tri An, and adjusted within +/-0.2Hz from 50Hz. In the end of the dry season, since many hydro power stations are shut down or operates for a few hours in a day, supply capability for demand supply control becomes short. When frequency deviates from predetermined range, NLDC gives instruction to Group 1 power stations, mainly hydro, and to Group 2 power stations including thermal in the case of further frequency deviation, to control the frequency. If frequency drops more, some of the loads are shed by the protection system. When supply shortage is estimated beforehand, scheduled outage is implemented with 5 days advance notice. Although the number of scheduled outage was decreased in 2011, there is no choice but to do since supply shortage continues due to the increase of maximum demand and electricity consumption.

Network of Vietnam is interconnected with China and Cambodia, to import from China with separating the system of Vietnam, and to export to Cambodia.

As stated above, there are issues of supply shortage, adjustment capability shortage, and undeveloped control system in terms of demand supply control and frequency control in Vietnam, and it is inevitable to improve them to aim for the stable electricity supply. Concerning the adjustment capability, although there are many hydro power stations with more than 30%, they are little available in the dry season and coal thermal power plants are planned to increase, from 3,940MW with 18.5% in 2010 to 27,765MW with 41.5% in 2020 and 73,595MW with 53.5% in 2030 in the power development plan. Hence there is a great need for Adjustable Speed PSPP in terms of power system operation.

5.2.5 Feasibility of introducing Adjustable Speed PSPP

To deal with continuously growing electric demand in Vietnam, vigorous power development is being undergone, with many projects of coal fired thermal power plants, hydro power plants including PSPP, to be conducted by EVN and/or IPP. At present, however, since sufficient supply capability has not yet been prepared, due to such reasons as the delay of project, planned outages have to be implemented.

For the demand supply control, since the ratio of the hydro power plant which can be used as adjustment capability is high, it is considered that the stable demand supply control is possible if appropriate control can be conducted. However, although the automatic frequency control function, LFC, is equipped with the SCADA/EMS system in NLDC, it is not linked with the generator control systems in the power stations, and as a result, the frequency of the network is controlled by telephone instruction, designating power stations to control network frequency. This is one of the causes of the problems such as shortage of adjustment capability in dry season, network frequency drop, and so on.

Figure 5.12 shows the power development plan in PDP7. In the record of 2010, ratios of hydro and oil/gas are 35% each, which makes 70%, while coal increases to 53% and hydro decreases to 17% in the plan of 2030.

It is projected that the supply adjustment to meet with demand fluctuation is possible using hydro power plant by 2015, since the ratio of hydro power is more than 35%. However, it is estimated that the power sources to supply secondary and tertiary reserve will be short after 2025, and the requirement of the Adjustable Speed PSPP will be raised in this situation of demand and supply.

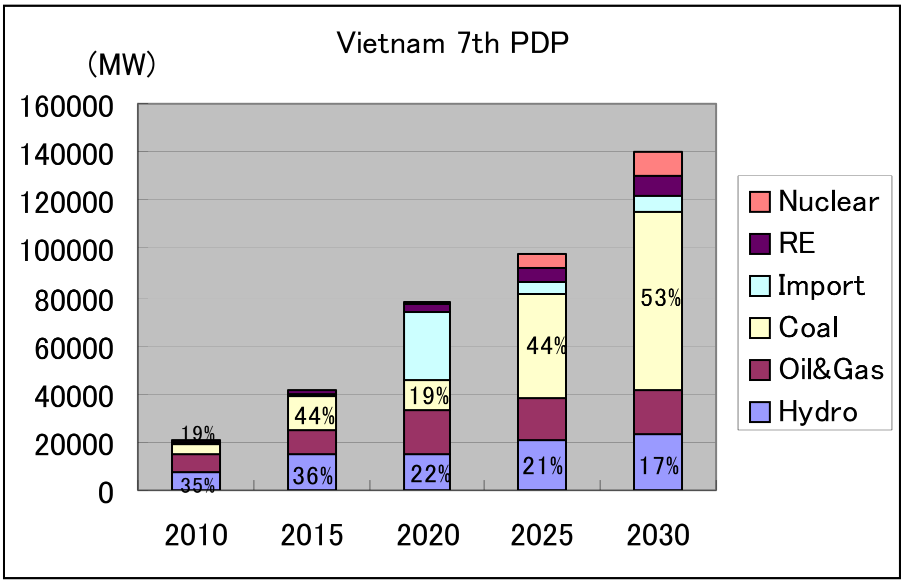


Figure 5.12 Power development plan from 2010 to 2030

Source: PDP7

Considering the above situations in Vietnam, it is necessary to pursue following measures simultaneously.

- Power development to resolve supply shortage

- Integrated system to control generated power appropriately
- Power sources for supply adjustment to stabilize network

Out of these measures, as the peak supply power source and as the power source for supply adjustment, it is desirable that Adjustable Speed PSPP is introduced by around 2025. Since it is estimated that the ratio of power plants of EVN, taking responsibility of conducting ancillary service, will be decreasing in proportion with the increase of power development by IPP, it is desirable to study the feasibility of Adjustable Speed PSPP within the power development projects of EVN, in the current situation.

Based on these findings, the JICA Study Team proposes further study consisting mainly of the following topics:

[Topics to be studies further]

- Holding of a workshop inviting stakeholders for further understanding of the technology and related benefit.
- Discussion over the cooperation/ coordination on the AS-PSPP development project with the other donors who have assisted the country's existing PSPP development plan.
- More detailed calculation of economic impact due to the introduction of PSPP, including AS-PSPP
- Formulation of PSPP development plan after the period of existing plan, estimating the impact of quality improvement and that of system operation improvement
- Introduction of automatic load frequency control function in the demand supply control
- Improvement of SCADA/EMS and telecommunication systems for efficient generation/ network control

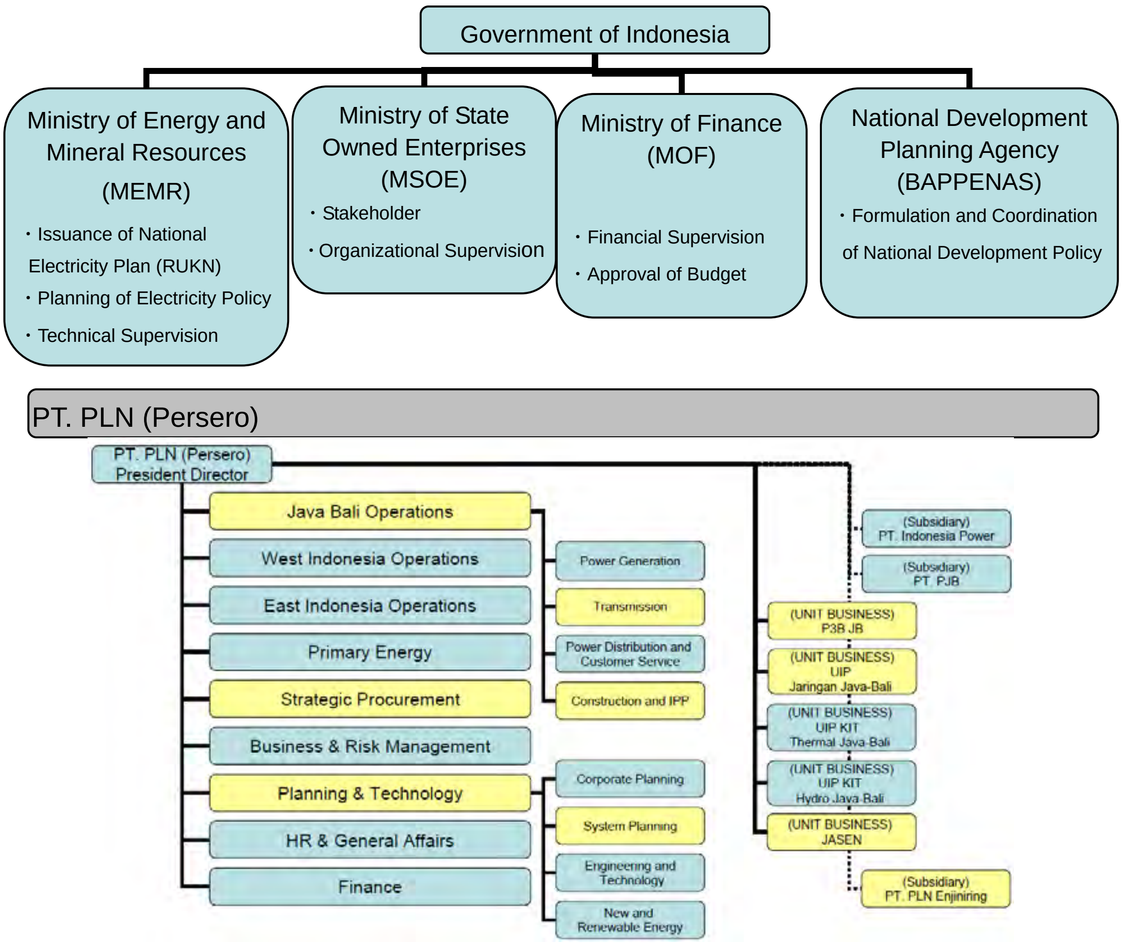
5.3 Feasibility of Introducing AS-PSPP in Indonesia

5.3.1 Electricity Supply System in Indonesia

(1) Electricity Industry

The structure of Indonesia's electricity industry is not like west European type "Market base system" which leaves the power development and operation to the market, but is similar to that of Japan, i.e. "Regulated system", where a few large-scale utilities are responsible for stable power supply.

Currently, under the supervision of the Ministry of Energy and Mineral Resources (MEMR) which oversees mineral resource and energy sector, PT. Perusahaan Umum Listrik Negara Persero (PLN), the state-owned-enterprise, its subsidiary companies, and IPPs run their business in generation market, while solely PLN operates transmission and distribution services. Although PLN has experienced company split-up in generation department and internal separation of transmission/ distribution departments in accordance with the progress of its restructuring, the company virtually supplies electricity over the country with its vertically integrated units (Figure 5.13).



SOURCE: JEPIC

Figure 5.13 Power sector correlation map

For the governmental bodies related to power sector, besides MEMR, there are DEN which is in charge of policy development related to energy development and BAPPENAS which is responsible for the development of national policy.

PLN has two power generation subsidiaries in Java-Bali area, which the company's business scale is large, namely IP and PJB, and has internal business unit of transmission and distribution. P3B Jawa Bali (P3B JB) is responsible for transmission service, while there are distribution units in five areas).

(2) Generation/ wholesale market

The entry of IPPs has been allowed in Indonesia since 1992. Its share as of the end of year 2009 is 4,718MW against the total installed capacity composed of that of PLN and IPP is approximately 30,355 MW, occupying around 16% of the market. Currently, PLN purchase the electricity produced by IPPs, and there is no wholesale exchange in the country (Figure 5.14).

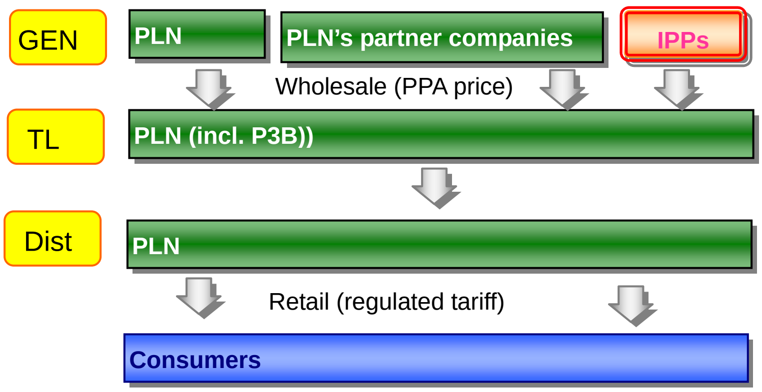


Figure 5.14 Electricity Supply System in Indonesia

Regarding the power development of Indonesia, based on the national energy policy, MEMR is responsible for the issuance of Rencana Umum Ketenaga Nasional (RUKN), a general electricity plan of Indonesia, in order to formulate a stable energy supply system and secure energy sources for the next 20 years. Under the national electricity plan, PLN creates an electricity supply business plan titled RUPTL (Rencana Usaha Penyediaan Tenaga Listrik). The RUPTL is made by PLN and after the MEMR's approval, it is issued and publicly released.

The second Crash Program (2010-2014) which promotes power development in order to address the tight demand supply balance, aims to develop power with total installed capacity of approximately 10,000 MW (of it, approximately 5,000 MW is of Java-Bali system). The Program is to be implemented not only by PLN but also by IPPs.

(3) System Operation

In case of Java-Bali system, P3B Jawa Bali's National Control Center (NCC) operates the system, including load dispatching, monitoring 500 kV network, and instruction to power plants. For the system with voltage less than 500 kV, regional control centers monitor and operates the system. Power plants' load dispatching is based on the economical competitiveness. Frequency control is implemented following its internal manual, stating the range of operational frequencies.

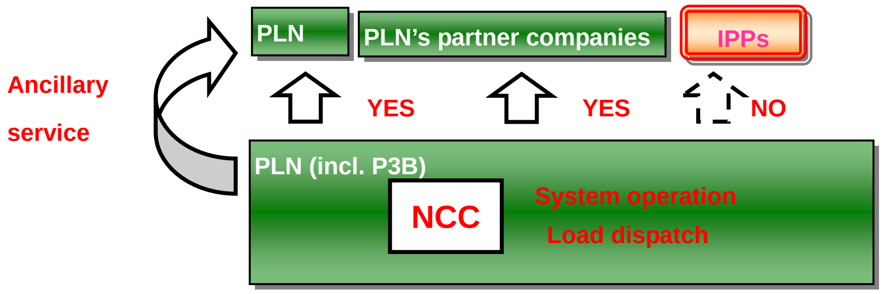


Figure 5.15　Institutional structure of Indonesia's system operation

Taking into account the fact that the planned PSPP will be developed and owned by PLN, PLN is and will be responsible for ancillary services including frequency control, and is capable of providing such services.

(4) The penetration of renewable energy – current status and plan

Among renewable energy, variable renewable energy (VRE) such as wind power generation and photovoltaic power generation, combined with which Adjustable Speed PSPP could maximize its advantage, has not penetrated over the country despite the fact that the government establishes the system to promote renewable energies. There has not been a plan to install significant amount of VRE so far. One of the major reasons is that the country intensively promotes geothermal power generation for the development or renewable energy. As of the end of 2010, the total capacity of 1,197 MW geothermal power plants is installed in Indonesia. Its amount is ranked third in the world, following U.S. and Philippines. The rest of the country's major renewable energy is hydro power generation (13 % of the total). Table 5.10 shows the penetration status of major renewable energies.

Table 5.10 Installed capacity of Indonesia

[Unit: MW]

	2005	2006	2007	2008	2009
Geothermal	1,035	1,035	1,055	1,155	1,100
Wind power	0	0	0.1	0.2	1.1
TOTAL	26,178	29,223	29,708	30,200	30,355

(SOURCE: JEPIC)

Similar to the case of Vietnam, renewable energy other than geothermal, e.g. small-hydro and photovoltaic, has been expected to contribute to rural electrification (Table 5.11).

Table 5.11 Instillation of renewable energy for rural electrification projects

[Unit: kW]

Type	2005	2006	2007	2008	2009
Wind power	80	160	735	200	72
Solar home system (SHS)	119.5	1,574	2,029	1,864	3,871
Concentrated type photovoltaic power	21,8	-	102.4	150	180
Small hydro power	314	702	1,169	1,765	1,170

(SOURCE: MEMR, JEPIC)

For the individual promotion of renewable energy, renewable energy projects conducted by private sectors do not have to go through usual competitive bidding process, but can sell their produced electricity to PLN. The decree of the State Minister on the purchase system for the spread of small scale renewable energy, promulgated in 2002 and 2006, covers the plants with capacity less than 10 MW and states the contract period to purchase the electricity as 10 years (the following decree promulgated in 2009 does not set the contract period.).

For the future outlook, the majority of planned installation of renewable energy is geothermal power generation. For example, approximately 54 % of the planned power plants in the second Crash Program (2010-2014) are power plants with renewable resources. Specifically, 41 of the total will be geothermal power plants utilizing its ample domestic geothermal resources.

Table 5.12 shows the renewable energy base power development plan of RUPTL 2010.

Table 5.12 Power development plan of Indonesia

[Unit: MW]

	2010	2015	2019	Total
Geothermal	10	70	665	5,990
Small hydro power	39			267
TOTAL	4,156	2,608	6,566	55,484

(SOURCE: JEPIC, RUPTL 2010)

As seen, it is found that there is not a plan to install large number of variable renewable energy based power plants (intermittent power sources) such as wind power and photovoltaic power would be installed in Indonesia.

(5) Conclusion

As seen above, although power generation market has been liberalized in Indonesia, the power produced by IPP is purchased by PLN. The share of IPPs is expected to increase near future, though a market exchange, where ancillary service is traded, has not been established, and is not planned so far. Currently, electricity supply has been mainly provided by the vertically integrated entity, PLN. PLN's market share is 84% by capacity as of the end of year 2009, giving PLN significant market power. Therefore, PLN would provide ancillary service with its own assets. When, however, the RUPTL is completed as planned, the market share of PLN is projected to decrease to approximately 67% in the next 10 years, as the half amount of power development capacity in the second Crash program is supposed to be implemented by IPPs. Therefore, it is not certain that PLN will still be able to provide ancillary service with its own assets in future. If not, appropriate framework for ancillary service would be to be developed, such as ancillary service contract between PLN and IPPs.

Table 5.13 Power supply system of Indonesia

Item	Status
Area of entry from private sector	Generation area
Status of unbundling (generation, transmission, and distribution business)	Its plan has been cancelled.
Power development	Implemented based on Power Development Master Plan (RPUTL).
Wholesale trading	Power purchase by PLN with PPA price. Plan to "a single buyer system" has been cancelled.
Wholesale exchange	No plan.
Ancillary service	Provided by National Control Center (NCC).
Liberalization of retail market	Cancelled the liberalization plan.

(SOURCE: JEPIC)

5.3.2 Outline of power development plan

As stated in the above section, MEMR creates the General Electricity Plan (RUKN) for 20 years and basically revises it every year, setting expansion plan for power source and network, development plan for new and renewable energies, investment forecast, target of electrification rate, and so on, based upon power demand forecasted by the economic growth rate.

Based upon RUKN, PLN forms RUPTL for 10 years, including demand forecast, expansion plan for power source and network, including IPP, optimal fuel balance plan, renewable energy development plan, investment plan, and so on. In addition, PLN also forms single year's plan (RKAP).

According to the RUPTL 2010-2019, current capacity of power sources is 30,230MW, which is around 20% of reserve rate that is much lower than the PLN's target value of 35% due to the rapid increase of power demand. Since it is expected that the average annual increase rate would be around 9.3% until 2019 (it is stated that the average annual increase rate would be around 8.46% until 2020in the draft RUPTL 2011-2020), securing supply power sources continues to be the crucial issue.

Although power development was tend to be delayed for last 10 years, brisk activities in development are planned from 2010 including IPP, according to the RUPTL 2010-2019. As a result, it is expected that the reserve rate, which indicates an aspect of demand and supply balance, will be improved in the future although it is currently tend to decrease. Hence, it is expected that the shortage of supply will be relieved, from the severest situation in 2009 and 2010.

Table 5.14 shows the outline of RUPTL 2010-2019. Forecast of electricity sales and peak demand is shown in Table 5.15, and the ratio of power source in shown in Table 5.16.

Table 5.14 Outline of RUPTL 2010-2019

Economic Growth Forecast	6.1% annually
Electrification Target	65% in 2009 → 91% in 2019
New Power Development (Total)	PLN: 31,958MW, IPP: 23,525MW, Total: 55,484MW
New Power Development (Java, Bali)	PLN: 23,095MW, IPP: 13,127MW, Total: 36,222MW
New Transmission Line Development (Total)	43,455km
New Substation Development (Total)	116,722MVA
New MV Distribution Line Development (Total)	172,459km
Average Annual Investment	9.7 Billion US$

Source: PLN RUPTL 2010-2019

Table 5.15 Forecast of Electricity Sales and Peak Demand

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Electricity Sales (TWh)	147.8	161.1	176.4	193.6	212.7	233.7	256.3	280.7	306.9	334.4
Peak Demand (MW)	26,246	28,796	31,692	34,813	38,206	41,916	45,938	50,270	54,896	59,863

Source: PLN RUPTL 2010-2019

Table 5.16 Power Source Ratio (Unit: %)

	Oil	Gas	Coal	Geothermal	Hydro
2009	23	22	43	6	7
2019	3	22	58	13	4

Source: PLN RUPTL 2010-2019

5.3.3 Outline of PSPP Project

PLN plans to develop PSPP in Java and Bali Region where demand is concentrated. In the Draft RUPTL 2011-2020, supply powers from PSPP are planned as shown in Table 5.17, 1,040MW from Upper Cisokan PSPP in 2016, 900MW from Matenggeng PSPP in 2019 and 2020 (450MW for each year), and 500MW from Grindulu PSPP in 2020.

Table 5.17 PSPP Project in Indonesia

Project Name	Commissioning year	Installed Capacity	Number of Units
Upper Cisokan	2016	1,040 MW	4
Matenggeng	2019	450 MW	2
	2020	450 MW	2
Grindulu	2020	500 MW	2

[Source: Draft RUPTL 2011-2020]

(1) Upper Cisokan PSPP Project

Upper Cisokan PSPP will be located in the upper stream of Cisokan River in West Bandung, 150km southeast of Jakarta, and will be of 260MW*4 units, 276m of effective head, 10 million m^3 capacity of upper reservoir, 10 million m^3 capacity of lower reservoir, and connected to the bulk network with 500kV double transmission lines. Total project cost is 800 million US$, with 160 million US$ funded by PLN and 640 million US$ funded by World Bank.

Figure 5.16 Location of Upper Cisokan PSPP

[Source: Upper Cisokan Pumped Storage Hydro Electric Power Plant Consolidated Environmental Impact Assessment, PLN]

(2) Outline of World Bank Project

World Bank decided to implement the project titled “Upper Cisokan Pumped Storage Hydro-Electrical Power (1,040 MW) Project”. The project now consists of the following three components.

- ■ Development of the Upper Cisokan Pumped Storage Power Project
  - ✓ Dam and appurtenant structures and access development, construction and operation of the UCPS Power Plant in West Java at the catchment of the Upper Cisokan River with an installed capacity of 1,040 MW(Megawatts)
  - ✓ Construction of two double circuit 500 kV transmission lines to connect the UCPS power plant to the existing Java-Bali power system at Cibinong- Saguling line
  - ✓ Assistance in pre-construction engineering design, procurement, and construction management and supervision, and project administration
- ■ Social and Environmental Impact management
  - ✓ Land acquisition, resettlement and livelihoods restoration, and environment management
- ■ Feasibility Study and Preparation of Basic Design and Bid Documents for Matenggeng Pumped Storage Power Project, and related Capacity Building
  - ✓ Feasibility study and the preparation of basic design and bid documents for the future planned Matenggeng pumped storage project in Central Java with a planned installed capacity of approximately 880 MW
  - ✓ Capacity building assistance to PLN for the planning, development and operation of hydropower projects, especially pumped storage hydropower projects

5.3.4 Situation of Power System Operation

After the power demand has dropped to a certain degree due to the Asian Currency Crisis in 1997, it has returned to increase as the economic recovery in Indonesia as shown in Figure 5.17. Average annual increase rates from 1997 to 2006 are 6.4% for electricity sales and 5.3% for peak demand. Demand of Java and Bali takes 80% of the total demand of Indonesia, where it is the center of politic and economic activities.

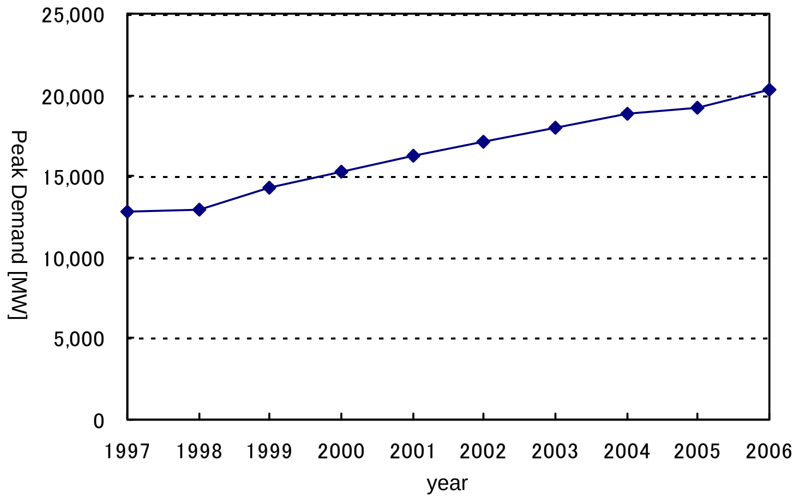


Figure 5.17 Peak Demand of Indonesia

Source: JEPIC, 2008

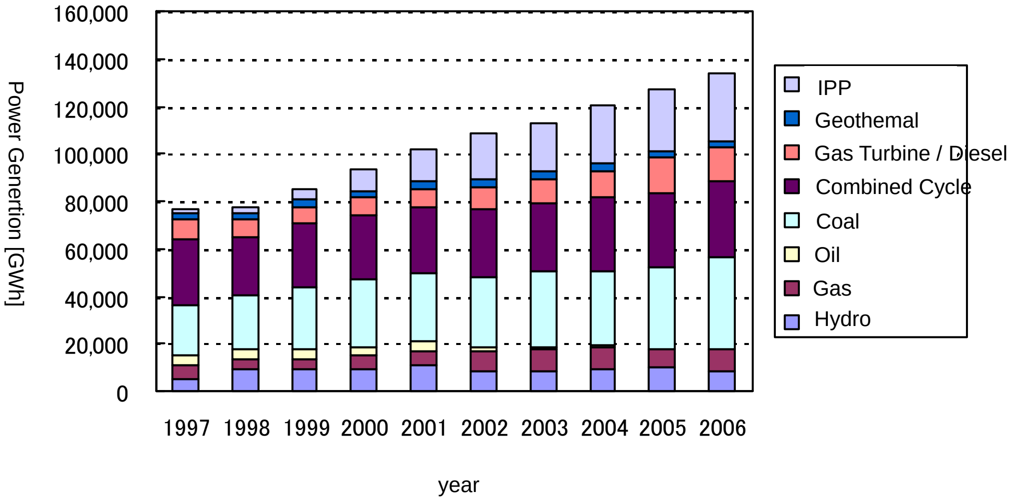


Figure 5.18 Annual Generation Amount by Power Sources in PLN

Source: JEPIC, 2008

In the generated energy in 2006, 104,500GWh was generated by PLN and its affiliated power producers, while 28,600GWh was generated by IPP and other private power supplier, which amounts to 22% of total supply amount as shown in Figure 5.18. On the other hand, while load factor was kept 70% and up from 2001 to 2005, it was decreased to 64.5% in 2006 as shown in Figure 5.19, which indicates the tendency of sharpening the peak demand as the demand increase. Figure 5.20 indicates this trend, which is appeared in the power system of Java and Bali.

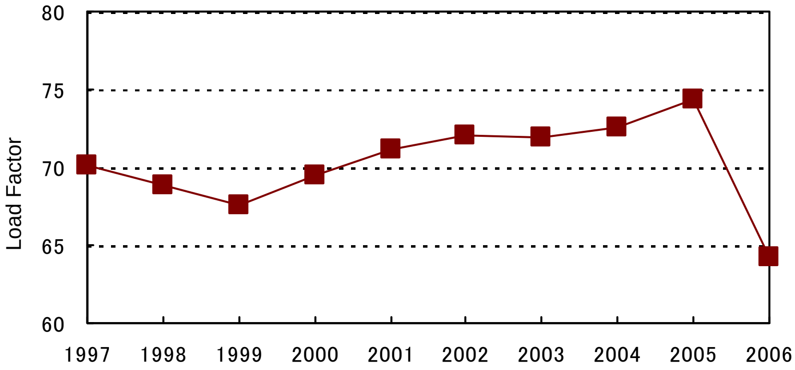


Figure 5.19 Load Factor in Indonesia

Source: JEPIC, 2008

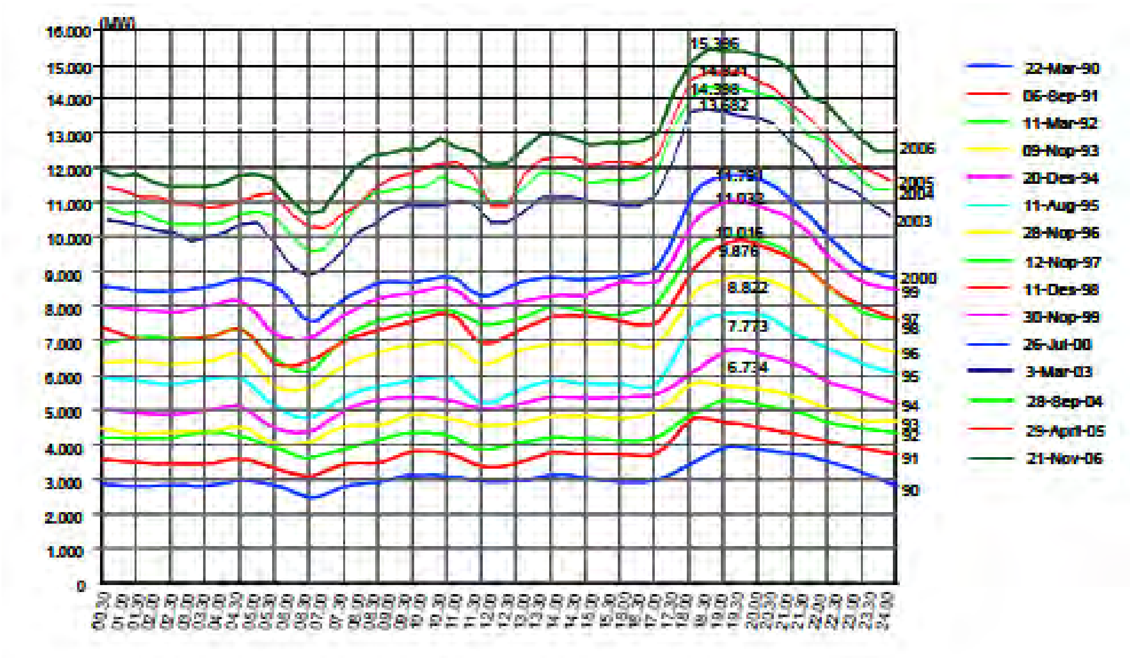


Figure 5.20 Load Curve of Annual Peak Demand in Java-Bali Power System

Source: Upper Cisokan Pumped Storage Hydro Electric Power Plant Consolidated Environmental Impact Assessment, PLN

In the Java-Bali Network, maximum demand of 19,624MW was recorded on September 28, 2011. Out of generation capacity in the region, which is 22,153MW, supply capability is 20,536MW, considering output decrease due to aging, periodical maintenance, shutdown due to trouble, and hydro output decrease in the dry season. This results in

912MW and 4.4% of reserve capacity, which indicates the difficult situation in demand supply control.

When reserve capacity becomes less than 600MW, which is the largest single unit of Suralaya Thermal PS, PLN declares the state of “Emergency” and prepares for load shedding. When supply capability becomes short, “Deficit” is declared and load shedding is implemented. Table 5.18 shows the number of “Emergency” and “Deficit” dates.

Table 5.18 Supply state in PLN

Year	Normal	Emergency	Deficit
2004 (Apr. to Dec.)	239	35	1
2005	213	110	42
2006	278	55	32
2007	295	57	13
2008	223	108	35
2009	323	19	23
2010	347	17	1
2011 (Jan. to Sep.)	141	80	52

Table 5.19 Situation of Load Shedding in Java-Bali in 2009

	Number	Energy (MWh)
UFR	23	7,628
MLS (Manual Load Shedding)	422	198,366
Other Load Shedding	112	18,598
Total	557	224,593

Figure 5.21 and Figure 5.22 show the hourly demand and supply sources in rainy season and dry season in Java-Bali. Frequency control is usually conducted by hydro power plants and High Speed Diesel (HSD) power plants in Java-Bali network. Coal thermal power plants are used for base load supply, but they are also used for frequency control occasionally, including IPP. As the reserve for frequency control, 2.5% of demand is reserved for LFC control every hour. There are three times of difficult condition for frequency control in a day, from 5 to 7 in the morning, with approx. 500MW of fluctuation, from 11 to 13 during noon, with approx. 1,000MW of fluctuation, and from 17 to 19 in the evening, with approx. 2,000MW of fluctuation. Although coal thermal power plants are available for frequency control with relatively high output in the time of noon and evening, only hydro and HSD are used for frequency control in the morning since thermal power plants operates at low output at the time. In addition, while annual peak demand is normally recorded in October or November as shown in Figure 5.23, it is difficult to

reserve the adjustment capacity for off peak hours in this season since hydro power plants operate for a few hours in a day due to the dry season.

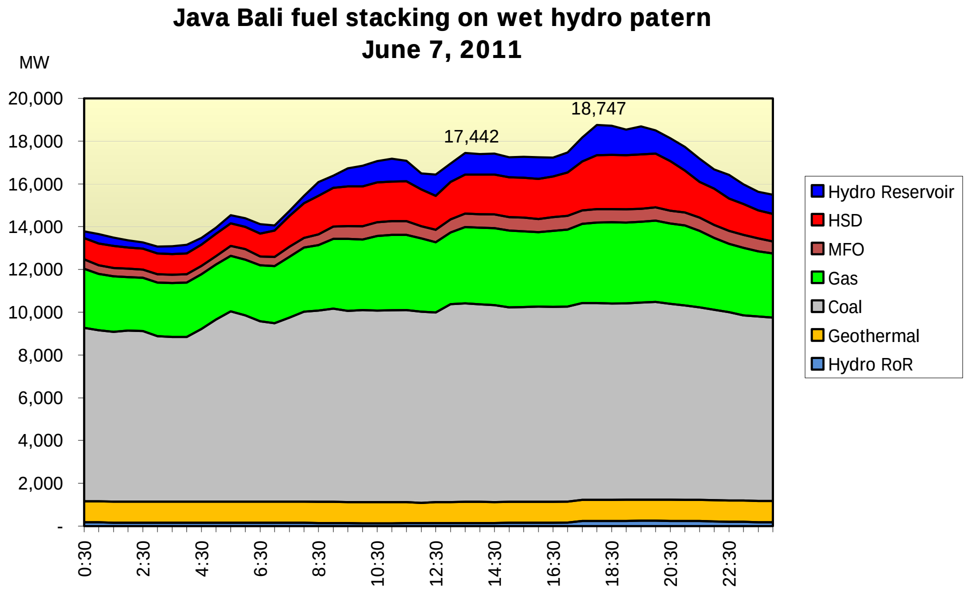


Figure 5.21 Hourly Demand and Supply Sources in Rainy Season in Java-Bali

Source: P3B

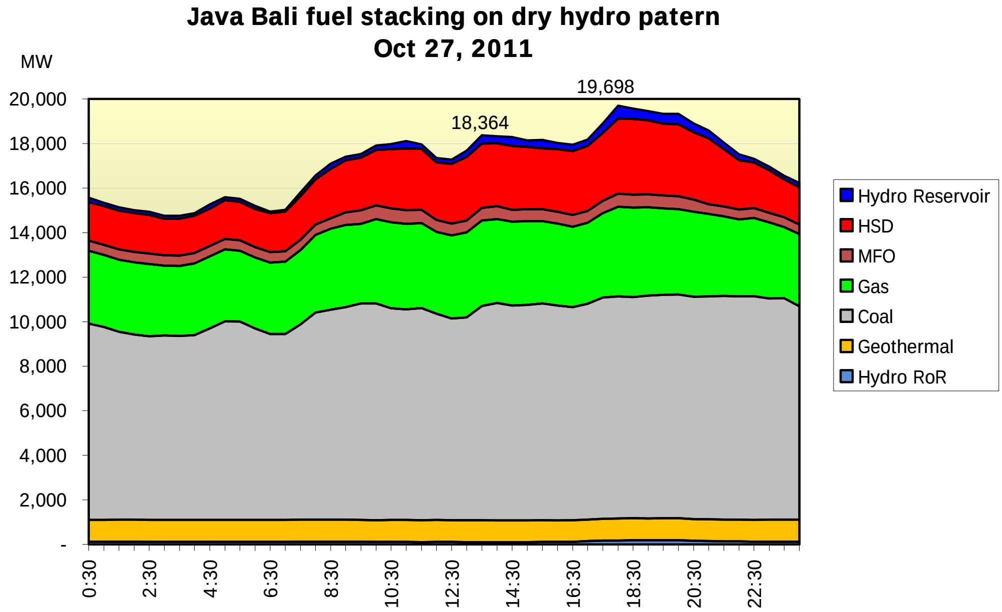


Figure 5.22 Hourly Demand and Supply Sources in Dry Season in Java-Bali

Source: P3B

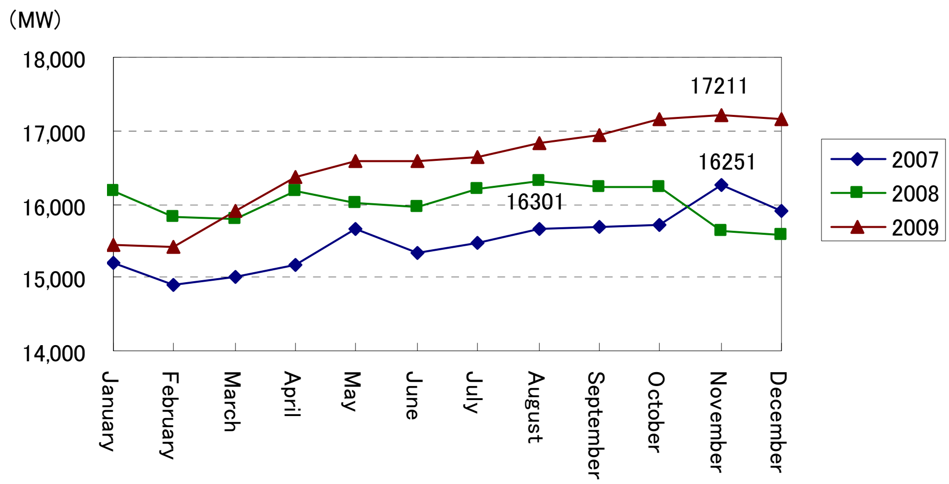


Figure 5.23 Monthly Maximum Demand from 2007 to 2009 in Java-Bali

Source: EVELUASI OPERASI SISTEM JAWA BALI 2009

From the viewpoint of reducing generation cost, network operator hopes to decrease the ratio of diesel thermal power plant, and it is stated in RUPTL 2011-2020 (Draft) that HSD will be substituted by coal thermal and geothermal in a few years. Since it is estimated that the share of coal thermal and geothermal increases in the future, there is a great need for the power source for adjustment.

5.3.5 Feasibility of introducing Adjustable Speed PSPP

Based on the above findings, this section analyzed the impact/ benefit which would be obtained from the application of adjustable speed type pumped storage power generation to Indonesia from the points of view raised in 5.1.2.

First, it is found that the country does not have a power development plan to install intermittent renewable energy based power generation, e.g. photovoltaic power generation and wind power generation in large scale for next 10 to 20 years, and that the country does not have an exchange to trade power products like ancillary service among players, and also does not have a plan to establish it as of now. Therefore, it is expected that it is less likely that Indonesia's power utility would operate its pumped storage power plants (PSPPs) in the way like the one which western Europe utilities do, i.e. switching pump-up mode and power generation mode frequently during day and night to meet the frequency control (ancillary service) demand.

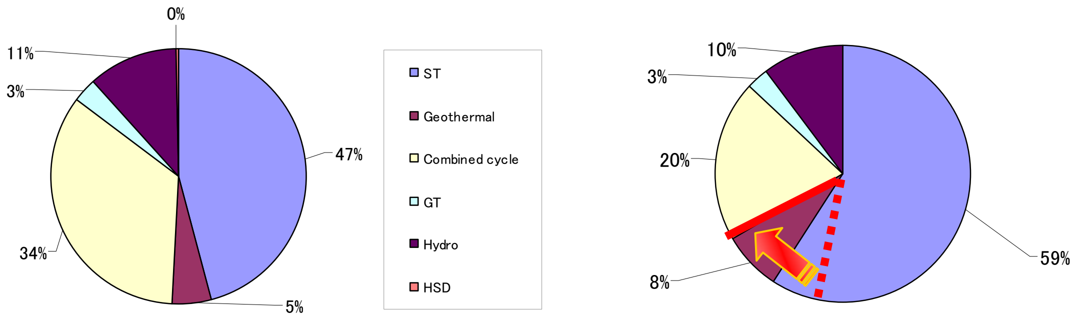
Secondly, according to PLN's 10-year power development plan (draft RUPTL

2011-2020, a large number of coal-fired power plants are planned to be developed, some of which will be financed from private sector. The more the base load supply source like coal-fired power plants is installed, the less the share of power source with frequency control capability during light load period will be. Therefore, at some point of time, any countermeasure should be taken to address the issue. The adjustable-speed pumped storage power plants (AS-PSPPs) would address the issue because the plant's technology not only generates power but also consumes power flexibly. In fact, one of the main reasons why AS-PSPPs have been installed in large scale in Japan is that the large amount of nuclear power plants – another base load power source – have been installed. Indonesia looks like to experience the similar situation in near future.

Based on those understanding, the following discusses whether the situation in future Indonesia will be the one where AS-PSPPs would play a key role as frequency control facility during light load time, and evaluates how much impact can we expect from the installation of the technology then.

(1) The shift of power generation composition

Here we reviewed the nation's power development plan to see if and by how far the share of base load power supply would increase in future. Figure 5.24 shows the shift of the composition of power supply capacity of Java-Bali system by technology.



YR 2009. 21,784 MW

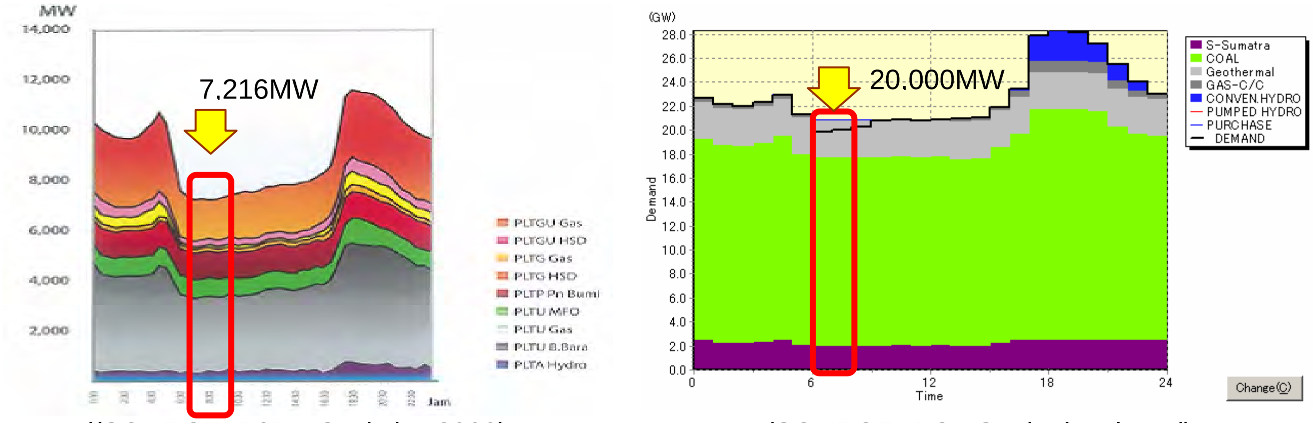
YR 2020. 52,624 MW

(SOURCE: P3B Statistics 2009)

Figure 5.24 Breakdown of power supply capacity of Java-Bali system by technology

As obvious from the above figure, the share of base load supply composed of ST (steam turbine. Mainly coal-fired power generation) and geothermal power generation will have gained its share from around 50% in 2009 to approximately 70% in 2020. Next analyzed the impact of such increase of the share by base load supply to the power supply composition during light load period.

Figure 5.25 shows the power supply composition during light load period of year 2009 and year 2020. For both, the day when power demand becomes minimum, immediately after the Ramadan period, has been selected as the severest analysis condition.



((SOURCE: P3B Statistics 2009) (SOURCE: JICA Study developed)

Figure 5.25 Power supply composition during light load period
(Left: YR2009, Right: YR2020)

In 2009, power supply combined by coal-fired power generation and geothermal power generation meets almost the half of demand (approximately 3,500 MW) at 6:00 am – the minimum load time during a day, while, in 2020, the power supply will meet most of the demand at the same time of a day in 2020, integrating the supply through Sumatra interconnection, also the base load supply. As a result, the share of power source which is capable of frequency control has decreased (*).

*: The data of YR 2009 is from actual data, while the data of YR 2020 is from economic-engineering simulation.

(2) Current situation of frequency control

As described in 5.3.3, National Control Center (NCC) of P3B Java Bali is responsible for frequency control of the Java Bali System. According to their operation policy, 2.5 % to 5 % of demand of every hour is to be secured for load frequency control (LFC or secondary control) reserve margin. The reserve margin will be assigned to each power plant which is equipped with automatic LFC facility by merit order. For reference, the rate of speed regulation, or primary control, is set as 5%. Table 5.20 shows the list of power plants which are expected to contribute to frequency control of Java-Bali system (as of January 2011). All the power plants in the table operate in governor-free mode. The plants on a green background stand for the plants equipped with automatic LFC function. Their SCADA system has been supplied by Siemens, starting operation in 2005.

Table 5.20 The list of power plants equipped with frequency control function
(as of January of 2011. Java-Bali system)

No.	Power Plant				Installed	GF	LFC readiness		
	Type	Plant name			Capacity		Scada	Unit	Regulasi (MW)
1	PLTU	SLAYA	#3		372	OK	NOK	NOK	–
2	PLTU	SLAYA	#4		372	OK	NOK	NOK	–
3	PLTU	SLAYA	#	5	575	OK	OK	OK	5
4	PLTU	SLAYA	#	6	575	OK	OK	OK	5
5	PLTU	SLAYA	#	7	575	OK	OK	OK	5
6	PLTU	PRIOK	#3		41	OK	NOK	NOK	–
7	PLTU	PRIOK	#4		41	OK	NOK	NOK	–
8	PLTGU	PRIOK	B.1		548	OK	OK	OK	15
9	PLTGU	PRIOK	B.2		514	OK	OK	OK	15
10	PLTU	MKRNG	#5		162	OK	NOK	NOK	–
11	PLTGU	MKRNG	B.1		420	OK	OK	OK	5
12	PLTGU	MKRNG	B.2		480	OK	NOK	NOK	–
13	PLTGU	CLGON	B.1		739	OK	NOK	NOK	–
14	PLTU	LBUAN	#1		280	OK	NOK	NOK	–
15	PLTU	LBUAN	#2		280	OK	NOK	NOK	–
16	PLTA	SGLNG	#1		175	OK	OK	OK	20
17	PLTA	SGLNG	#2		175	OK	OK	OK	20
18	PLTA	SGLNG	#3		175	OK	OK	OK	20
19	PLTA	SGLNG	#4		175	OK	OK	OK	20
20	PLTP	DRJAT	#1		52	OK	NOK	NOK	–
21	PLTA	CRATA	#1		119	OK	OK	OK	20
22	PLTA	CRATA	#2		119	OK	OK	OK	20
23	PLTA	CRATA	#3		119	OK	OK	OK	20
24	PLTA	CRATA	#4		119	OK	OK	OK	20
25	PLTA	CRATA	#	5	119	OK	OK	OK	20
26	PLTA	CRATA	#	6	119	OK	OK	OK	20
27	PLTA	CRATA	#	7	119	OK	OK	OK	20
28	PLTA	CRATA	#	8	119	OK	OK	OK	20
29	PLTGU	MTWAR	B.1		630	OK	OK	OK	15
30	PLTGU	MTWAR	B.2		290	OK	NOK	NOK	–
31	PLTGU	MTWAR	B.3		420	OK	NOK	NOK	–
32	PLTGU	MTWAR	B.4		420	OK	NOK	NOK	–
33	PLTG	CIKARANG			150	OK	NOK	NOK	–
34	PLTA	JTLHR	#1		30	OK	NOK	NOK	–
35	PLTA	JTLHR	#2		30	OK	NOK	NOK	–

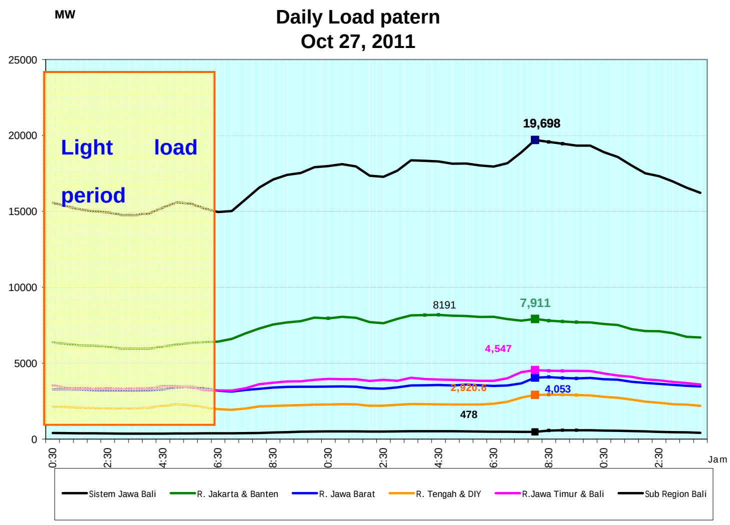
No.	Power Plant				Installed	GF	LFC readiness		
	Type	Plant name			Capacity		Scada	Unit	Regulasi (MW)
36	PLTA	JTLHR	#3		30	OK	NOK	NOK	–
37	PLTA	JTLHR	#4		30	OK	NOK	NOK	–
38	PLTA	JTLHR	#5		30	OK	NOK	NOK	–
39	PLTA	JTLHR	#6		30	OK	NOK	NOK	–
40	PLTP	DRAJAT	3		106	OK	NOK	NOK	–
41	PLTP	DRAJAT	2		90	OK	NOK	NOK	–
42	PLTP	KMJNG	#4		60	OK	NOK	NOK	–
43	PLTA	MRICA	#1		60	OK	NOK	NOK	–
44	PLTA	MRICA	#2		60	OK	NOK	NOK	–
45	PLTA	MRICA	#3		60	OK	NOK	NOK	–
46	PLTU	TBROK	#1		41	OK	NOK	NOK	–
47	PLTU	TBROK	#2		41	OK	NOK	NOK	–
48	PLTGU	TBROK	B.1		400	OK	OK	OK	10
49	PLTGU	TBROK	B.2		300	OK	OK	OK	10
50	PLTU	TJATI	#	1	661	OK	OK	OK	10
51	PLTU	TJATI	#	2	661	OK	OK	OK	10
52	PLTU	CLCAP	#	1	20	OK	NOK	NOK	–
53	PLTU	CLCAP	#	2	20	OK	NOK	NOK	–
54	PLTU	PAITON	JP	#5	610	OK	NOK	NOK	–
55	PLTU	PAITON	JP	#6	610	OK	NOK	NOK	–
56	PLTGU	GRATI	B.1		450	OK	OK	OK	15
57	PLTGU	GRATI	B.2		300	OK	NOK	NOK	–
58	PLTA	STAMI	#1		34	OK	NOK	NOK	–
59	PLTA	STAMI	#2		34	OK	NOK	NOK	–
60	PLTA	STAMI	#3		34	OK	NOK	NOK	–
61	PLTU	GRSIK	#1		80	OK	NOK	NOK	–
62	PLTU	GRSIK	#2		80	OK	NOK	NOK	–
63	PLTU	GRSIK	#3		167	OK	NOK	NOK	–
64	PLTU	GRSIK	#4		167	OK	NOK	NOK	–
65	PLTU	PITON	#1		370	OK	NOK	NOK	–
66	PLTU	PITON	#2		370	OK	NOK	NOK	–
67	PLTGU	GRSIK	B.1		480	OK	OK	OK	20
68	PLTGU	GRSIK	B.2		420	OK	OK	OK	20
69	PLTGU	GRSIK	B.3		480	OK	OK	OK	20
TOTAL					17,034				420

Legend: GF) Governor-free operation, Regulasi: the range of LFC.
(SOURCE: PLAN OF OPERATION POWER SYSTEM JAVA-BALI 2011, Original title: "RENCANA OPERASI SISTEM TENAGA LISTRIK JAWA-BALI 2011")

The automatic LFC function is provided by hydropower plants, gas combined cycle power plants, and gas turbine power plants fueled by high speed diesel (GT-HSD), including Saguling hydropower plant, Cirata hydropower plant, Suralaya coal-fired power plant #5,#6, and #7, Tanjung Jati coal-fired power plant #1 and #2, Tanjung Priok combined cycle power plant Block 1&2, Muara Karang Combined cycle power plant Block 1, Gresik combined cycle power plant block 1, 2, and 3, Grati combined cycle power plant Block 1. Although coal-fired power plants are usually categorized as base load power supply source, they can be used for frequency control purpose. Coal-fired power plants owned by IPPs also follow this rule (IPPs would not financially lose their benefit thanks to the current Take-or-Pay contract). The total amount of LFC reserve margin is 420 MW as of January 2011, while the amount is short of the expected LFC reserve margin during peak load time (the size of peak load is estimated to be 20,000 MW) because approximately 500 to 1,000 MW is necessary theoretically. The system operator, P3B, plans to meet the rest of the LFC reserve margin with supply from the other coal-fired power plants. Coal-fired power plants owned by IPPs are not supposed to be equipped with automatic LFC facility currently, NCC dispatches commands of tertiary control on phone to those plants, too, because of their Take-or-Pay contract. In theory, those IPP-owned plants can be counted as those for automatic LFC service if telecommunication system is installed between NCC and those power plants, without any legally or regulatory modification.

(3) The capacity needed for LFC during light load time

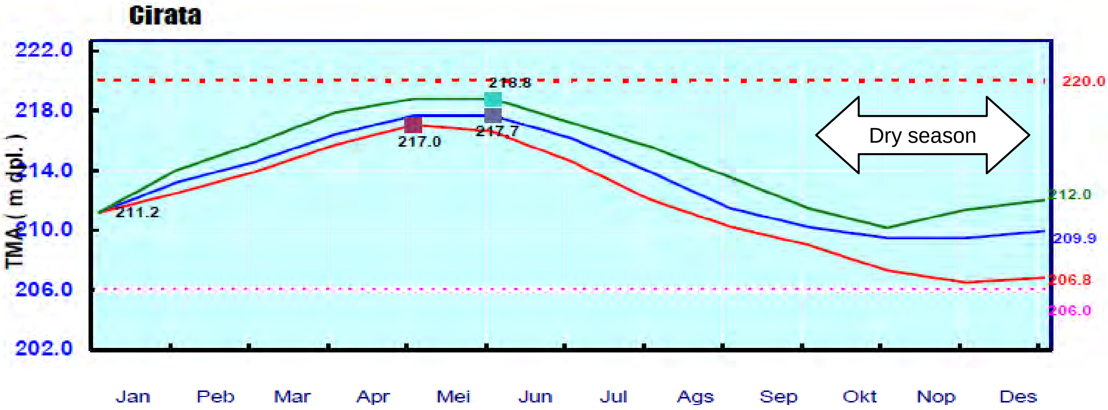
According to P3B's operation staff, while coal-fired power plants can contribute to load frequency control during peak time around noon and evening because of their output level, they cannot provide the function during light load, or off-peak, period in the early morning, because they are operated almost with minimum output, which limits the range to reduce the output. Likewise, less combined cycle generators operate during light load period than daytime (4 generators in the early morning, while 10 generators during daytime). Therefore, in order to secure the capacity of LFC, hydropower plants and GT-HSD with high generation cost are expected to play a role as LFC function supplier. Figure 5.26 shows the typical daily load curve of Java-Bali system.



(SOURCE: P3B)

Figure 5.26 Typical daily load curve

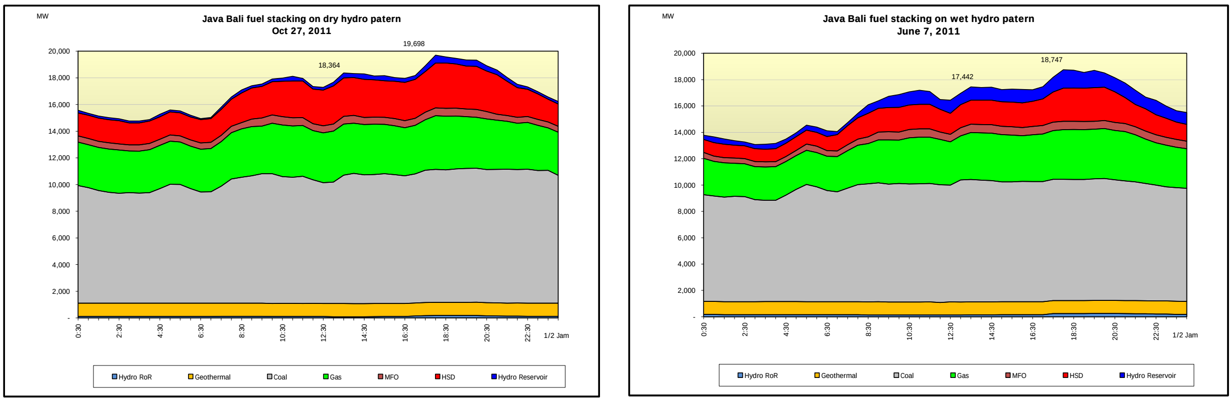
In terms of seasonal operation, the supply capability of hydropower plants decreases in dry season from October to December. As the plants operate only for approximately 4 hours a day during the season, less contribution to LFC is expected from the hydropower plants than in the other seasons (Figure 5.27 and Figure 5.28).



Legend: Blue) average year, Red) dry year; Green) Wet year

(SOURCE: PLAN OF OPERATION POWER SYSTEM JAVA-BALI 2011, original title: “RENCANA OPERASI SISTEM TENAGA LISTRIK JAWA-BALI 2011”)

Figure 5.27 Rule cover of major hydro power plant (Cirata power plant)



Dry season Wet season

(SOURCE: P3B)

Figure 5.28 Comparison of Demand Supply Balance

In summary, the early morning during dry season is the most challenging time for load frequency control, specifically for the control to adjust the output downward, as the load is lightest (which means little room is left for power sources capable of LFC due to the majority of base load supply source) and the LFC capability from hydropower plants is the smallest through the year.

Based on those study result, it is anticipated that the power supply source which is capable of providing LFC would lose its share, specifically in meeting the demand during light load time in 2020. It might also occur that the source would not be able to cover the reserve margin necessary for LFC purpose (estimated to be from 500 to 1,000 MW against the total demand of 20,000 MW). Among others, because the share of coal-fired power plants, which operate with minimum output during off-peak time, in total power supply capability is planned to increase in future, AS-PSPPs are expected to raise their value more because of their unique capability to absorb the increase of load by its pumping-up operation.

(4) Evaluation of the installation impact of AS-PSPPs

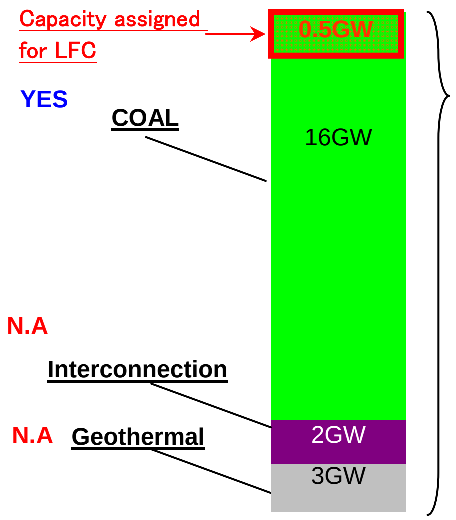


Figure 5.29 Power supply composition during light load time (2020)

Based on the finding above, the JICA Study Team has calculated the benefit of installing AS-PSPPS in Java-Bali system. The data used for this demand supply balance simulation have been cited from the past studies including JICA's study in 20086 and PLN's draft RUPTL 2011-2020. The calculation picked up the supply demand balance around 7:00 am in holidays of September in 2020, since the share of LFC function supply source would be the smallest, which means the most severe condition for system operator. Figure 5.29 shows the calculation result – the breakdown of power sources by generation technology (original demand supply balance image shown in the right side of Figure 5.25).

The load of one giga-watt among total load of 21 GW is from Upper Cisokan PSPP which operates in pumping-up operation.

In 2020, the following PSPPs are in operation: Upper Cisokan PSPP with installed capacity of 1,040 MW (260 MW x 4 units), Matenggeng PSPP with installed capacity of 900 MW (450 MW x 2 units), and Grindulu PSPP with installed capacity of 500 MW (250 MW x 2 units). The total installed capacity of PSPPs in operation in 2020 amounts to 2,440 MW.

According to the result, 5 GW out of total demand of 20 GW during off-peak time comes from geothermal power plants and interconnection power supply from Sumatra system, neither of which contribute to LFC. Suppose that the necessary capacity for LFC then is 2.5 % of the total demand, the amount will be calculated like below:

20 GW x 2.5 % = 500 MW.

At a glance, it looks that the amount can be procured from the remaining coal-fired power plants. More than half of the power plants, however, are owned by IPPs which usually operate in full output in accordance with their Take-or-Pay contract as shown in Figure 5.30.

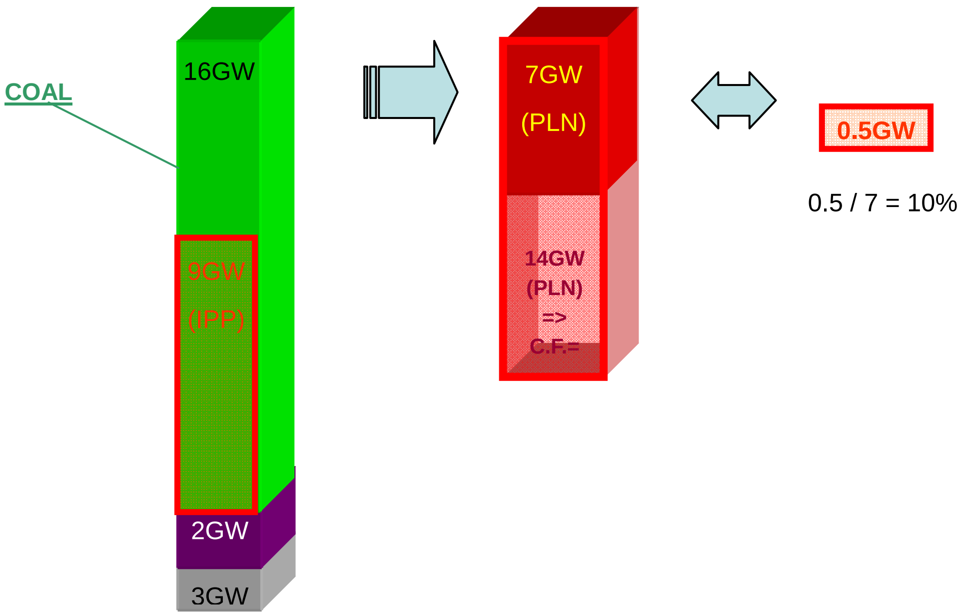


Figure 5.30 The breakdown of coal-fired power supply

Power plants owned by IPPs are not equipped with telecommunication system linking to P3B's NCC currently (Table 5.20. Paiton #5,6 and Cilacap #1,2). Since the situation might not change in future, those plants would not be counted as power sources providing LFC function. In conclusion, 7 GW, the remaining obtained by subtracting 9 GW out of total 16 GW, is the amount of power source which the P3B's system operator can utilize for LFC purpose. Another critical point is, however, that total installed capacity of power plants owned by PLN and its subsidiary companies is around 14 GW, which means that these power plants are operated with capacity factor of 50%. It would need to reduce the capacity factor down to around 40 % so that the PLN-related coal-fired power plants could provide 0.5 GW LFC capacity. Taking into account that typical minimum output of coal-fired power plants is around 20 to 30 percent, this would not be preferable not only because such activity would lower the generation efficiency making the plants' operation

[6] The study on optimal electric power development in Java-Madura-Bali in the Republic of Indonesia : final report, JICA, December 2010.

uneconomical but also because the activity might let the system operation status not in good status.

In summary, the study team analyzed the capability of load frequency control in future Java-Bali system from the points of power source composition by technology. The result tells that the situation where more stable and more economical power source is requested for the LFC purpose would rise in near future. Consequently, it has turned out that the value of AS-PSPPs would likely rise then as the most promised candidate for the purpose.

(5) Economic impact evaluation

This subsection evaluates the economic benefit of installing AS-PSPPs instead of existing GT-HSD[7], which plays a main role as LFC power source during off-peak time early in the morning now.

a. Calculation Premise

Unit generation cost is set as follows:

- GT-HSD: 2,697 Rp/ kWh
- AS-PSPP: 854 Rp/ kWh (Assumption: 1) 70% of total efficiency; 2) coal-fired power plants for pumping-up operation, whose unit generation cost is set as 598 Rp/ kWh.

Note: The figures refer to “Study report on Power industry in Indonesia: 2010,” JEPIC

b. Cost

Because Indonesia already has a plan to develop pumped storage power plants, additional cost to change those plants’ design from conventional PSPP to AS-PSPP is selected as the cost used for this evaluation. This is estimated roughly as 10 % of the total investment cost, as O&M cost would not differ significantly between the two types. Assuming that the typical unit investment cost of PSPP as approximately 800 USD/ kW and that all the four units of planned Upper Cisokan PSPP would adopt the adjustable speed type, the additional cost would be led like below:

1,040 MW x 800 USD/ kW x 10% = 83.2 million USD.

c. Benefit

For the economic benefit, the diesel fuel cost saved by replacing GT-HSDs by AS-PSPPs has been chosen. As shown in Table 5.14, the total amount of LFC reserve margin provided by GT-HSDs is 145 MW as of 2011. The required amount of LFC reserve

[7] According to the latest Indonesia’s long-term power development plan, the draft RUPTL 2011-2020, most of existing GT-HSDs are scheduled to retire in next 10 years. The JICA Study Team refers to them, as the purpose of this subsection is to lead a quantitative indication as future reference.

margin during off-peak time in 2011 is calculated like below:

7,000 MW x 2.5 to 5.0 % = 175 to 350 MW.

Therefore, it can be assumed that all the LFC capacity provided by GT-HSD is required to cover the total reserve margin in dry season when little contribution is expected from hydropower plants. For reference, provided that all the 4 units of Upper Cisokan PSPP are to be designed as AS-PSPP, the LFC capacity provided by the PSPP is calculated as follows:

±50 MW x 4 units = ±200 MW.

As seen, this would fairly cover the capacity currently provided by the existing GT-HSDs.

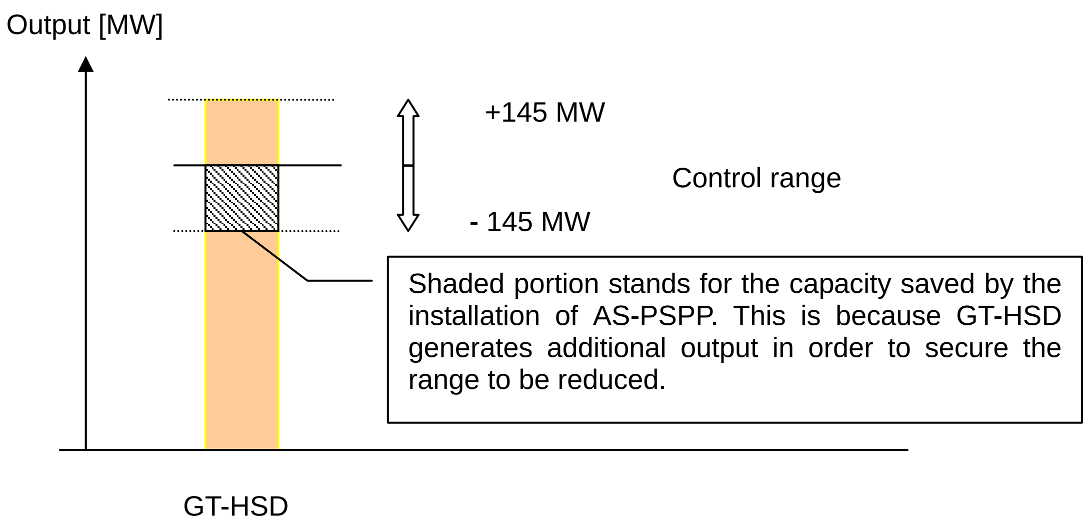


Figure 5.31 The image of Economic benefit

Assuming that the period requiring LFC for off-peak load is from 3:00 am to 6:00 am early in the morning, which is estimated from the typical daily load curve shown in Figure 5.26, and that the LFC during off-peak load is necessary every day through the year, the annual economic benefit obtained by replacing the existing GT-HSDs with AS-PSPPs is estimated in the following manner:

145 MW x 3 hours x 365 days x (2,697 – 845 Rp/ kWh) = 290 billion Rp.

= 33 million USD/ year.

Note: The currency exchange rate is set as 8,800 Rp/ USD. (Source: Yahoo Finance, December 12, 2011).

d. Conclusion

From the economic cost and benefit estimated above, the payback period of the installation of AS-PSPP is calculated as follows:

83.2 million USD / 33.0 million USD = 2.5 years.

Finally, the evaluation obtained the prospect that the installation project of AS-PSPP would recover its additional investment cost necessary to adopt adjustable speed type in less than 3 years.

(6) Recommendation: Items to be studied further

In this section, we analyzed the feasibility of applying AS-PSPPs in Java-Bali system. Through the interview with staff of PLN's planning section as well as P3B's system operation section, it is clear that they understand the AS-PSPP's advantage and necessity. Further, they once conducted the similar feasibility study in the past, and therefore, there is also possibility that any of units of planned PSPPs on the current long-term power development plan would adopt the adjustable-speed type. The planned PSPPs are Upper Cisokan (COD in 2016, 4 units), Matenggeng (COD in 2019 and 2019, 2 units), and Grindule (COD in 2020, 2 units). There is also another plan to develop a PSPP in Sumatra system. Among those, it would be possible for Upper Cisokan PSPP, whose development has been currently assisted by the World Bank, to adopt AS-PSPP because its development project has a schedule to float its EPC Tender in 2012 in the International Competitive Bidding (ICB) manner, which lets the design aspect also open to adjustable-speed type.

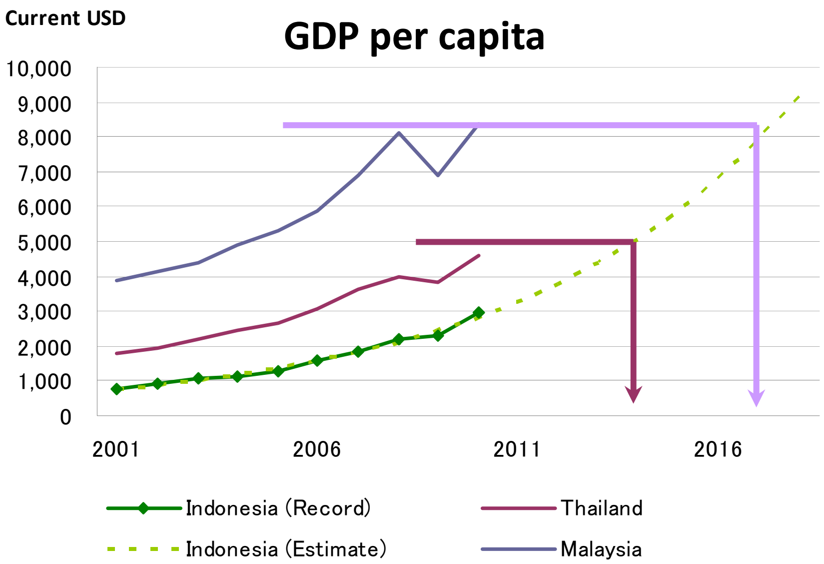


Figure 5.32 The shift of GDP per capita

In Indonesia, the need for quantity of power supply is still given much more priority than the need for quality now, as demonstrated by the fact that there are several and/ or more days of load-shedding due to the tight demand-supply balance through the year. On the other hand, however, the number of Japanese companies like those from automotive industry which expand their business to the country is increasing sharply these days, partly as the measure to hedge business risks, e.g. China plus one. As one of indicators to show such needs for the electricity quality, the shift of GDP per capita is shown in Figure 5.32. As seen, by the time of planned PSPPs' COD, the Indonesia's GDP per capita is expected to reach the level of surrounding nations such as Thailand and Malaysia. Consequently, it is expected that the requirement level for the quality of power supply would become high soon, and therefore, the requirement for AS-PSPPs which can provide LFC service economically is expected to rise before long. Figure 5.33 summarizes the evaluation result by factor in a comprehensive manner.

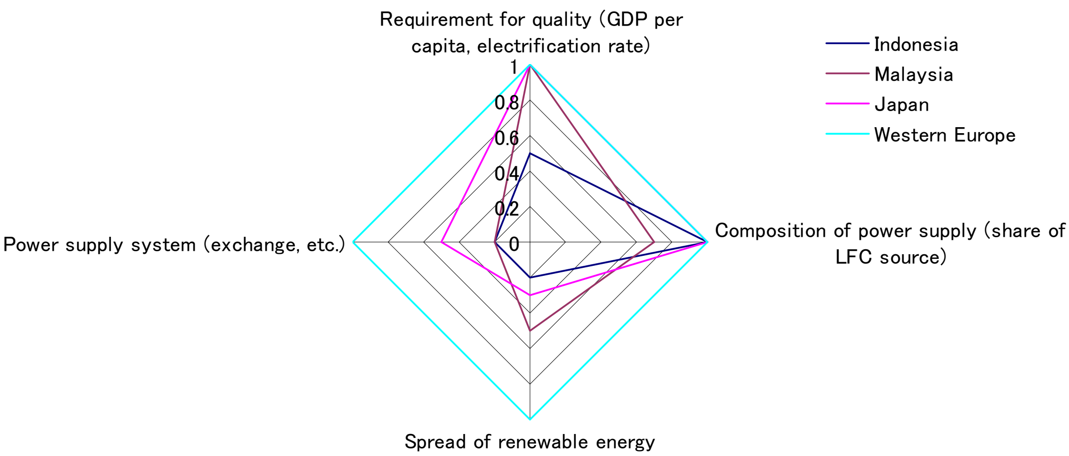


Figure 5.33 Evaluation result

As shown in the above figure, while the impact of adopting AS-PSPPs in Indonesia as well as Malaysia is small for the factors well seen in Western European countries (i.e. power supply system and spread of renewable energy), it is clear that that impact is estimated to be high for the factors well seen in Japan (i.e. requirement for quality of power supply and composition of power supply sources). Based on these findings and the request for comprehensive master plan of pumped storage power plants by PLN, the JICA Study Team proposes further study consisting mainly of the following topics:

[Topics to be studies further]

- Holding of a workshop inviting stakeholders for further understanding of the technology and related benefit.

- Discussion over the cooperation/ coordination on the AS-PSPP development project with the other donors who have assisted the country's existing PSPP development plan.
- Identification of optimal installed capacity, location, and timing of the AS-PSPP which would maximize their benefit.
- More detailed calculation of economic impact. Specifically, the evaluation of the impact of Yen loan as financing resource to absorb the additional investment cost resulted from the modification from conventional type to Adjustable-Speed System.
- Formulation of power development plan integrating additional PSPPs, estimating the impact of quality improvement and that of system operation improvement.

5.4 Feasibility of Introducing AS-PSPP in Other Asian Country

In this Study, feasibility of introducing AS-PSPP is studied for Vietnam and Indonesia, where there are development plans for introducing PSPP. For both countries, it is found that there is the demand for AS-PSPP as the reserve for demand supply control, as well as the demand for supply capability development to deal with increasing power demand. In this section, a preliminary study for Malaysia is conducted based on available secondary data, as a country with different stage of development and one of the feasible countries of AS-PSPP stated in 5.1.3.

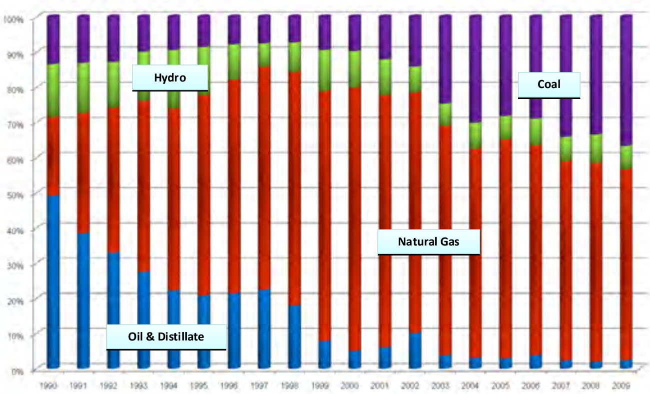
5.4.1 Feasibility of introducing AS-PSPP in Malaysia

(1) Analysis of the situation

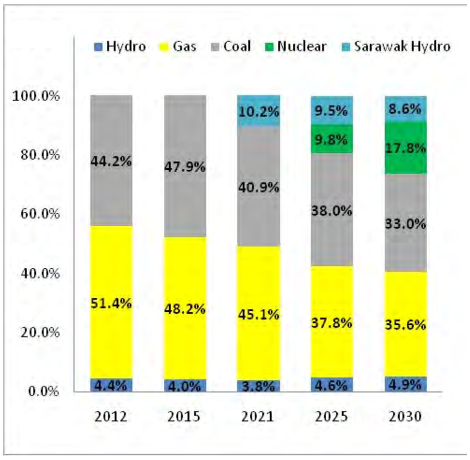
Because the power industry of Malaysia is similar to that of Indonesia and Japan, it is highly expected that the impact of adopting adjustable speed pumped storage power generation as power source to supply LFC function would be large.

a. Power supply composition

Because the share of coal-fired power plants, which would be used as pumping-up power of PSPPs, has increased since the start of 21st century, it is prospected that the economy of PSPPs rises in future (Figure 5.34). In addition, the country plans to install the other economic power source, nuclear power plants, in the long term.



Power Generation Mix

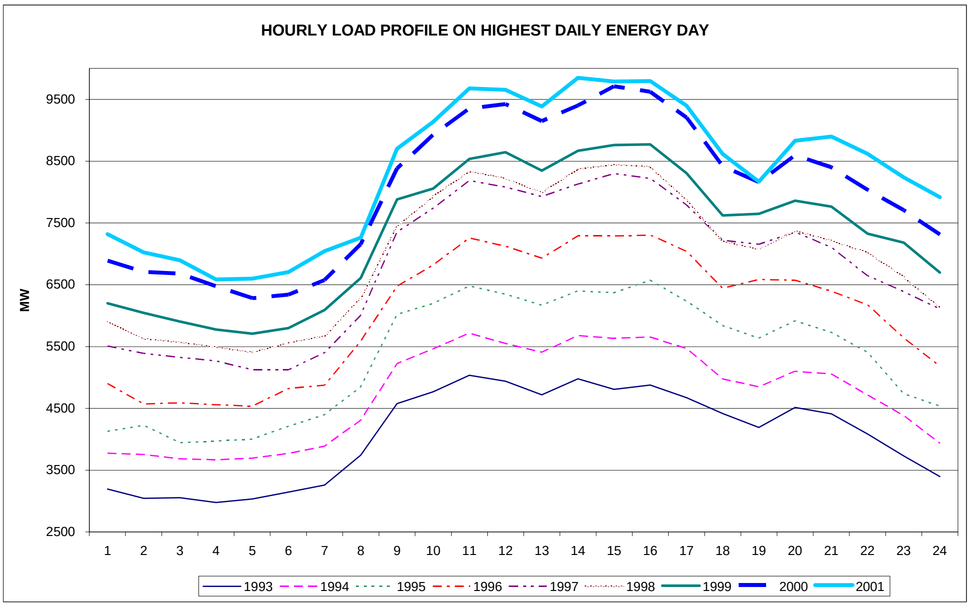


Power Generation Mix Projection

(SOURCE: Country Report: MALAYSIA, Nov. 2011, NEDO, ARI, IEEJ, SERT)

Figure 5.34 The shift of power supply composition (left) and future plan (right)

As obvious from the above figure, the base load power supply only will occupy more than half of power supply capacity in 2030. Considering that the rate of maximum load to minimum load during a day is around 65 to 70 % in average (Figure 5.35), the country's off-peak load would be supplied by the base load power source by 70% of the total.



(SOURCE: "Master plan study on pumped storage power project and optimization for peaking power generation in Vietnam: final report.")

Figure 5.35 Daily Load Curve of Malaysia

While the other technology would cover the remaining 30 % of the load, those technologies are also responsible for LFC, whose necessary reserve margin is around 5%. Since thermal power plants usually have the limit of minimum-output operation, the nation's system operator would need to largely rely on hydropower plants for load adjustment, specifically for downward adjustment.

Considering all those aspects, it is concluded that the requirement for AS-PSPP is likely to rise in future in Malaysia, too.

b. The spread of renewable energy power generation

According to the country's long-term power development plan, a large number of photovoltaic (PV) power plants, the intermittent power source is planned to be installed in the country (Figure 5.36). The country promotes PV power generation and biomass power generation (palm oil mill waste) intensively as renewable energy power generation. Since detailed potential for wind energy and geothermal are yet to be fully examined, those two power sources are not counted.

SOURCE: Country Report: MALAYSIA, Nov. 2011, NEDO, ARI, IEEJ, SERT

Figure 5.36 Power Development Plan of Malaysia
(Left: whole, right: renewable energy power generation)

According to their plan, approximately 11 % of total power supply capacity is projected to be supplied by renewable energy oriented power generation in 2030. Among those, the amount of 1,370 MW is planned to be installed for PV power generation then. Because the nation's grid system operator would need to procure backup power source of 1,370 MW to prepare for the case when this amount of power source instantly disappear/ fluctuate. In this sense, it is expected that the value of AS-PSPP would also rise in large scale then because the technology can flexibly adjust its output both upward and downward in economic manner and because the technology has larger storage size compared with its potential alternative technologies such as batteries and flywheels.

(2) Recommendation: Further study to be conducted

Finally, it is found from the preliminary study based on the secondary data that the outlook of the country's situation is promising for AS-PSPPs. As shown in the previous comprehensive evaluation result (Figure 5.33), the requirement for the quality of power supply has been high in Malaysia partly because the country actively invites direct foreign investment like the development of semi-conductor factories of overseas manufactures.

In conclusion, the JICA Study Team recommends Malaysia as the other country where the impact of installing adjustable speed type pumped storage power plants is estimated to be large, and therefore, proposes further study consisting mainly of the following topics:

[Topics to be studies further]

- Identification of optimal installed capacity, location, and timing of AS-PSPP which would maximize their benefit.

- Detailed calculation of economic impact.
- Formulation of power development plan integrating additional PSPP.
- Holding of a workshop inviting stakeholders for further understanding of the technology and related benefit.
- Discussion over the cooperation/ coordination on the project with the other donors who have assisted the country's power development projects.