3. System Operation

(Voltage Control and System Protection)

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KANSAI ELECTRIC POWER CO., Inc.

3. System Operation
(Voltage Control and System Protection)

Technical Transfer Seminar

Study on Optimal Electric Power Development in Java-Madura-Bali in the Republic of Indonesia

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NEWJEC Inc.
The Kansai Electric Power Co., Inc.

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3-1. Fault Extension Protection Relay System

- ♦ Type and Role of Protection Relay System
- ♦ Type and Role of Failure Extension Protection Relay System
- ♦ Step-Out Separation Relay System
- ♦ Power Shedding Relay System
- ♦ Frequency Control Relay System
- ♦ Power System Stabilizing System
- ♦ Overload Protection Relay System

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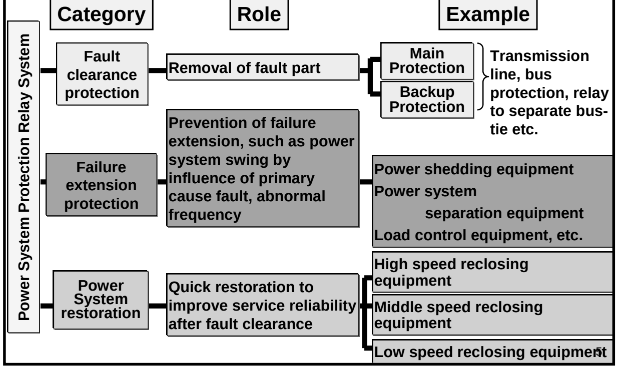
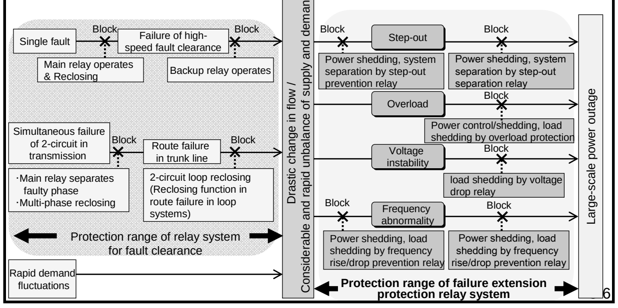
♦ Type and Role of Protection Relay System



3. System Operation
(Voltage Control and System Protection)

♦ Type and Role of Failure Extension Protection Relay System (1)

Operation failure of main protection relays or CB may cause various abnormal system conditions, and if such a situation is not properly handled, it may result in large-scale power outages.
Therefore failure extension protection relay system is installed.



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♦ Type and Role of Failure Extension Protection Relay System (2)

- Maintenance of Stability -

Failure extension protection Relay: **Maintenance of stability** / Maintenance of frequency / Over load resolution

	Fault continuation separation	Power shedding	Step out separation	Frequency separation	Special protection system (BSS)	Emergency load shedding	Bus separation	Pumped storage load interruption
Stability collapse prevention and step out separation due to a delay of fault interruption	○		○				○	
Step out prevention and step out separation of local systems due to fault interruption		○	○					
Step out prevention among power systems due to assumed large power drop faults					○			
Prevention of chain reactions to other companies due to step out			○					
Prevention of collapse of all systems due to faults out of assumption			○					

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♦ Type and Role of Failure Extension Protection Relay System (3)

- Maintenance of Frequency, Overload Resolution -

Failure extension protection Relay: Maintenance of stability / **Maintenance of frequency** / **Over load resolution**

	Fault continuation separation	Power shedding	Step out separation	Frequency separation	Special protection system (BSS)	Emergency load shedding	Bus separation	Pumped storage load interruption
Prevention of frequency drops due to assumed large power drop faults					○			○
Power drop faults out of assumption, fault of 1 outer loop in case of radial operation, maintenance of frequency in case of isolated faults of main power systems						○		○
Prevention of chain reactions to abnormal frequency in case of faults to other companies				○				
Over load resolution of sound equipment due to fault interruption		○						

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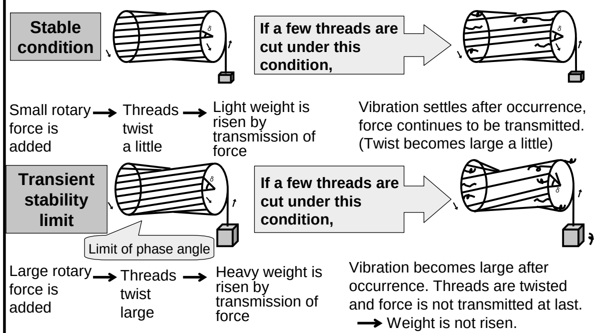
♦ Step-Out Separation Relay System (1)



Once twisted, threads cannot recover → Step out among power systems

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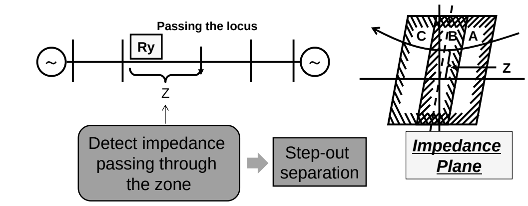
♦ Step-Out Separation Relay System (2)

-Distance Relay Method

Based on the characteristics of impedance trajectory during step-out, a few zones are created through combination with distance relay. This method detects the sequential passing of the impedance trajectory through these zones. Detection is possible using only the local voltage and the current information.



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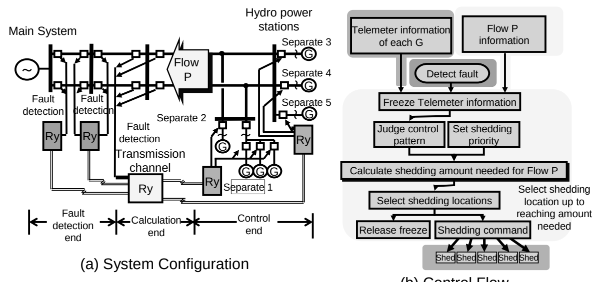
♦ Power Shedding Relay System

In case of severe faults in power systems, some of generators are controlled quickly in the early stage, anticipating collapse of stability, or such measures as system separation will be taken so as to prevent step-out.



Example of Power Shedding Relay

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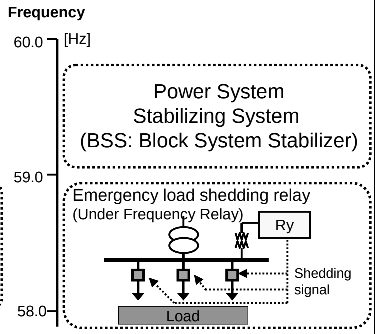
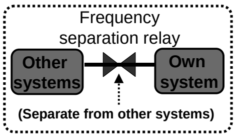
3. System Operation
(Voltage Control and System Protection)

♦ Frequency Control Relay System

- When supply (generation) becomes insufficient for demand (load), frequency drops.
- When supply (generation) exceeds demand (load), frequency rises.

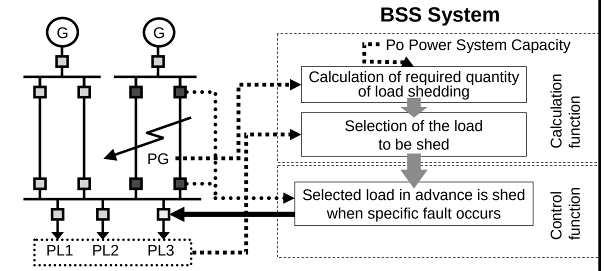




♦ Power System Stabilizing System (1)

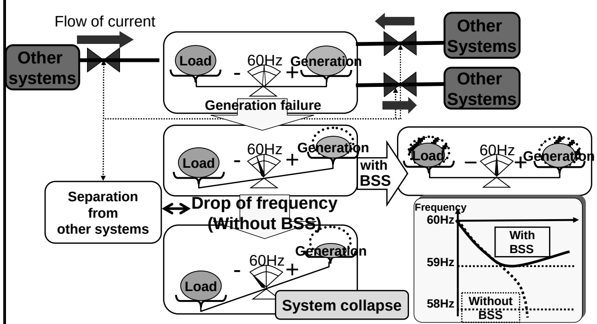
(BSS: Block System Stabilizer)

Purpose of installation : Maintenance of frequency and stability of power systems



Control finish time: 0.5sec.

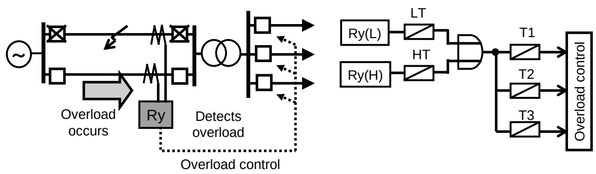
♦ Power System Stabilizing System (2)



Power system is stabilized through load shedding by BSS

♦ Overload Protection Relay System

This relay system detects overload current in case overload occurs in transmission lines or transformers and conducts overload control such as generator shedding or load shedding. Such an operation is carried out properly in coordination with the overload capacity of protected facilities.



3. System Operation

3-2. Reactive Power Equipment

- ♦ Type of Reactive Power Equipment
- ♦ Conventional Reactive Power Equipment
- ♦ Static Var Compensator : SVC
- ♦ Static Var Generator : SVG
- ♦ Planning of Reactive Power Equipment

3. System Operation
(Voltage Control and System Protection)

♦Type of Reactive Power Equipment

(1) **Conventional Reactive Power Equipment**

- Static Condenser (Shunt Capacitor, SC)
  Installed typically in 77 kV or higher main substations to mitigate voltage drop when load is heavy. Sometimes installed at terminal substations with long transmission lines.

- Shunt Reactor (ShR)
  Installed in typically 77 kV or higher substations to suppress voltage rise when load is light.

(2) **Static Var Compensator (SVC)**
Installed to suppress voltage fluctuation at substations where there is considerable load fluctuation.

(3) **Static Var Generator (SVG)**
Installed to suppress voltage fluctuation at substations where there is considerable load fluctuation. SVG has more advanced performance than SVC in reactive power correction.

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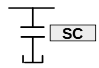
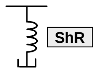
♦Conventional Reactive Power Equipment

Shunt Capacitor (SC)



Shunt Reactor (ShR)



Characteristics:
- Poor response and continuity of control
- Voltage fluctuates with switching operation
- Constant impedance characteristics of SC accelerates voltage fluctuation, because reactive power is directly proportional to voltage squared.

$Q_c = V^2/X_c$
(Voltage drop leads to reactive power drop resulting in further voltage drop)

- If load is disconnected in an accident during SC operation, excess reactive power raises system voltage.
- ShR suppresses voltage rise.

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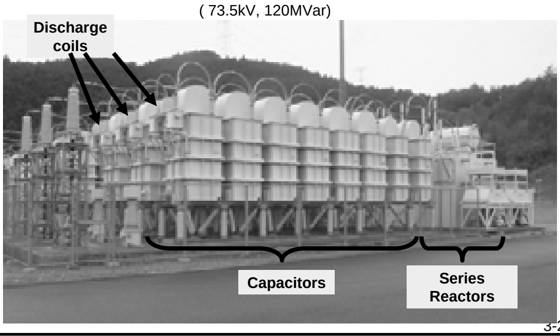
♦Appearance of SC

Shunt Capacitor Insulated Structure Type
(Reactor is directly installed on concrete foundation)
(73.5kV, 120MVar)



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♦Appearance of SHR

Shunt Reactor

Bushing Type
(77kV, 40MVar)

Elephant Type
(77kV, 40MVar)

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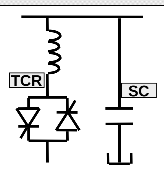
♦Static Var Compensator : SVC

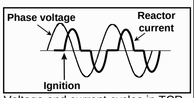
TCR (Thyristor Controlled Reactor)
TCT (Thyristor Controlled Transformer)
TSC (Thyristor Switched Capacitor)



TCR circuit configuration

Principle:
Reactor is connected to thyristor valve for lagging power control. Leading power is controlled by combination with SC.

Characteristics:
Reactive power can be continuously controlled by reactive current at every 1/2 cycle.
In extra high-voltage systems, TCTs are often used, in which transformers with high impedance are connected to thyristors for secondary current control.



Voltage and current cycles in TCR

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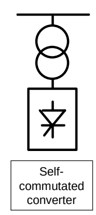
♦Static Var Generator : SVG

SVG



Principle:
Reactive power is regulated by controlling voltage of self-commutated converter.

Characteristics:
High-speed control of reactive power from leading to lagging phase is possible.

If combined with functions such as low-order harmonics absorption and unbalanced current (negative-phase-sequence current) compensation, quality of power supply of the entire power system can be improved.

Rotary condensers are also used as synchronous compensators with the same functions as SVG.

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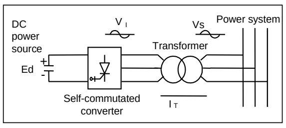
3. System Operation
(Voltage Control and System Protection)

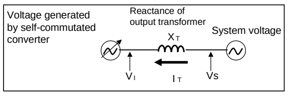
♦Operation Principle of SVG

System voltage (Vs) is stabilized by synchronization of voltage (Vi) generated by self-commutated converter

Basic circuit



Equivalent circuit



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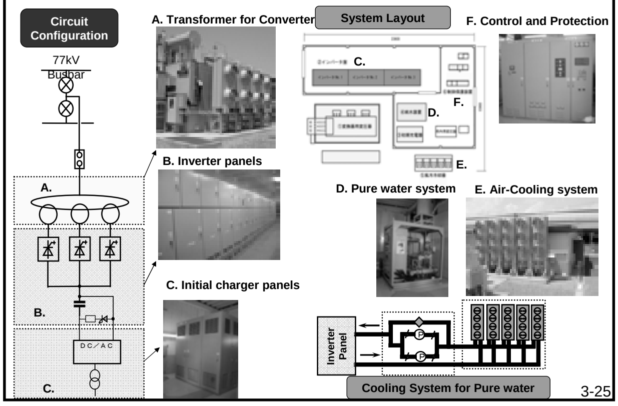
♦Appearance of SVG



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♦Planning of Reactive Power Equipment

1. Recognition of study phase
   - ・Static Capacitor (SC) : Analysis of feature of max. demand load curve
   - ・Shunt Reactor (ShR) : Analysis of feature of min. demand load curve
2. Forecast of future demand
   - ・Check actual data of active power and reactive power
   - ・Forecast of future demand
3. Basic concept of planning of reactive power equipment
   - ・Balance of system block
4. Decision of required capacity of reactive power equipment
   - ・Consideration of generators' power factor in each block
5. Decision of single capacity of reactive power equipment
   - ・Consideration of voltage deviation

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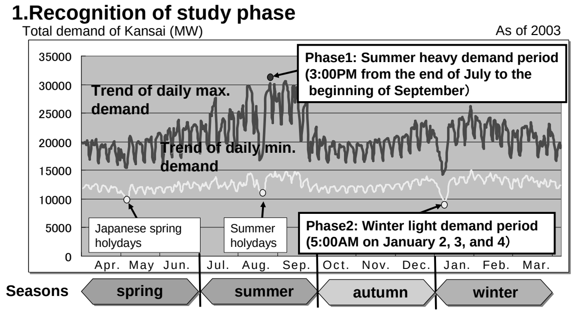
♦Planning of Reactive Power Equipment (1)

1.Recognition of study phase



Phase1: Study for need of Static Capacitor, system voltage tends to be low during summer heavy load period.

Phase2: Study for need of Shunt Reactor, system voltage tends to be high during winter light load period.

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♦Planning of Reactive Power Equipment (2)

2.Forecast of future demand

- Study on actual data of active power (P) and reactive power (Q)

Load data: Active and reactive power measured at secondary side (77kV) of transformers at each primary substation (154kV, 275kV and 500kV)

- Demand forecast in summer heavy load period

P: future P demand is forecasted with some economical index correlated with power demand (GDP, population, number of households, number of offices, and shipment value of commercial products)

Q: future Q is derived from correlation between past P and Q

- Demand forecast in winter light load period

P: P is derived from historical record by linear regression analysis

Q: Q is derived from correlation between past P and Q

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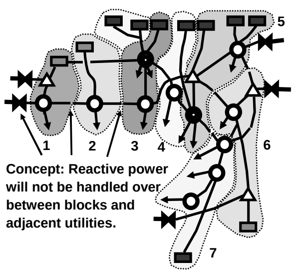
♦Planning of Reactive Power Equipment (3)

3. Basic concept of planning of reactive power equipment

Reactive power must be balanced not only in whole system but in major block.

For example, there are seven blocks in main 500kV substations in KANSAI.



<Concept of Block Balance>

Balancing reactive power in each block prevents both voltage differences among substations by large reactive power flow on trunk line and severe voltage rising or drop in case trunk lines are cut off.

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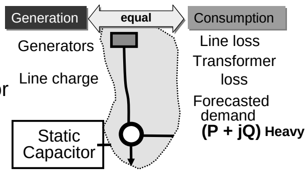
3. System Operation
(Voltage Control and System Protection)

♦Planning of Reactive Power Equipment (4)

4. Decision of required capacity of reactive power equipment

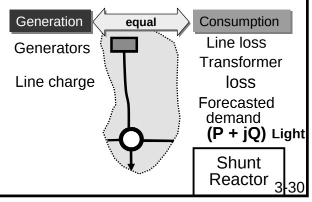
・Summer heavy load period

Installation of Static Capacitor is studied.



・Winter light load period

Installation of Shunt Reactor is studied.



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♦Planning of Reactive Power Equipment (5)

5. Decision of single capacity of reactive power equipment

<Regulated voltage deviation (normal condition)>

Nominal Voltage	Application	Allowance	Note
100V	Light, refrigerator, cleaner, etc.	101 ±6 V	Electric utility law enforcement regulations
200V	Large size air conditioner, IH cooking heater, etc.	202 ±20 V	

<Allowance of voltage deviation (switching on and off of equipment)>

Nominal Voltage	Application	Allowance	Note
6.6kV	Distribution line, customer	Within 10%	Grid-interconnection Code
22 - 77kV	Transmission line, distribution line, customer	Within 2%	

The single capacity of reactive power equipment is limited by acceptable voltage shock due to connection and disconnection of the equipment.

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3. System Operation

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3-3. Voltage Operation

- ♦ **Voltage Standard in Japan**
- ♦ **Typical Operation of System Voltage**
- ♦ **Basic Characteristics Regarding Voltage Stability**
- ♦ **P-V（Nose) Curve**
- ♦ **Case Study of Black Out Caused by Voltage Instability**

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♦ Voltage Standard in Japan

Regulation in Japan

Voltage class at customers	Reference voltage	Voltage variation range
100V	101V	101±6V
200V	202V	202 ±20V

Higher voltage systems are operated properly to maintain voltage within the regulated variation range.

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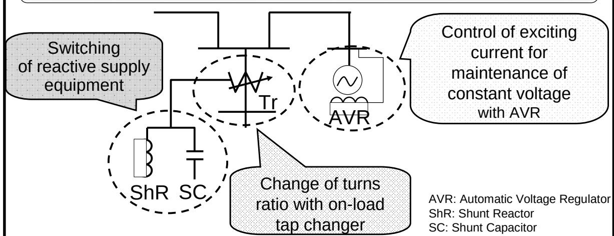
♦ Typical Operation of System Voltage



UP High

-Turn on SC or Turn off ShR
- Increase on-load tap
- Increase exciting current of generators

Voltage

-Turn on ShR or Turn off SC
- Reduce on-load tap
- Reduce exciting current of generators

DOWN Low

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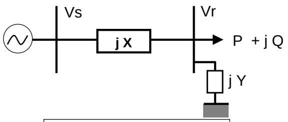
♦ Basic Characteristic Regarding Voltage Stability



Active power and reactive power (P and Q) supplied to the load, can be expressed as follows:

$$\begin{cases} P = (Vs \cdot Vr) / X \cdot \sin\theta \\ Q = (Vs \cdot Vr) / X \cdot \cos\theta - (1 / X - Y)\, Vr^2 \end{cases}$$

This formula is used in discussion of steady-state and transient stabilities

Solve these 2 equations for Vr (to consider voltage stability)

Delete θ since $\sin^2\theta + \cos^2\theta = 1$

$$P^2 + (Q + (1 / X - Y) \cdot Vr^2)^2 = (Vs \cdot Vr / X)^2$$

For simplification, let $\alpha = Q / P$

$$Vr = \sqrt{\frac{(Vs^2 / X^2 - 2P(1 / X - Y)\alpha \pm \sqrt{(Vs^4 / X^4 - 4P(1 / X - Y)\alpha \cdot Vs^2 / X^2 - 4P^2(1 / X - Y)^2)}}{2(1 / X - Y)^2}}$$

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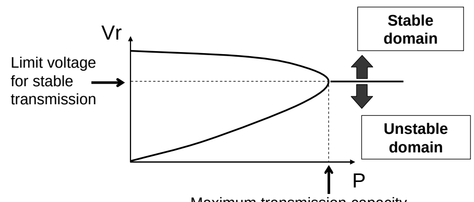
♦ P-V (Nose) Curve (1)

$$Vr = \sqrt{\frac{(Vs^2 / X^2 - 2P(1 / X - Y)\alpha \pm \sqrt{(Vs^4 / X^4 - 4P(1 / X - Y)\alpha \cdot Vs^2 / X^2 - 4P^2(1 / X - Y)^2)}}{2(1 / X - Y)^2}}$$

The above equation expresses change of receiving voltage (Vr) in response to change in demand (P, Q). When power factor is constant, Vr is plotted against P as follows:



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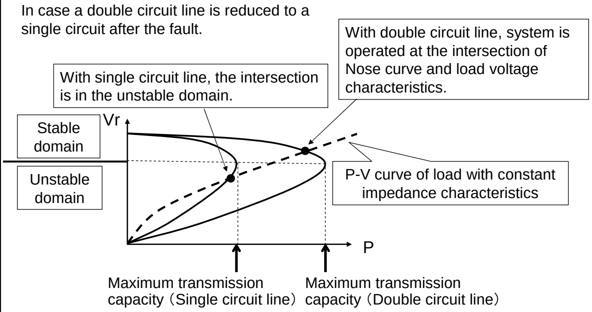
♦ P-V (Nose) Curve (2)

In case a double circuit line is reduced to a single circuit after the fault.



When one of the two circuits trips in high voltage transmission lines with heavy power flow, voltage may reach the unstable domain and eventually collapse.

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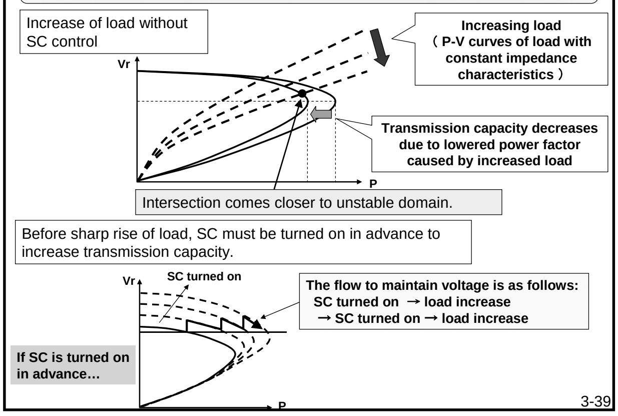
♦ P-V (Nose) Curve (3)



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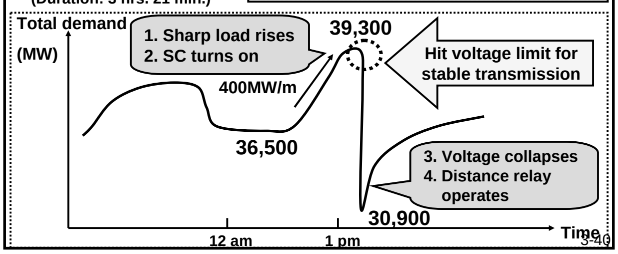
♦ Case Study of Black Out Caused by Voltage Instability (1)

Time & Date:
1:19 pm on July 23, 1987
Location:
Tokyo
Details:
Interrupted power: 8,179 MW
Recovered at 4:40 pm
(Duration: 3 hrs. 21 min.)

1. **Load increased at industrial demand peak at around 1pm combined with rising of temperature**
2. **SC turned on to sustain voltage**
3. **Impossible to follow the demand; voltage dropped**
4. **Large-scale outage by operating of distance relay**



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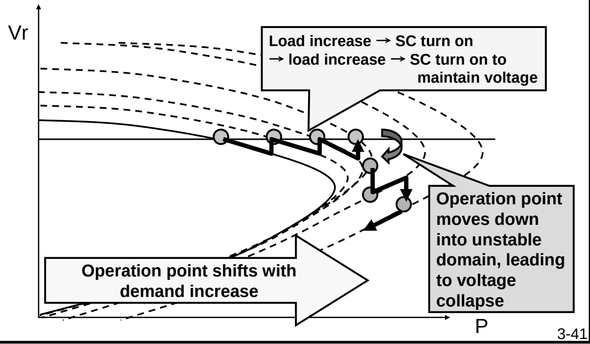
♦ Case Study of Black Out Caused by Voltage Instability (2)

How voltage was collapsed due to delayed switching of SC



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3-4. HVDC Technology

- **Outline of HVDC**
  - Advantage of HVDC
  - Outline of HVDC System Diagram
  - Outline of Converter Station
- **Kii Channel HVDC**
- **Developed HDVC Control Method**
  - DC Continuous Operation Control
  - Power Modulation

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3. System Operation

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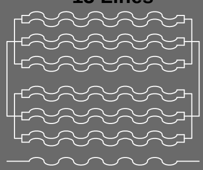
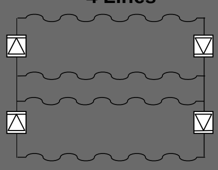
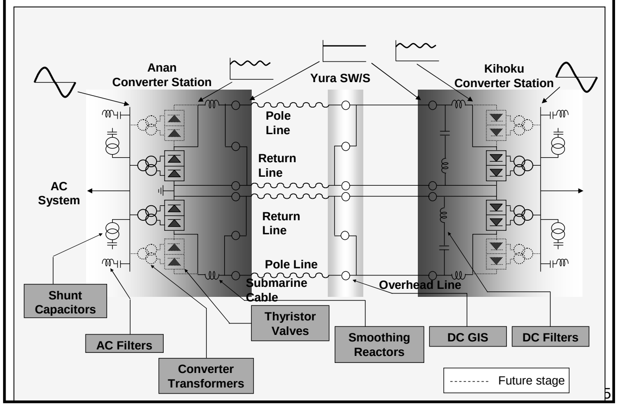
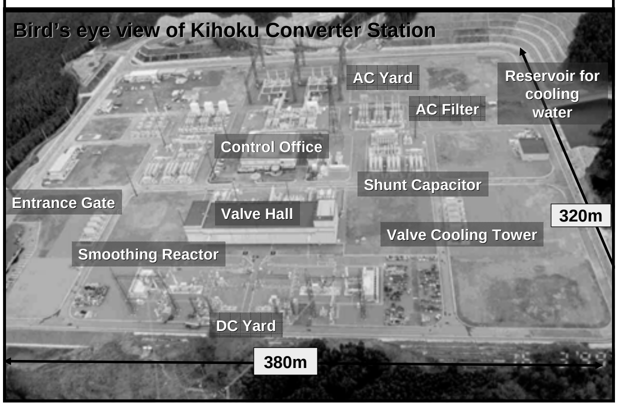
♦ Advantage of HVDC

	AC	DC
Outline	13 Lines 	4 Lines 
Operation	Poor	Good (controllable)
Environment	Poor	Good (less cables)
Cost	Poor	Good (advantage)
Evaluation	Poor	Good

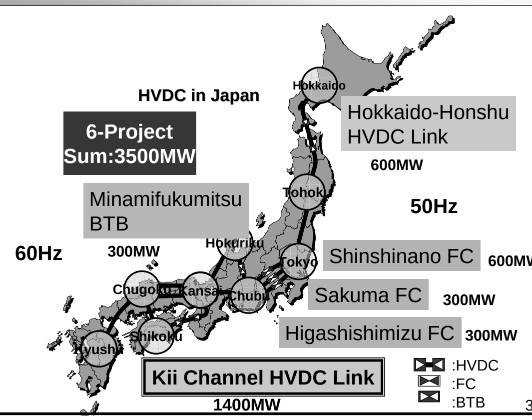
♦ Outline of HVDC System Diagram



♦ Outline of Converter Station



♦ HVDC in Japan



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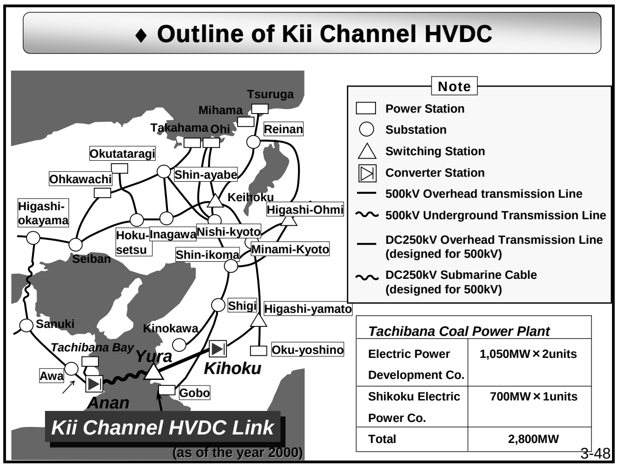
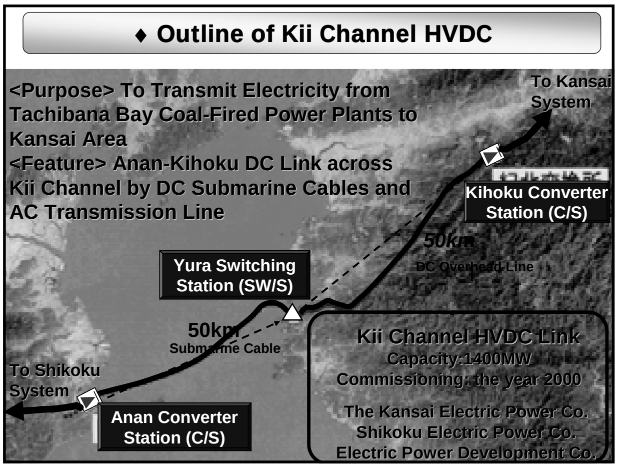
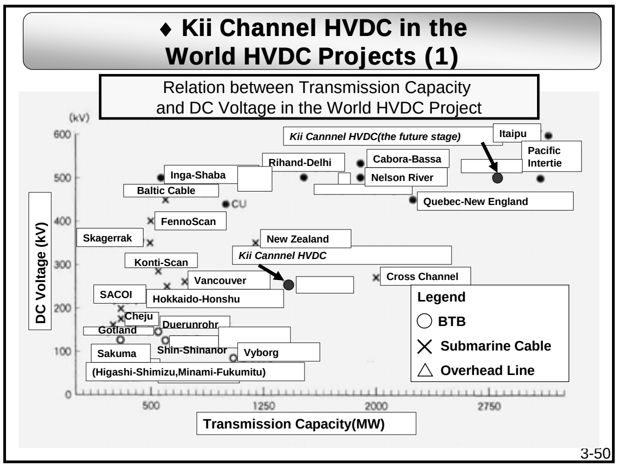
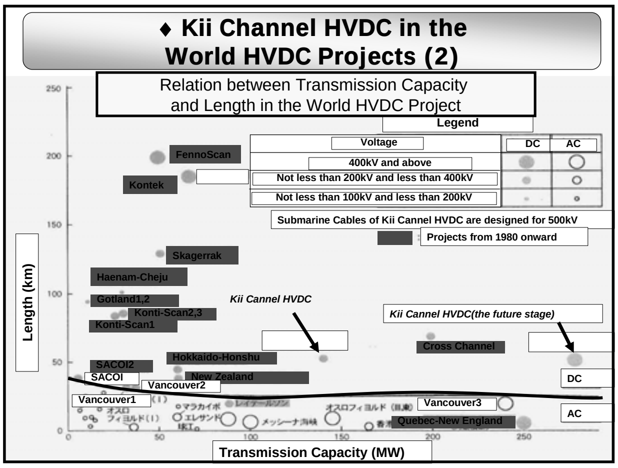
3. System Operation
(Voltage Control and System Protection)







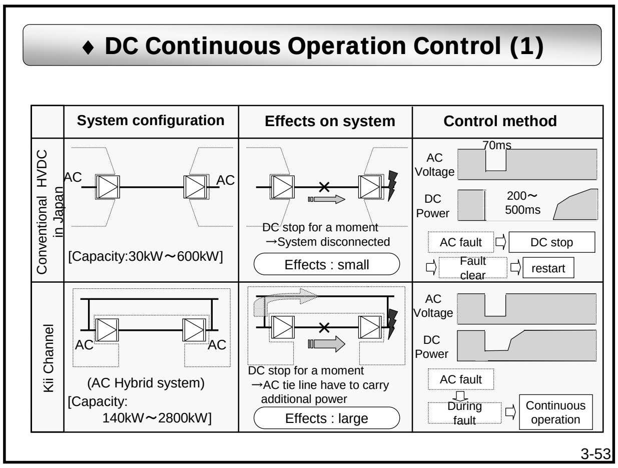


♦ Developed HDVC Control Method

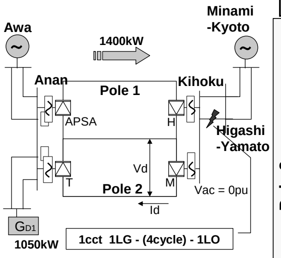
Recent Technology on HVDC which is developed and successfully used in Japan

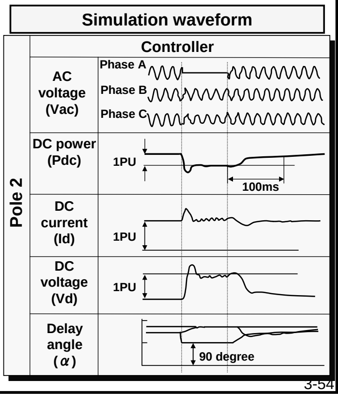
- **DC Continuous Operation Control**
- **Power Modulation**

3-52



♦ DC Continuous Operation Control (2)



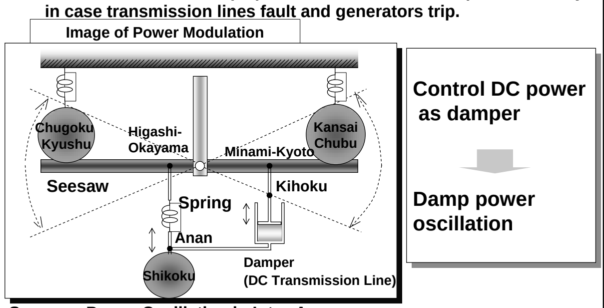


DC system power was recovered to 90% of the rated value in about 100ms after the fault clearing.

3-54

♦ Power Modulation (1)

Power Modulation damps power oscillation and keeps the stability in case transmission lines fault and generators trip.

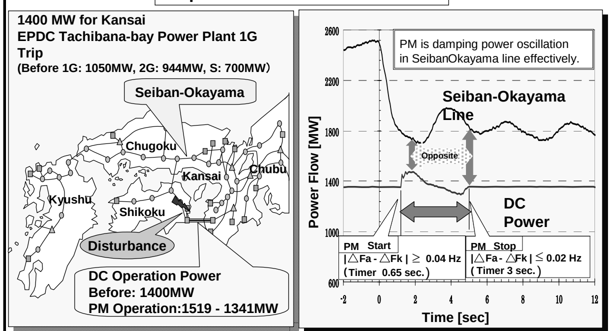


Seesaw : Power Oscillation in Inter-Area between Kansai and Chugoku (3sec. Cycle)
Spring : Power Oscillation in Shikoku Local Area (2sec. Cycle)

3-55

♦ Power Modulation (2)

Operation of Power Modulation



3-56

3. System Operation

3-57

3-5. Hydropower Operations with the Developed Support System

- ♦ Hydropower Generation and Operation in Japan
- ♦ Optimal Hydropower Operation with the Developed Support System
- ♦ Summary

3-58

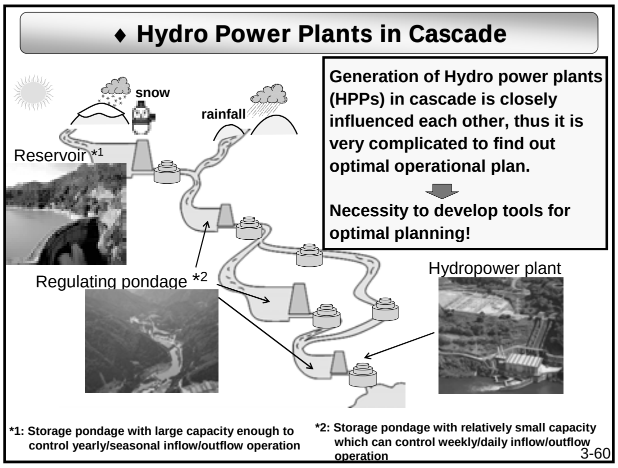
♦ What is Developed Support System for Optimal Hydropower Operation?

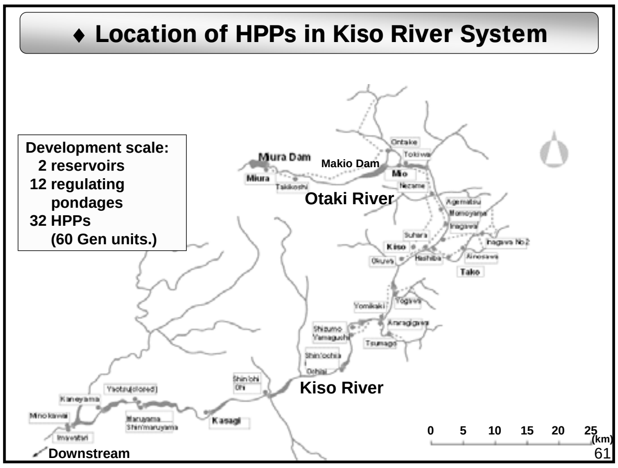
Purpose: To Optimize 1) Annual operation of big reservoir

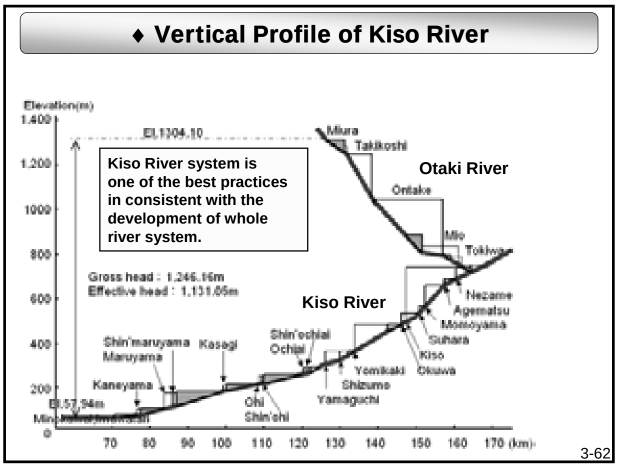
2) Daily and/or weekly operation of power plants with regulating pondage

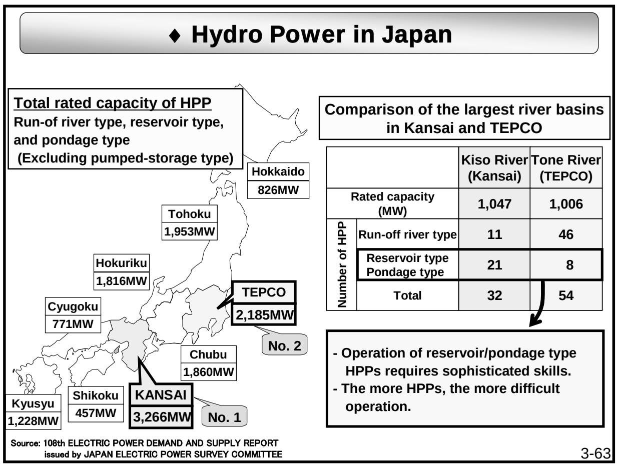
under constraints of hydro power plants complex developed in cascade.

3-59

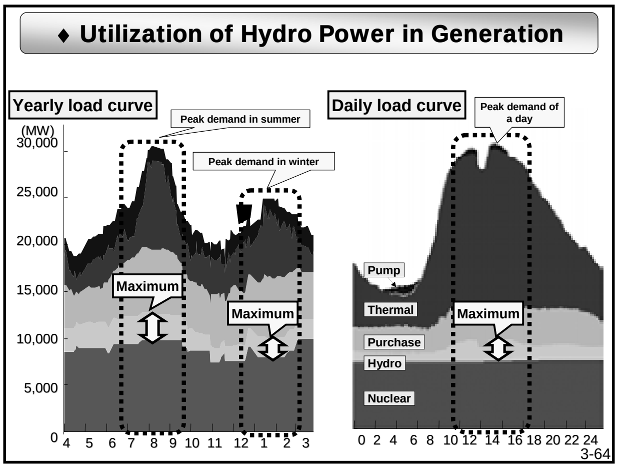


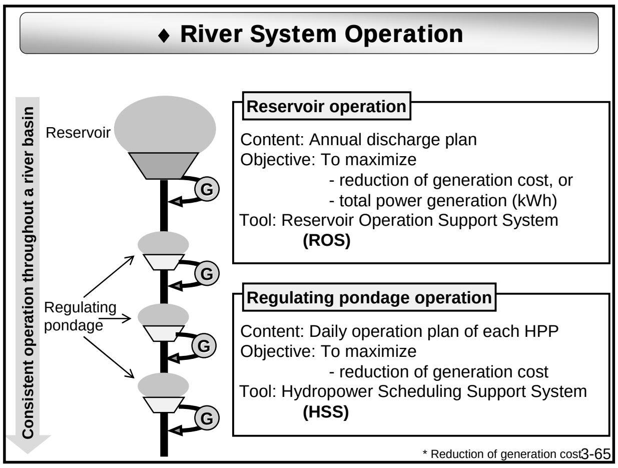




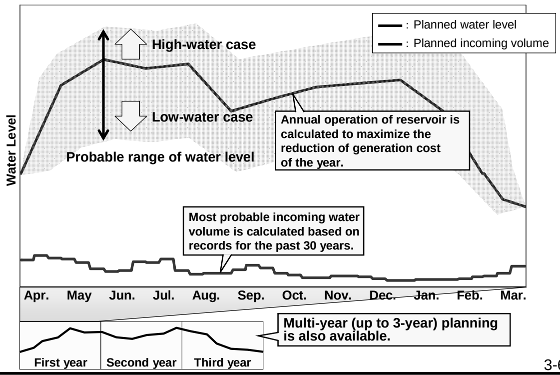


		Kiso River (Kansai)	Tone River (TEPCO)
Rated capacity (MW)		1,047	1,006
Number of HPP	Run-off river type	11	46
	Reservoir type Pondage type	21	8
	Total	32	54



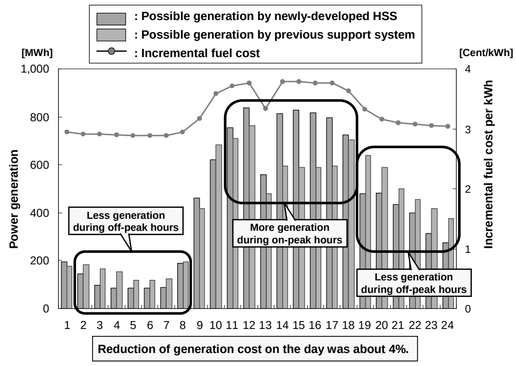


♦ Optimal Reservoir Discharge Plan with ROS



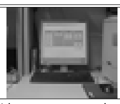
3-66

♦ Optimal Hydropower Operation with HSS



3-67

♦ Evaluation of Effects of ROS and HSS

	Previous work/system	Newly-developed system	Effect of installation in KANSAI
ROS Reservoir Operation Support System			- Reduction of generation cost by 1.9% on average, which corresponds to **2.3 million USD** per year - Substantial reduction of working hours required
Algorithm	Hand calculation based on experience	Dynamic programming	
Working hours	More than 1 week	1 day	
HSS Hydropower Scheduling Support System			- Reduction of generation cost by 1.6% on average, which corresponds to **2.8 million USD** per year
Algorithm	Nonlinear programming (Reduced gradient method)	Linear programming (Network flow method)	
Working hours	2 hours	1.5 hours	

Note: Actual effect depends on each river condition.

3-68

♦ Summary

- ♦Tools (ROS and HSS) for optimal planning of HPPs were developed to fully utilize hydro potential in a consistently developed river basin.
- ♦ Efficient and reliable hydropower operation is available with the use of developed ROS and HSS, which leads to maximization of reduction of generation cost or total power generation.

3-69

3. System Operation

3-1. Fault Extension Protection Relay System
3-2. Reactive Supply Equipment
3-3. Voltage Operation
3-4. HVDC Technology
3-5. Hydropower Operation with the Developed Support System
3-6. Pumped-Storage Power Station
3-7. Power System Analysis
3-8. Introduction of Past Large Scale Power Outages in KANSAI

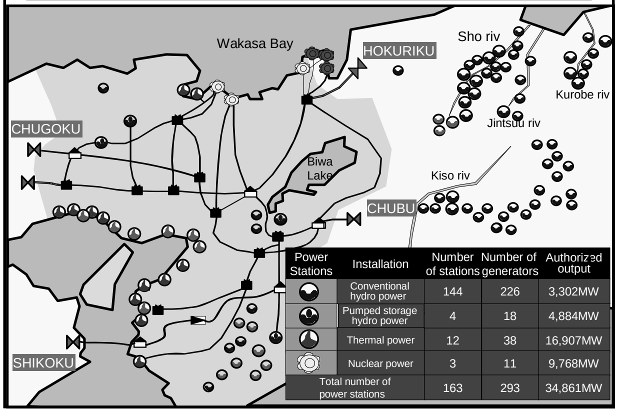
3-70

3-6. Pumped-Storage Power Station

- ♦ Introduction
- ♦ General Pumped-Storage Power Station
- ♦ Adjustable Speed Pumped-Storage Generation System

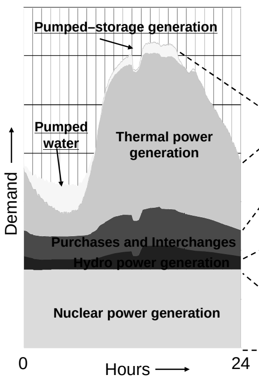
3-71

♦ Locations of Power Stations in KANSAI



Power Stations	Installation	Number of stations	Number of generators	Authorized output
	Conventional hydro power	144	226	3,302MW
	Pumped storage hydro power	4	18	4,884MW
	Thermal power	12	38	16,907MW
	Nuclear power	3	11	9,768MW
Total number of power stations		163	293	34,861MW

♦ Features of Generators



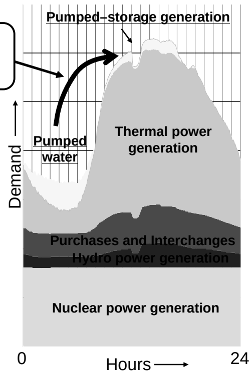
generators	Features		
	Fuel Cost	Load following	Note
Pumped – storage	30% loss	Very Good	Use low-priced power at nighttime
Thermal	Large	Good	Limited by times or hour of start and stop
Purchases and Interchanges	Small	poor	Constituted by nuclear, thermal, and hydro
Hydro	0	Good	Influenced by a natural phenomenon
Nuclear	Small	Very poor	Constant power generation

3-73

♦ Outline of General Pumped-Storage Power Station

[Unit cost of pumped hydro power] = [Unit cost of Pumping] / 0.7

It is more advantageous to generate power with pumped water using inexpensive power sources at midnight, rather than operating expensive oil thermal power plants at peak time.



3-74

♦ Roles of Pumped-Storage Power Station (1)

Measure for Demand and supply control

- Measure for supply capability → Used as peak supply source to cope with peak demand. (Power generation)
- Measure for frequency fluctuation and load following → Used as a supplementary measure to regulate frequency and cope with load following. (Power generation and pumping)
- Measure for faults → Used as emergency supply source in case of tripping of generators. (Power generation)
- Measure for Surplus power → Used to absorb surplus power during light load condition at midnight due to increase of power sources with fixed output. (Pumping)

3-75

♦ Roles of Pumped-Storage Power Station (2)

- Economic measure → Cost reduction by the operation of pumped storage power plants instead of short-time operation of expensive peak thermal power units (Power generation and pumping)

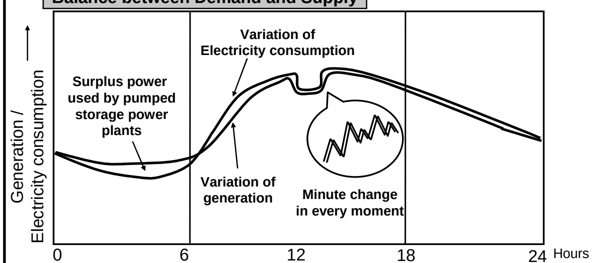
Others

- System reliability → Used to reduce the amount of load shedding in case of power source tripping. (Power generation and pumping)
- Power flow control → Used to control power flow at the time of switching in power system. (Power generation and pumping)
- Voltage control → Used to absorb reactive power through pumping operation in case of system voltage increase at midnight. (Pumping)

3-76

♦ Roles of Adjustable Speed Pumped-Storage Generating System (1)

Balance between Demand and Supply

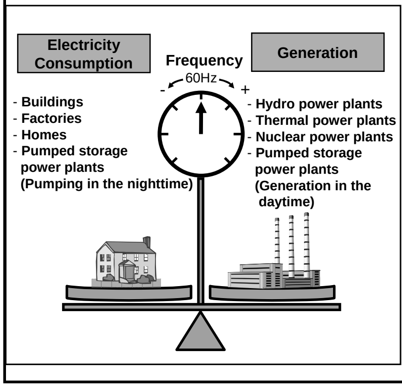


It is important to maintain the balance between generators and electricity consumption at all times.

Adjustable speed pumped-storage generation system can control pumping power (cf. conventional system cannot) and can control generation widely by changing the rotation speed of the motor/generator.

3-77

♦ Roles of Adjustable Speed Pumped-Storage Generating System (2)



Daytime frequency control

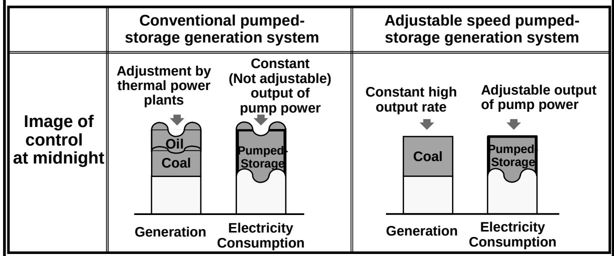
Adjustable speed pumped-storage generating system makes it possible to increase or decrease generation as electricity consumption increases or decreases.

Nighttime frequency control

Adjustable speed pumped-storage generating system makes it possible to decrease or increase the pumping power as electricity consumption increases or decreases. Conventional pumped-storage plants cannot change the pumping power.

3-78

♦ Effects of Adjustable Speed Pumped-Storage Generating System

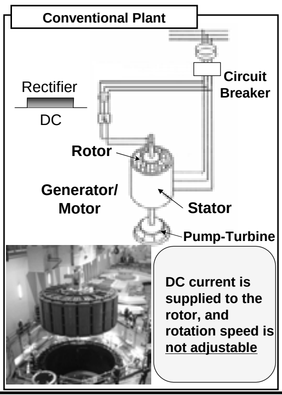


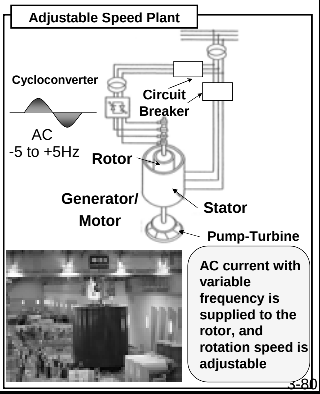
Effects

- Decrease of the amount of pumping (pumping losses)
- Increase of output rate of thermal power plants

3-79

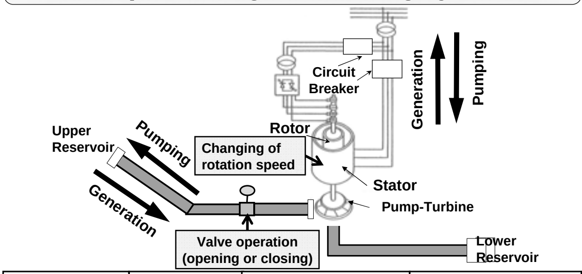
♦ Mechanism of Adjustable Speed Pumped-Storage Generating System





3-80

♦ Operating Method of Adjustable Speed Pumped-Storage Generating System



	Operating method	Generating mode	Pumping mode
Conventional plants	Valve operation	Limited Control range	- More power losses - Power is uncontrollable
Adjustable speed plants	Valve operation & Changing of rotation speed	Wide Control range	- Less power losses - Power is controllable

3-81

3. System Operation

3-82

3-7. Power System Analysis

- ♦ Stability Classifications
- ♦ Concept of Steady-State Stability
- ♦ Concept of Transient Stability
- ♦ Power System Analysis Methods
- ♦ Measurement Method of Characteristics of Generator and Excitation System

3-83

3. System Operation
(Voltage Control and System Protection)

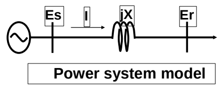
♦Stability Classifications

Time range classification	Time range after occurrence of disturbance	Causes of disturbance	Concept figure
Transient stability			
Transient period	From occurrence of system disturbance to the first wave (lasting about 1 second)	Back-up protection relay operates because of failure of main protection relay after fault occurrence (e.g. ground / short circuits)	θ / Phase angle / Time
Steady-state stability			
Inter-mediate period	Time period (after transient period) during which the system continues to be disturbed for a few (2 to about 15) cycles of disturbance. (lasting from 2 to about 15 seconds)	Intermediate-scale disturbance which includes the following cases: oscillation is not damped or is amplified during transient period; transmission line is opened or closed; power source or load is cut off from the system.	θ / Phase angle / Time
Steady-state period	Time period longer than intermediate period	Particular instability mode that potentially exists in each power system	θ / Phase angle / Time

3-84

♦Concept of Steady-State Stability (1)

- **Es is sending voltage**
- **Er is receiving voltage**
- **Z ≈ jX is line impedance**
- **I is current**
- **θ is phase angle**



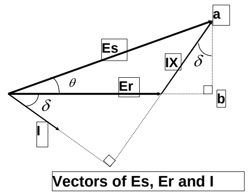
Power (P = Er x I x cosδ) is:

IX x cosδ = $\overline{a \times b}$, $\overline{a \times b}$ = Es x sin θ

IX x cosδ = $\overline{a \times b}$ = Es x sin θ

$$I \times \cos\delta = \frac{\overline{a \times b}}{X} = \frac{Es \times \sin\theta}{X}$$

$$P = Er \times I \times \cos x = \frac{Es \times Er}{X} \sin\theta$$



Internal phase angle of generator is neglected

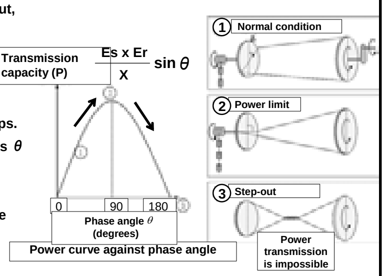
3-85

♦Concept of Steady-State Stability (2)

① → ②
- **The greater the generator output, the greater θ until θ reaches 90 degrees.**

② → ③
- **After θ is greater than 90 degrees, generator output drops.**
- **The generator is accelerated as θ gets bigger**

③
- **Magnetic coupling between the armature and rotor breaks and eventually causes step-out.**



"Steady-state stability" is the degree of stable operation of the generators in steady state. The maximum transmission capacity in this state is expressed as the "Steady-state power limit"

3-86

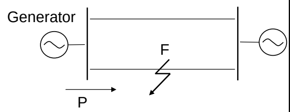
♦Concept of Transient Stability (1)

"Transient Stability" is the degree of power system stability in case of sudden and major disturbances which include the following cases:

a. System fault and subsequent protection relay operations;

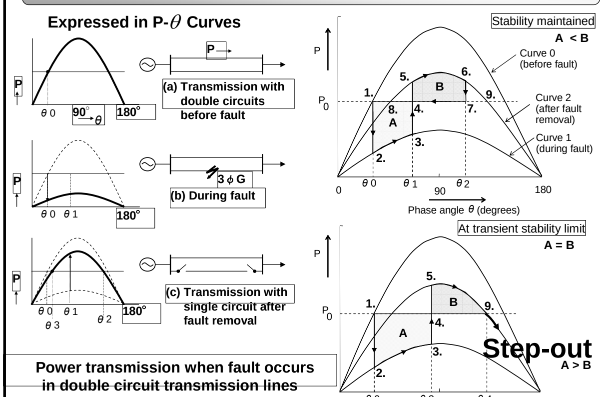
b. Large-scale generator tripping or load sheddig, sudden changes in impedance due to changes of system configuration with CB operation.

Transient stability can be explained with **Equal area method**, where fault occurs at point F in a parallel double circuit transmission line.



3-87

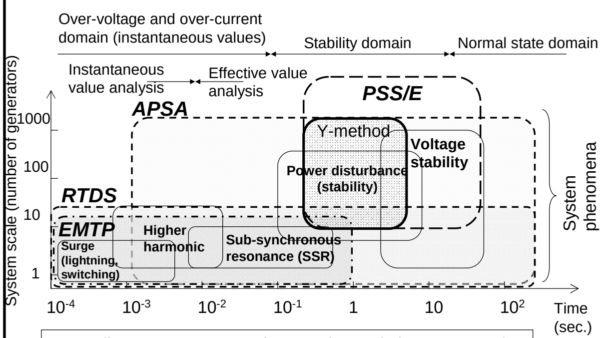
♦Concept of Transient Stability (2)



Power transmission when fault occurs in double circuit transmission lines

3-88

♦Power System Analysis Methods (1)



Depending on system control, protection and phenomena to be analyzed, appropriate time domain and system scale must be chosen to determine the right analysis method accordingly.

3-89

3. System Operation
(Voltage Control and System Protection)

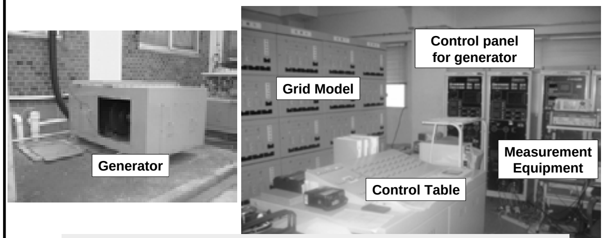
♦Power System Analysis Methods (2)

	Technical check points	Analysis methods
Normal state domain	**Performance during normal operation** -Power flow balance (active / reactive power) -Voltage fluctuations **Short circuit current**	-Power flow calculation program (L-Method developed by CRIEPI) -APSA -PSS/E
Stability domain	**Operation performance and stability during transient period** -Stability of synchronism in AC system -Stability of frequency -Fault recovery in DC system **Voltage stability** -Reactive power control	-Stability analysis program (Y- and S- Methods developed by CRIEPI) -APSA -PSS/E
Over-voltage or instantaneous value domain	**Overvoltage (insulation coordination)** -Lightning surge and switching surge **Abnormal phenomena** -Sub-synchronous resonance	-EMTP

3-90

♦ Measurement Method of Characteristics of Generator and Excitation System

In KANSAI, research activity with affiliate company in order to measure the characteristics of generator and excitation system was conducted.



Measurement was conducted using test model in research center.

3-91

♦ Measured Constant and Test Item

Constant for Generator	Test Item
xd, xd', xd'', Tdo', Tdo'', xq, (xq'), xq'', (Tqo'), Tqo''	- Static Characteristics Test - D-axis Load Shedding Test - Q-axis Load Shedding Test

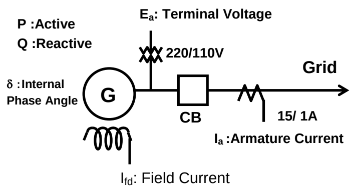
Constant for Control System	Test Item
Constant for Excitation System	- Indicial Response Test - Frequency Response Test
Constant for PSS	- Indicial Response Test - Frequency Response Test
Constant for Governor	- Indicial Response Test - Frequency Response Test

3-92

♦ Measurement Method of Constant for Generator

$$X_d = \frac{E_a \cos\delta + X_l I_{fd}}{I_{fd} - I_d}$$

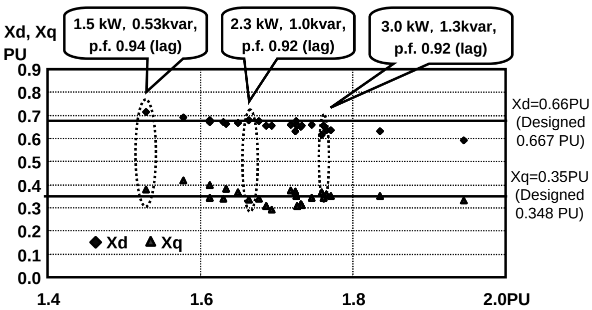
$$X_q = \frac{E_a^2 \tan\delta}{P - Q\tan\delta}$$



Characteristics are obtained by changing P and Q

3-93

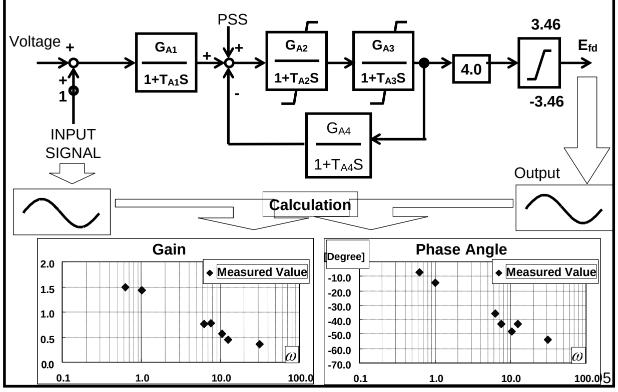
♦ Test Result on Constant for Generator



Measured value consists with designed value.

3-94

♦ Measurement Method of Constant of Excitation System



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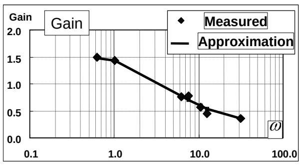
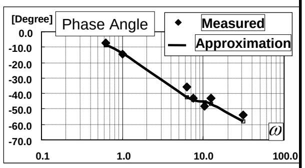
♦ Test Result on Constant of Excitation System





	G_{A1}	T_{A1}	G_{A2} G_{A3}	T_{A2}	T_{A3}	G_{A4}	T_{A4}
Approximation	1	0	1.5	0.1	0.001	0.1	0.1
Designed	1	0.2	1.5	0.1	0.02	0.2	0.05

Measured value consists with designed value.

3-96

♦ Summary

- For system analysis, characteristics of generator and excitation system in accordance with actual performance shall be used.
- In KANSAI, measurement method on characteristics of generator and excitation system was researched and developed.
- With the measurement method, characteristics of generator and excitation system where constants are unknown can be identified and used for system analysis.

3-97

3. System Operation

3-1. **Fault Extension Protection Relay System**
3-2. **Reactive Supply Equipment**
3-3. **Voltage Operation**
3-4. **HVDC Technology**
3-5. **Hydropower Operation with the Developed Support System**
3-6. **Pumped-Storage Power Station**
3-7. **Power System Analysis**
3-8. **Introduction of Past Large Scale Power Outages in KANSAI**

3-98

3-8. Introduction of Past Large Scale Power Outages in KANSAI

- ♦ **Past Large Scale Power Outages in KANSAI**
- ♦ **Miboro Power Plant Accident Case**
- ♦ **Great Hanshin-Awaji Earthquake Case**
- ♦ **Large Power Plant Trunk Lines Accident Case**

3-99

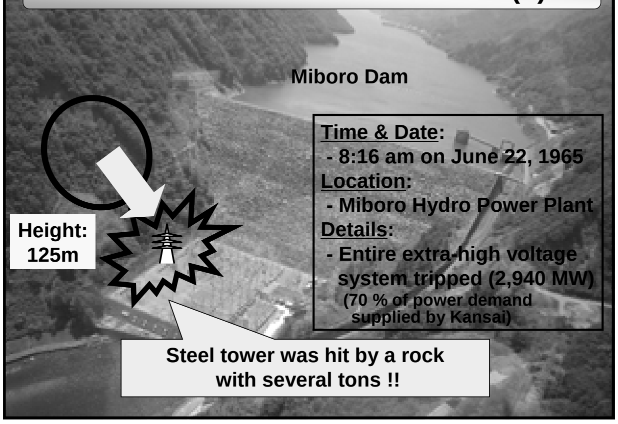
♦ Past Large Scale Power Outages in KANSAI

	Miboro Power Plant Accident (June 22, 1965)	**Great Hanshin-Awaji Earthquake (January 17, 1995)**	**Large Power Plant Trunk Lines Accident (December 22, 2005)**
Interrupted Demand (MW) (A)	2,940	2,840	1,890
Duration (B)	3hrs. 4min.	153hrs. 17min.	39min.
System* Capacity (MW) (C)	4,100	12,700	25,300
$\frac{(A)}{(C)} \times 100$	72%	22%	7.5%

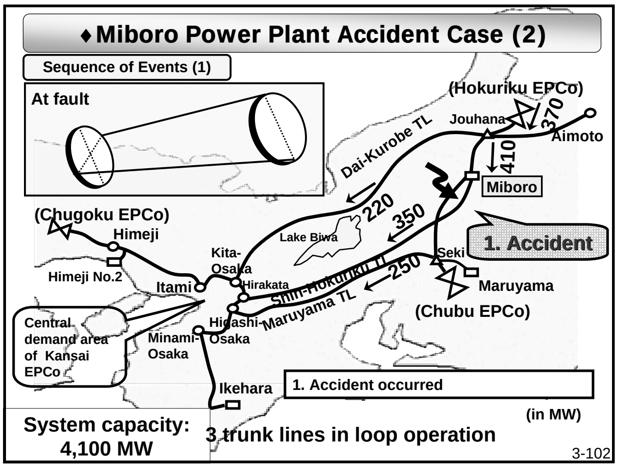
* at the time of outage

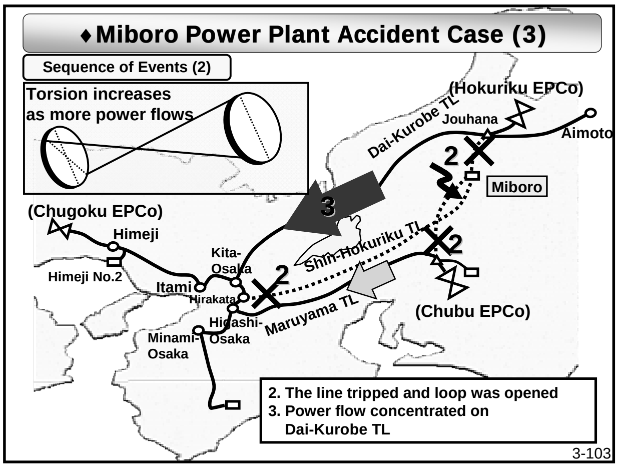
3-100

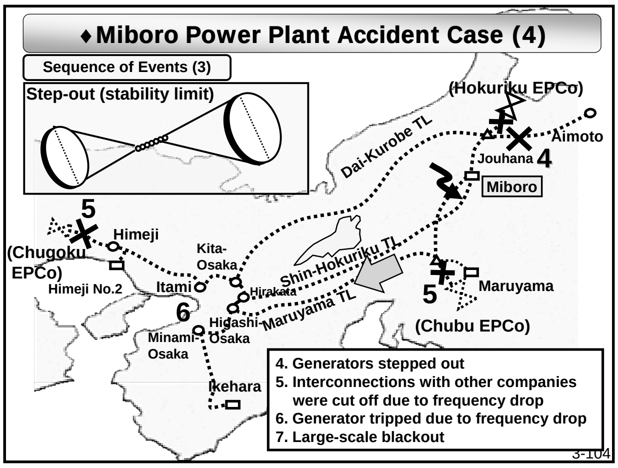
♦ Miboro Power Plant Accident Case (1)

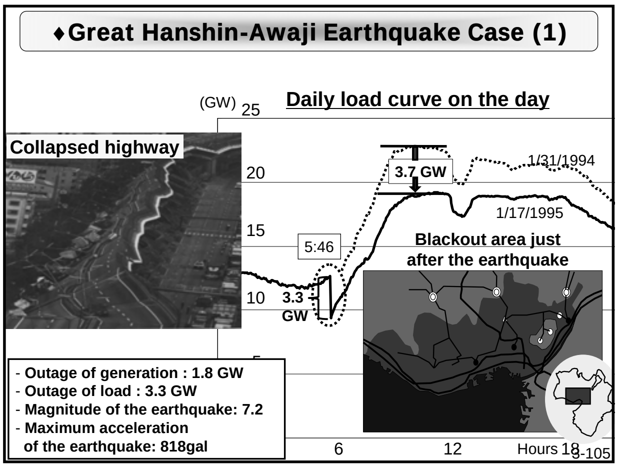


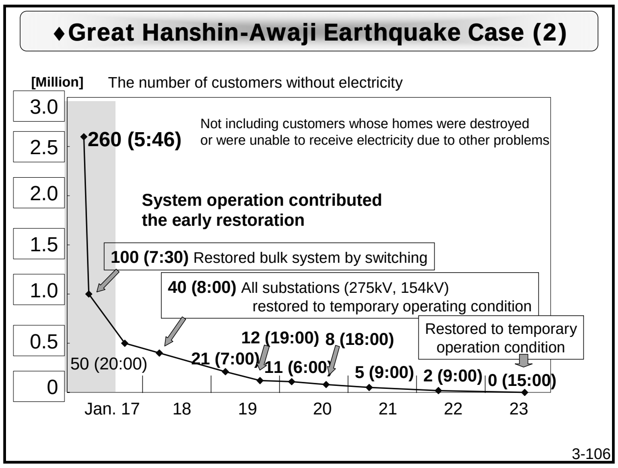
3. System Operation
(Voltage Control and System Protection)

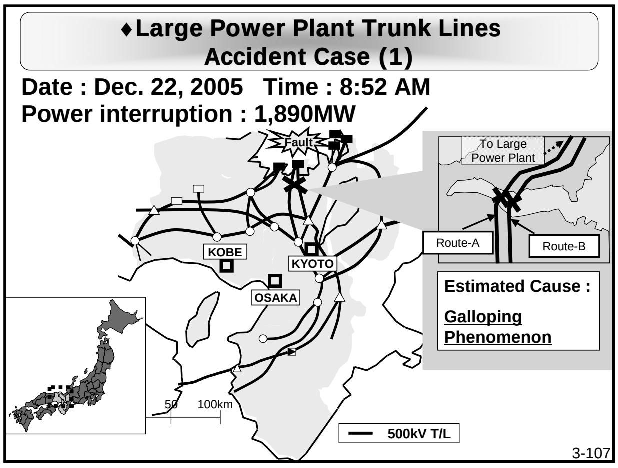




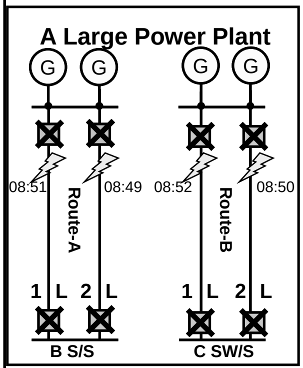








♦Large Power Plant Trunk Lines Accident Case (2)



Dec.22, 2005
08:49 Trip of Route-A 2L
08:50 Trip of Route-B 2L
08:51 Trip of Route-A 1L
08:52 Trip of Route-B 1L

Loss of 4,800MW generation triggered by four lines tripping

(Area total demand : 25,300MW)

Load shedding according to periodical pre-calculation by "BSS"

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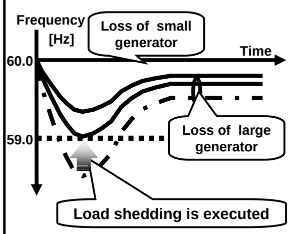
♦Large Power Plant Trunk Lines Accident Case (3)

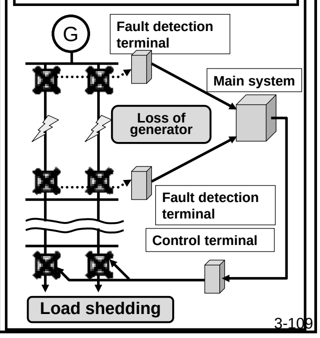
< Outline of BSS >

Purpose



To keep system frequency greater than 59.0Hz and to avoid cascading line tripping.

Functional diagram



3-109

♦Large Power Plant Trunk Lines Accident Case (4)

With BSS

- By preventing frequency drop in advance, separation from other interconnected systems was avoided.
- Limited outage areas and quick restoration

Outage power: approx. 2.2GW
Restoration time: about 40 min.

Without BSS

- Frequency drop causes separation from other systems and load shedding (Under frequency relay operated)
- Outage in wider areas and delay in restoration

Outage power: approx: 4.6GW
Restoration time: about 150 min.

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♦Lessons from the Outages

➢ **Miboro Power Plant Accident**

✓The importance of fault extension protection relays was recognized in case large generators drop.
The accident eventually lead to the development of "BSS (Block System Stabilizer)" later.

➢ **Great Hanshin-Awaji Earthquake**

✓Outage was restored to temporary operation condition earlier than any other infrastructures such as water supply and city gas, due to the effects of consistent training in KANSAI.

➢ **Large Power Plant Trunk Systems Accident**

✓The effectiveness of "BSS" against severe accident was confirmed because power system was fully restored in a very short time despise the large scale outage.

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