

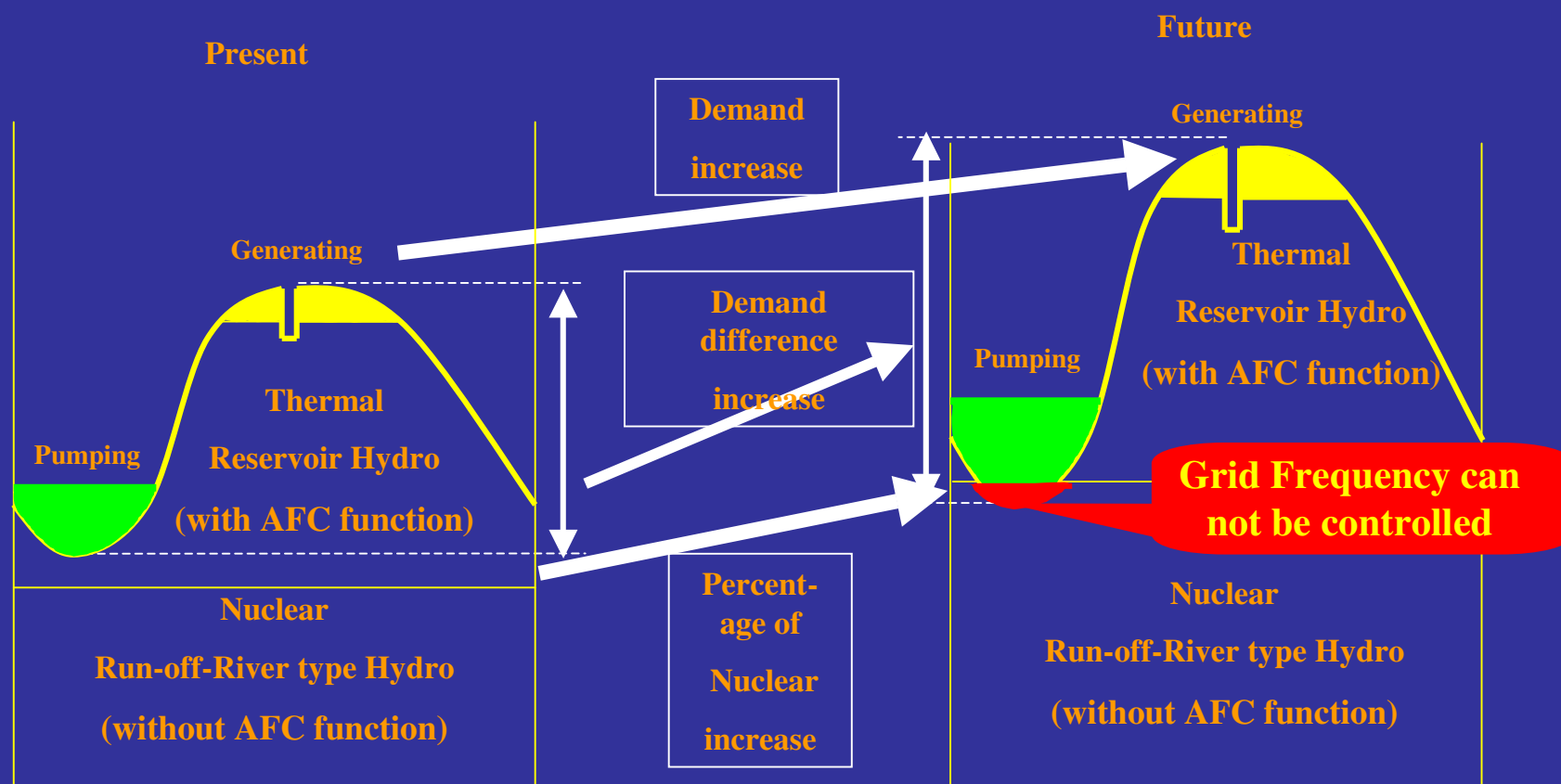
# Pumped Storage Power Station with Adjustable Speed Pumped Storage Technology



MITSUBISHI ELECTRIC CORPORATION

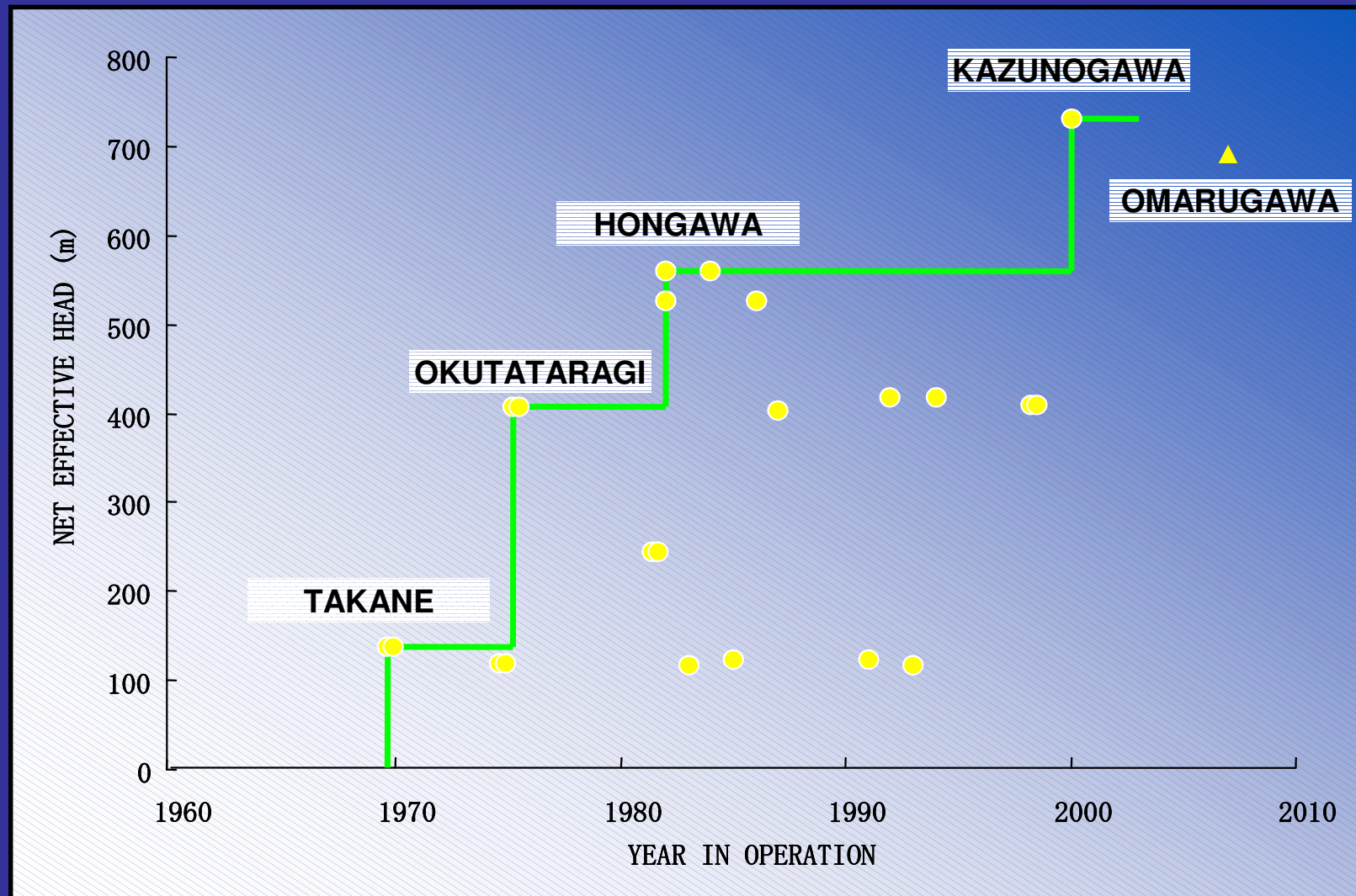
Feb, 2008

## Trend of power supply system

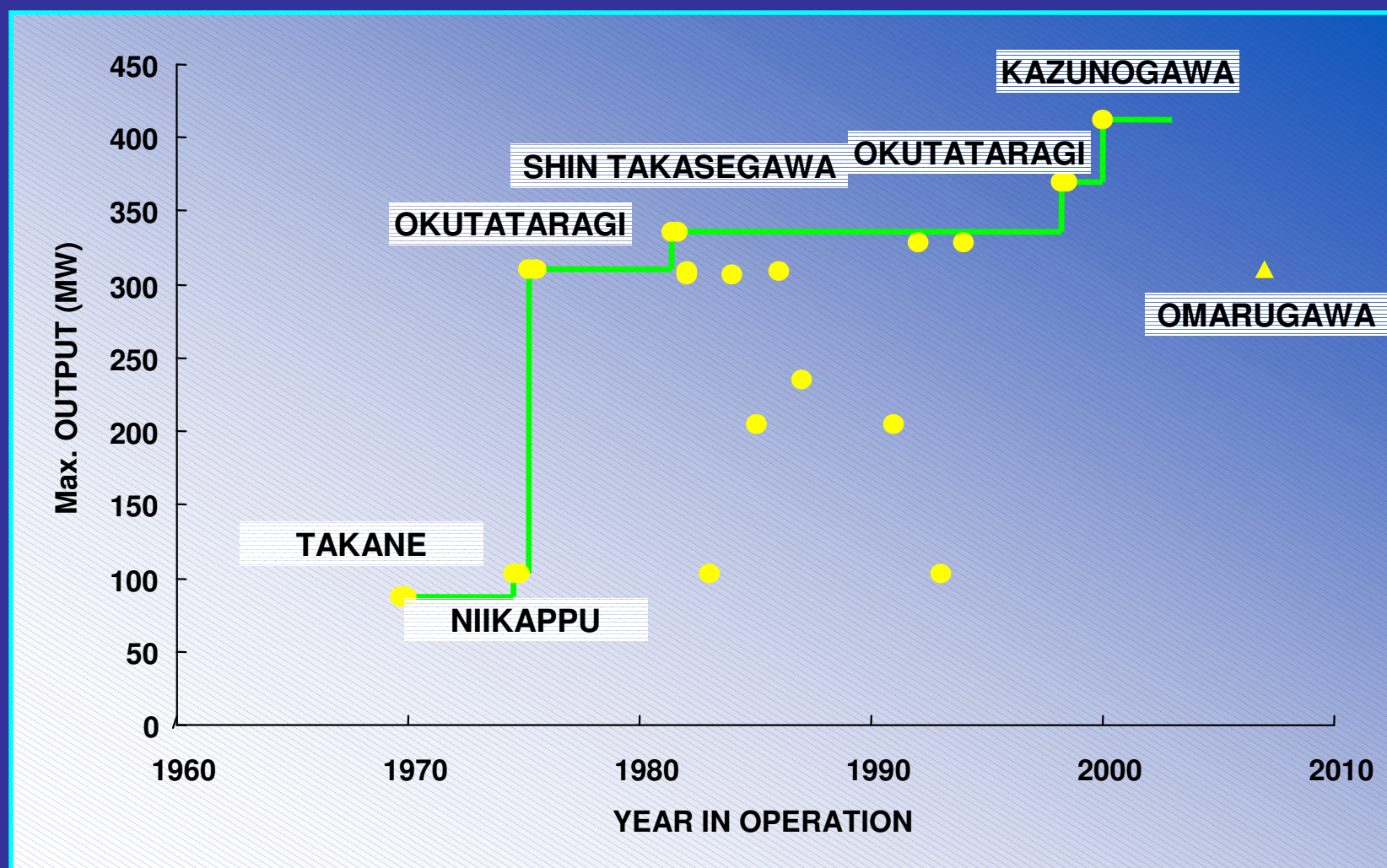


Note) AFC : Automatic Frequency Control

## Trend of Max. Head of Pump-Turbines



# Trend of Max. Output of Pump-Turbines

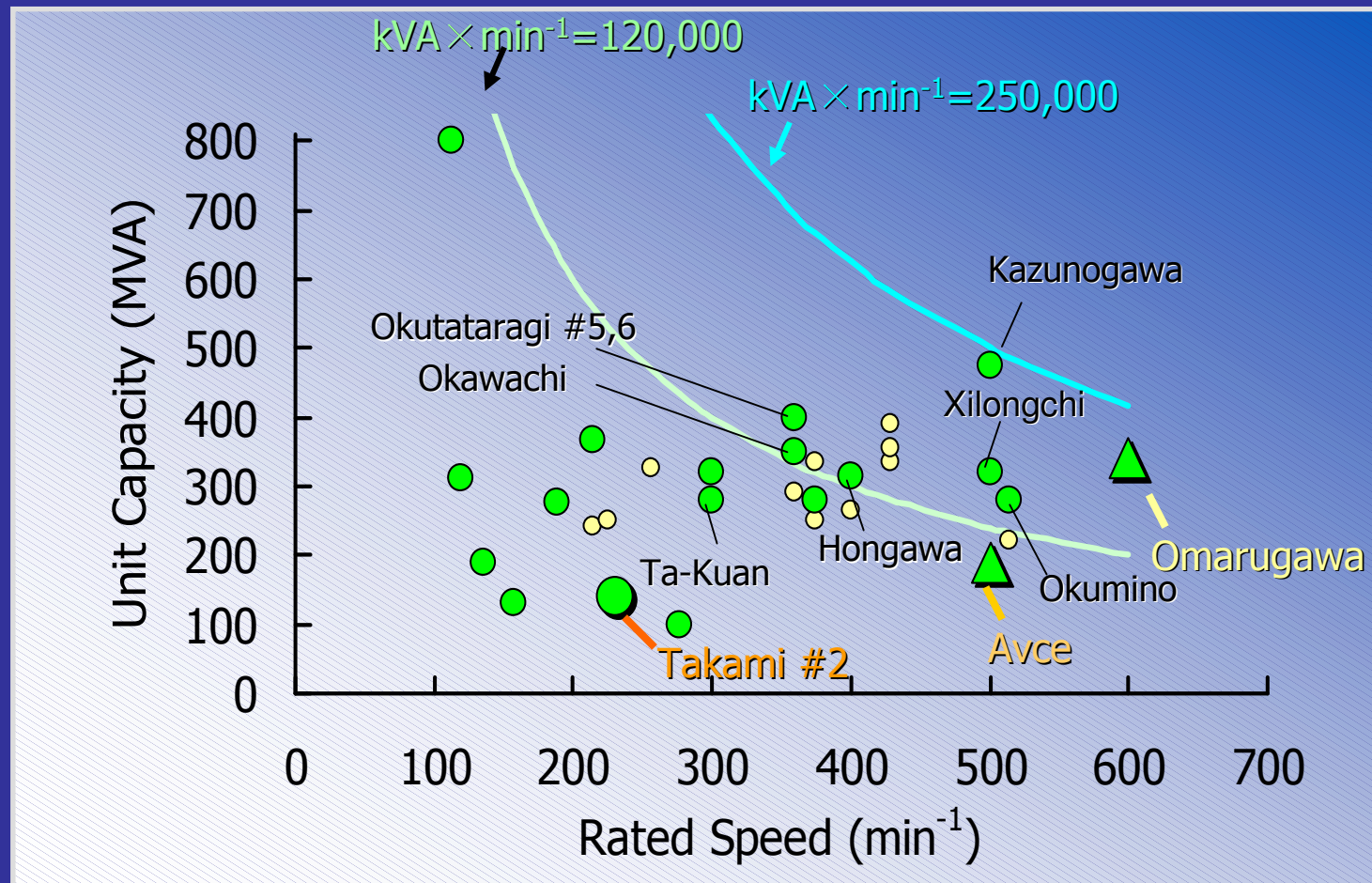




# Maximum Unit Capacity(G/M)



- : Manufactured by Melco
- ▲ : Under construction by Melco
- : Manufactured by Others



### Improvement for the quality of power supply system



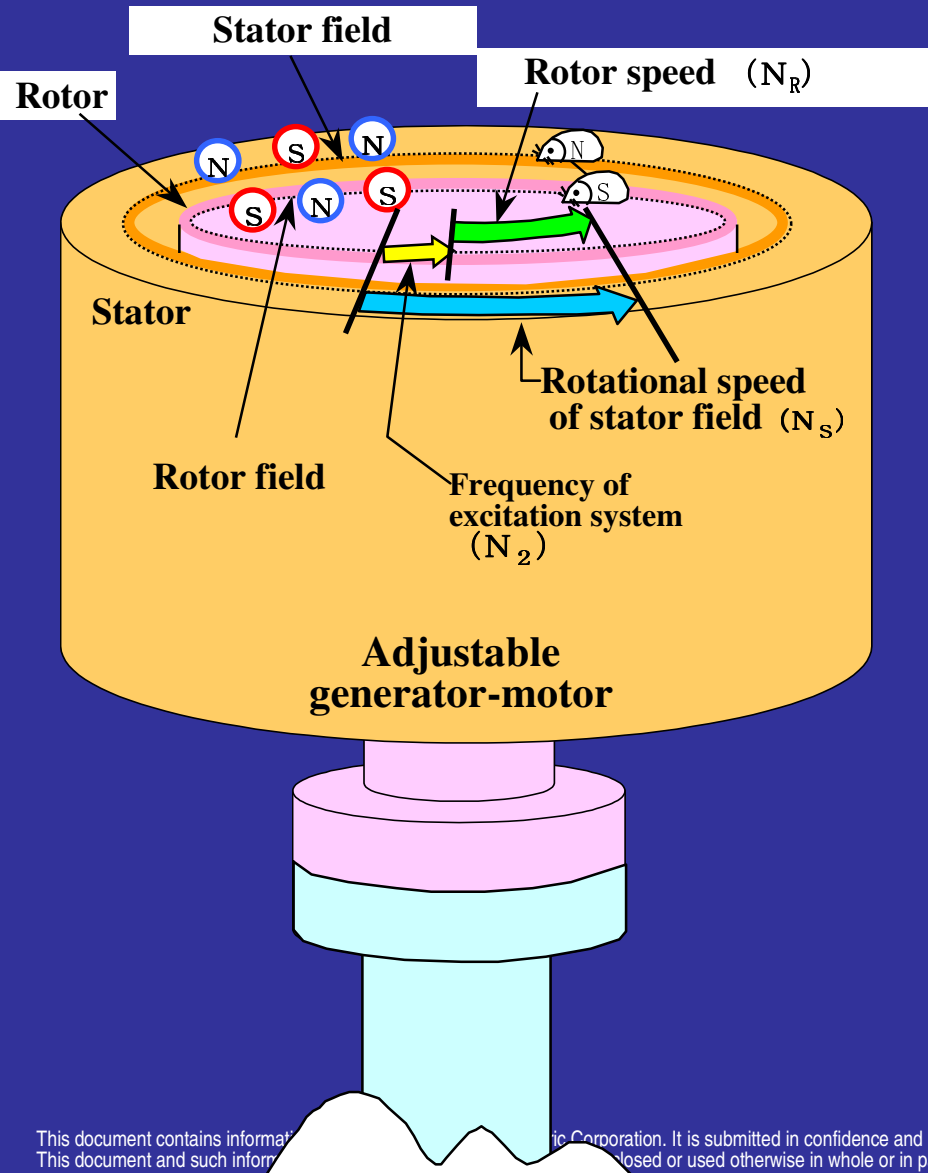
- Wide operating head range & high efficiency
  - Adjusting input power in pumping operation
  - Guarantee the AFC(Automatic Frequency Control) capacity in pumping operation
  - Reducing the power failure rate
  - Improving the frequency stability
  - Improving the voltage stability



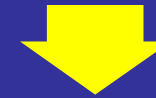
**The quality can be improved by applying the adjustable speed technology**

# **1. Principle for Adjustable Speed system**

# Principle of Adjustable Speed Control



Usually, a constant speed generator-motor is excited by the DC excitation system fixed on the rotor.  
The rotational speed of the rotor field equals the rotor speed.



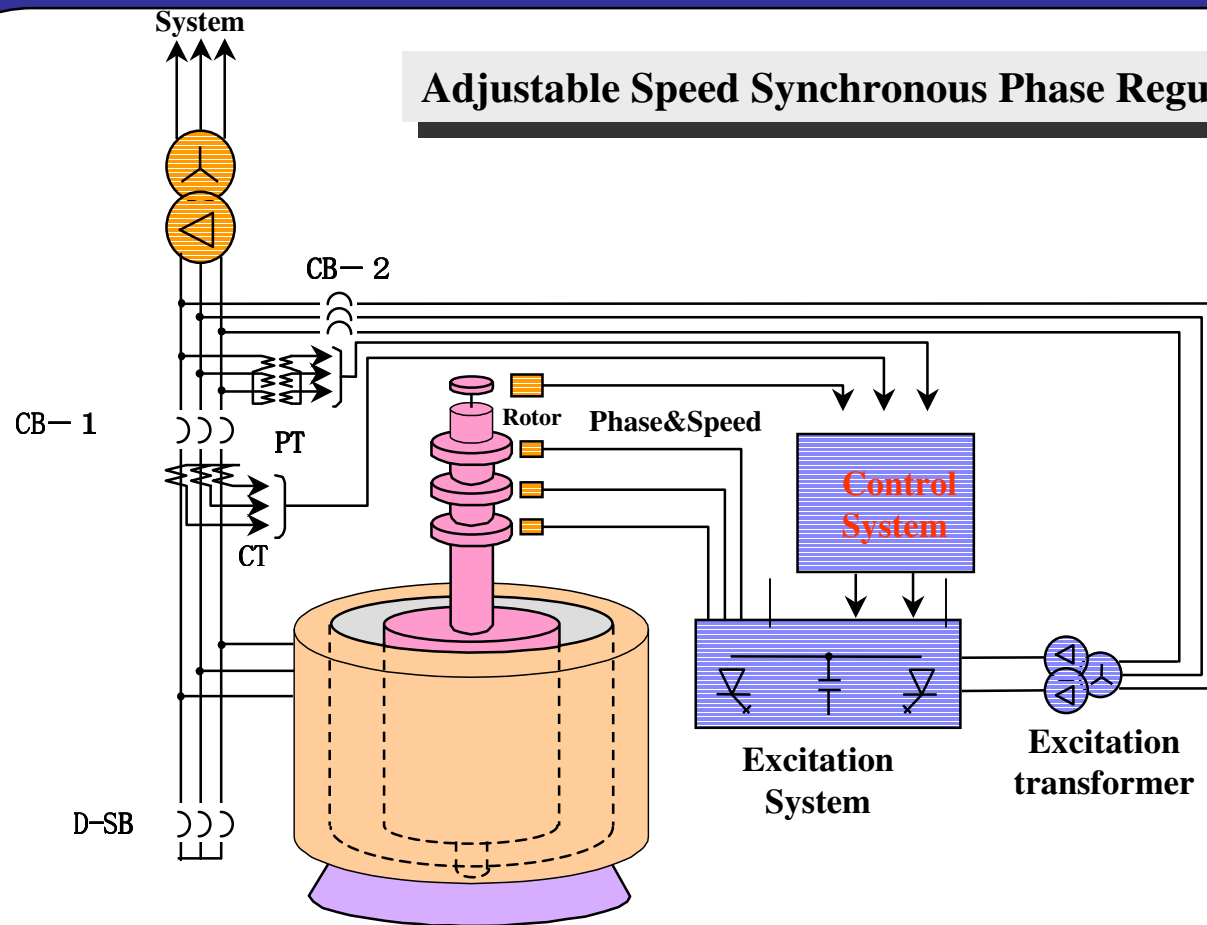
However, an adjustable speed generator-motor is excited by the AC excitation system fixed on the rotor.  
Therefore, the rotational speed of the rotor field equals the sum of the rotor speed and the frequency of the AC excitation.



$$n_S = n_R \pm n_2$$



## Adjustable Speed Synchronous Phase Regulation System



# Comparison of Constant Speed and Adjustable Speed

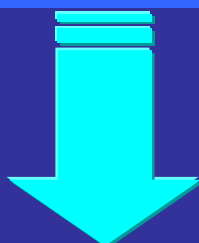


➡ Construction of rotor is different from the Constant speed generator-motor.

## Constant Speed Type Generator-motor

DC excitation

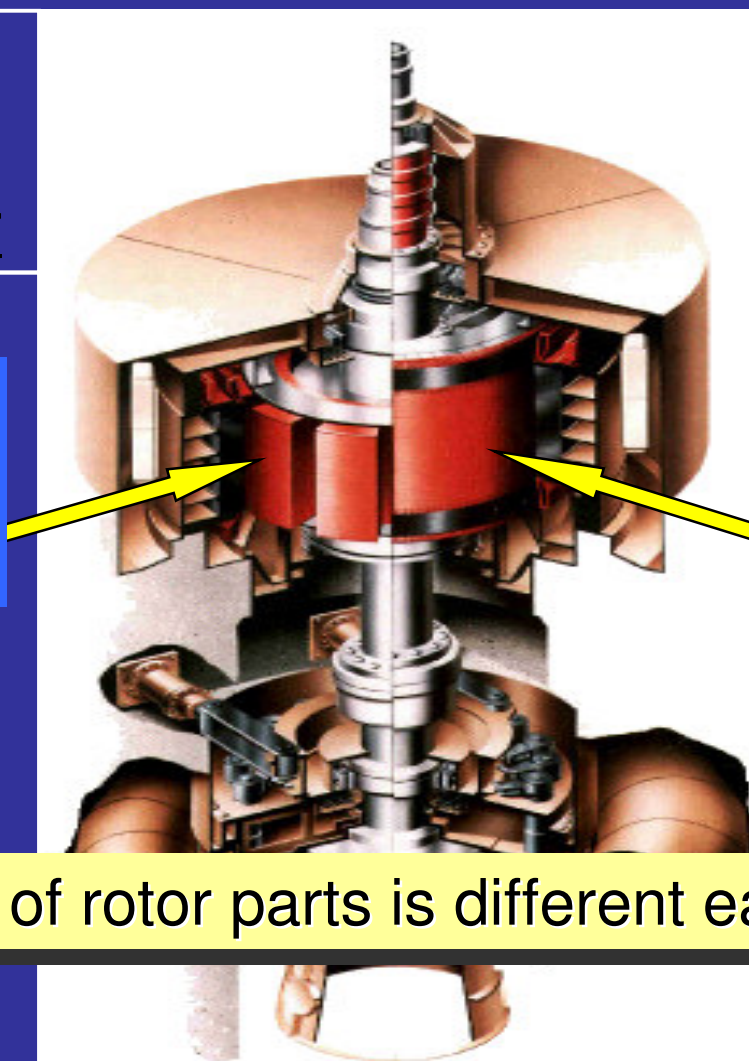
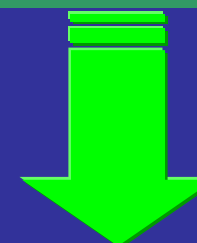
Rotor has  
“Salient pole”  
with solenoid type  
field coil.



## Adjustable Speed Type Generator-motor

AC excitation

Rotor is  
cylindrical type  
with three-phase  
windings.



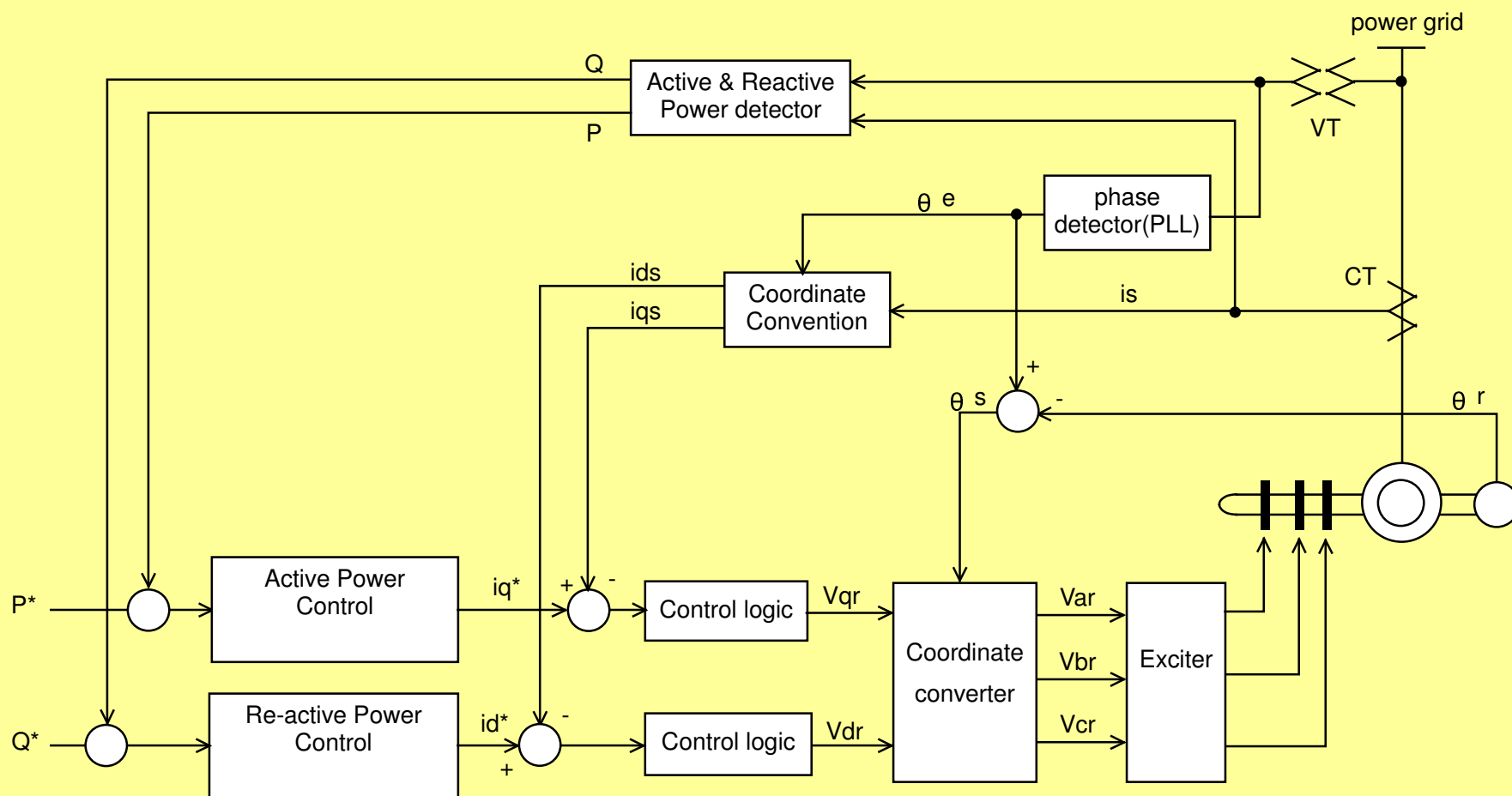
Shape of rotor parts is different each other.

# Reference record of Adjustable Speed



No.	Power Station		Generator/Motor Unit Cap. & Units	Principal of Secondary Excitation system				Manufacturer	Operation Date
	Customer	Name of P/S	MVA/MW x Unit	Method	Cap. (MVA)	Speed Range	Start		
In Japan									
1	Hokkaido Electric Po. Co.	TAKAMI	105/140 x1	GTO Inverter	24.3	10%	Exc.	Mitsubishi	1993
2	Kansai Electric Po. Co.	OKAWACHI	395/388 x2	Cyclo-Converter	72	8.3%	SFC	Hitachi	1993 1995
3	Tokyo Electric Po. Co.	SHIOBARA	360/330 x1	Cyclo-Converter	51.1	8%	SFC	Toshiba	1995
4	Electric Po. Development Co.	OKUKIYOTSU No.2	345/340 x1	GTO Inverter	31.5	5%	Exc.	Toshiba	1996
5	Electric Po. Development Co.	YAMBARU	31.5/30 x1	GTO Inverter	3.96	5%	Exc.	Toshiba	1999
6	Kyuusyuu Electric Po. Co.	OMARUGAWA No.3,4	350/330x1	GCT Inverter	27.4	4%	SFC	Mitsubishi	2008
			370/330x1	Cyclo-Converter	43.3	4%	SFC	Hitachi	2008
7	Kyuusyuu Electric Po. Co.	OMARUGAWA No.1,2	350/330 x1	GCT Inverter	27.4	4%	SFC	Mitsubishi	2010
			370/330 x1	Cyclo-Converter	43.3	4%	SFC	Hitachi	2010
In EU									
1	Germany	Goldisthal	331/330 x2	Cyclo-Converter	?	10%	SFC	VA-Tech	2002
2	Slovenija	AVCE	195/185.3 x1	GCT Inverter	10 (24.2)	4%	Exc.	Mitsubishi	2009

# Adjustable Speed Control Block Diagram



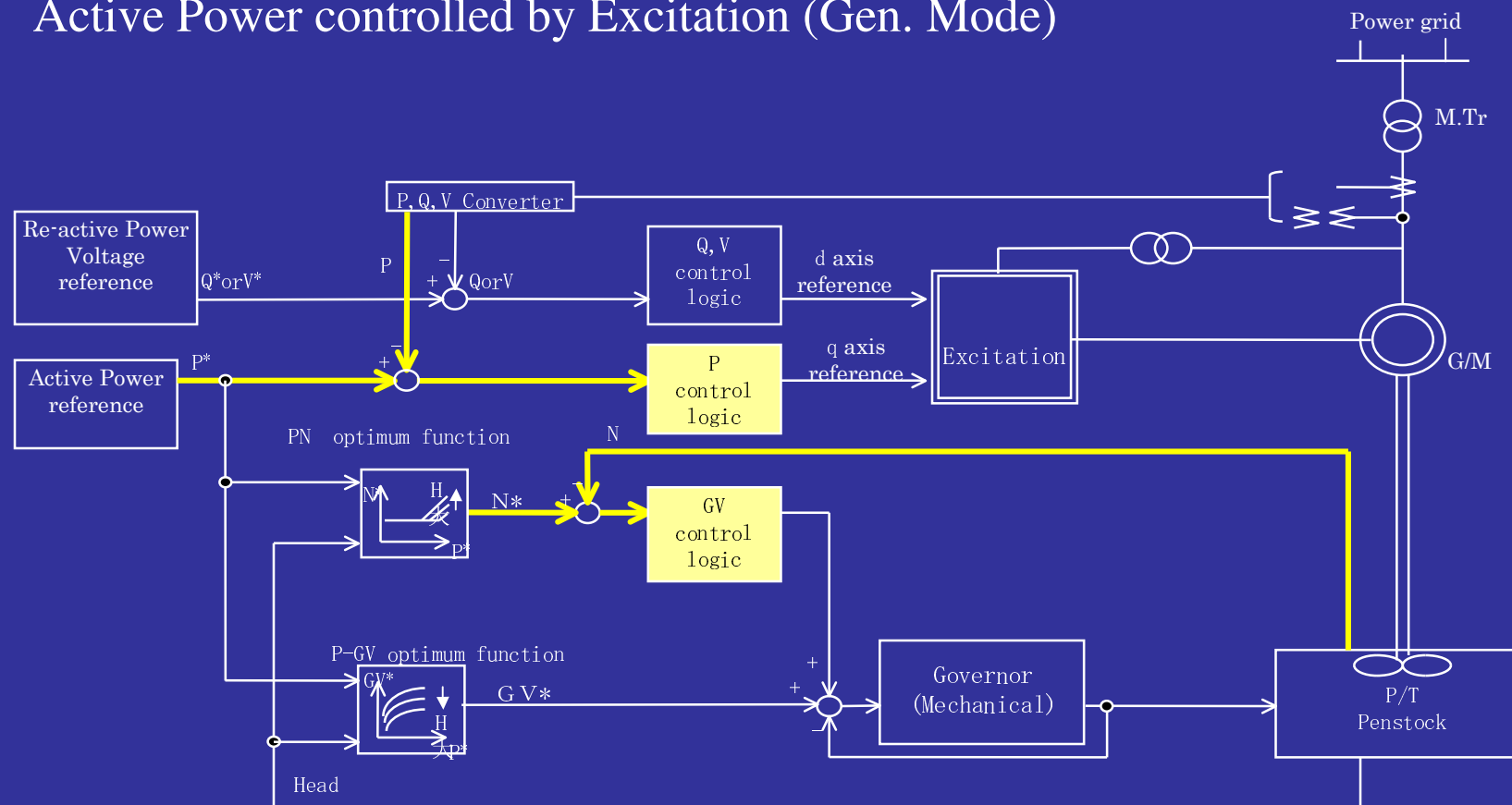
## **2. Operation outline of Adjustable Speed Pumped-Storage system**

# Adjustable Speed Control Block Diagram



## Generation Mode

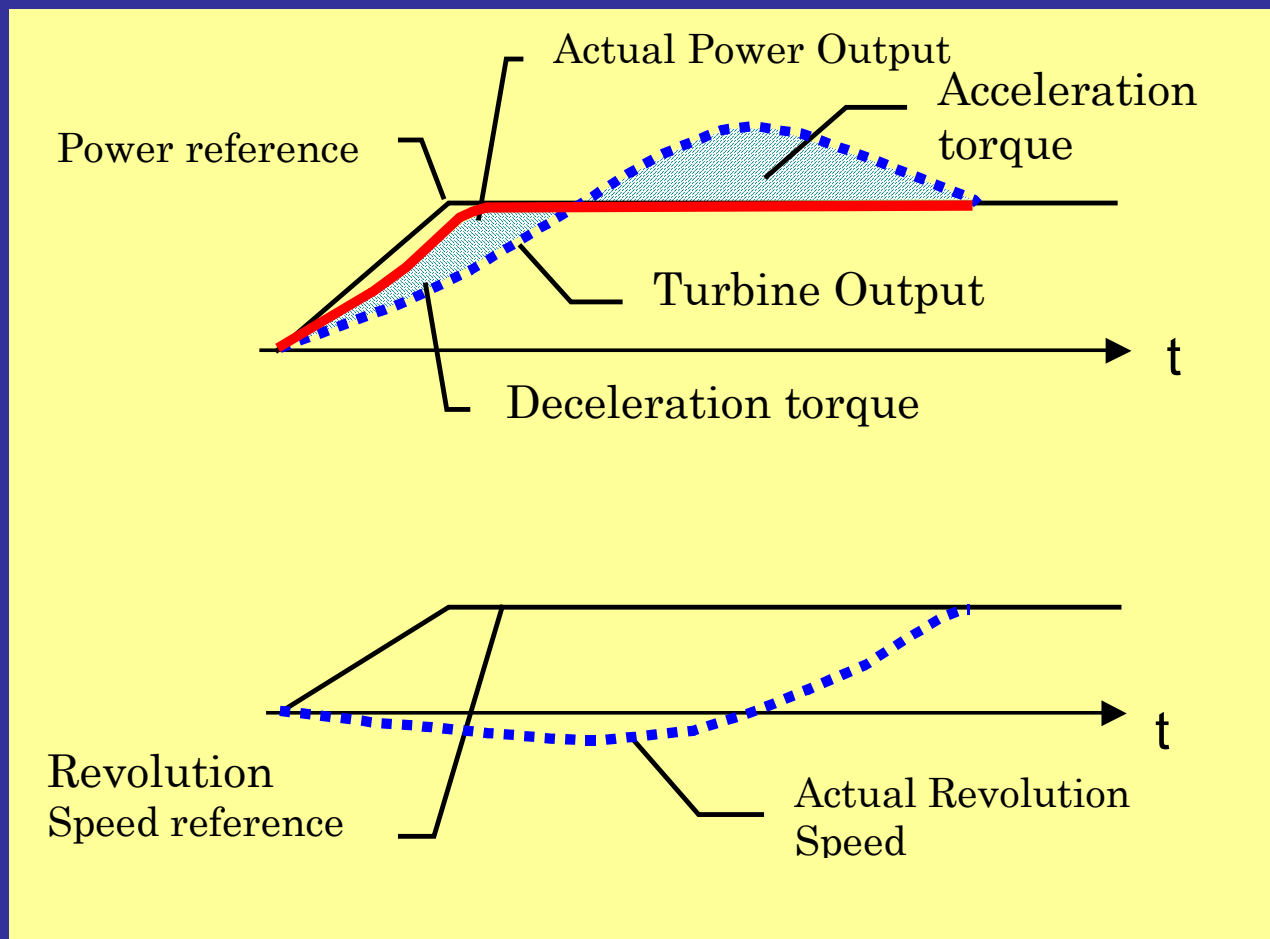
### Active Power controlled by Excitation (Gen. Mode)





## Generation Mode

### Active Power controlled by Excitation (Gen. Mode)

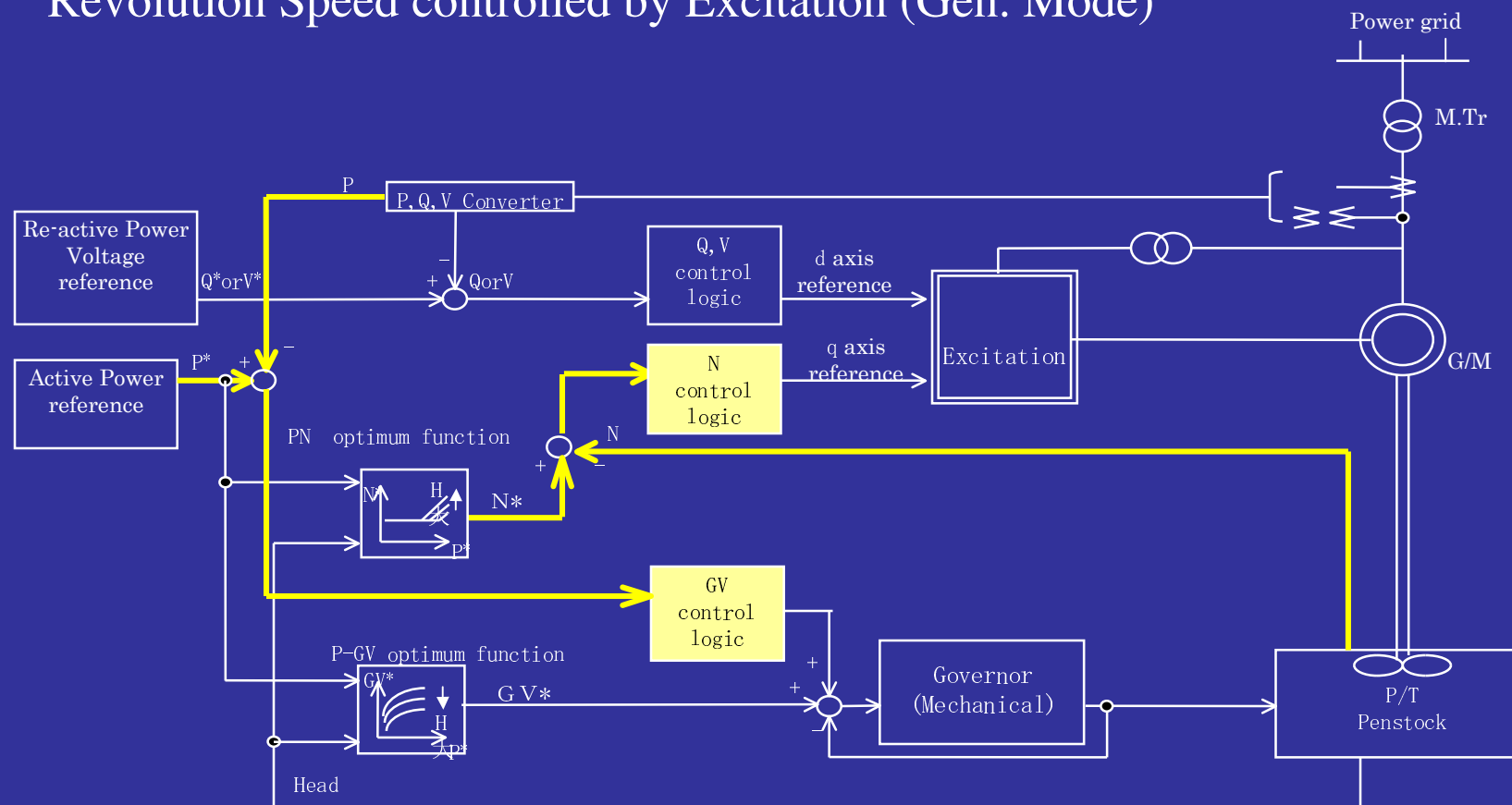


# Adjustable Speed Control Block Diagram



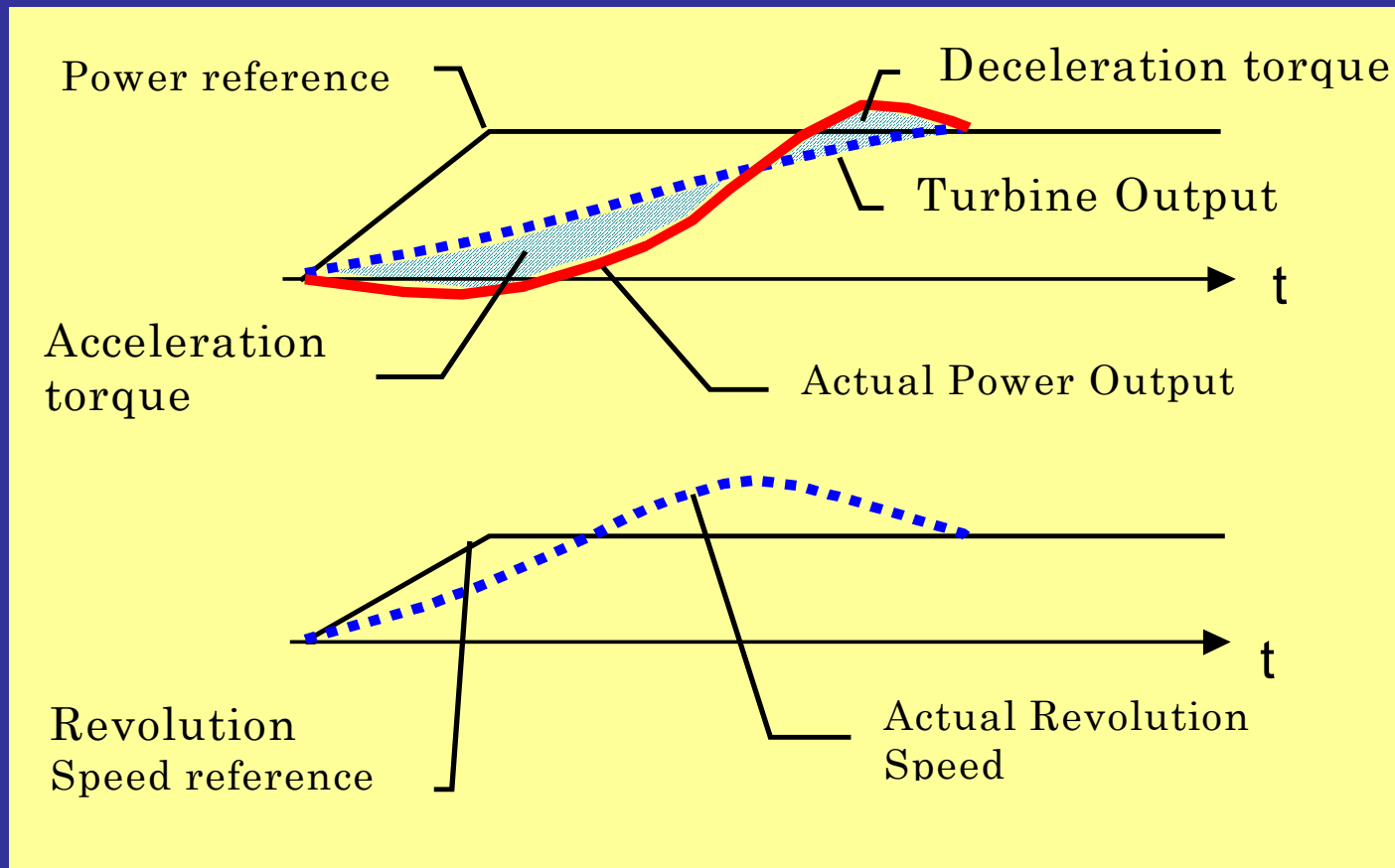
## Generation Mode

### Revolution Speed controlled by Excitation (Gen. Mode)



## Generation Mode

### Revolution Speed controlled by Excitation (Gen. Mode)

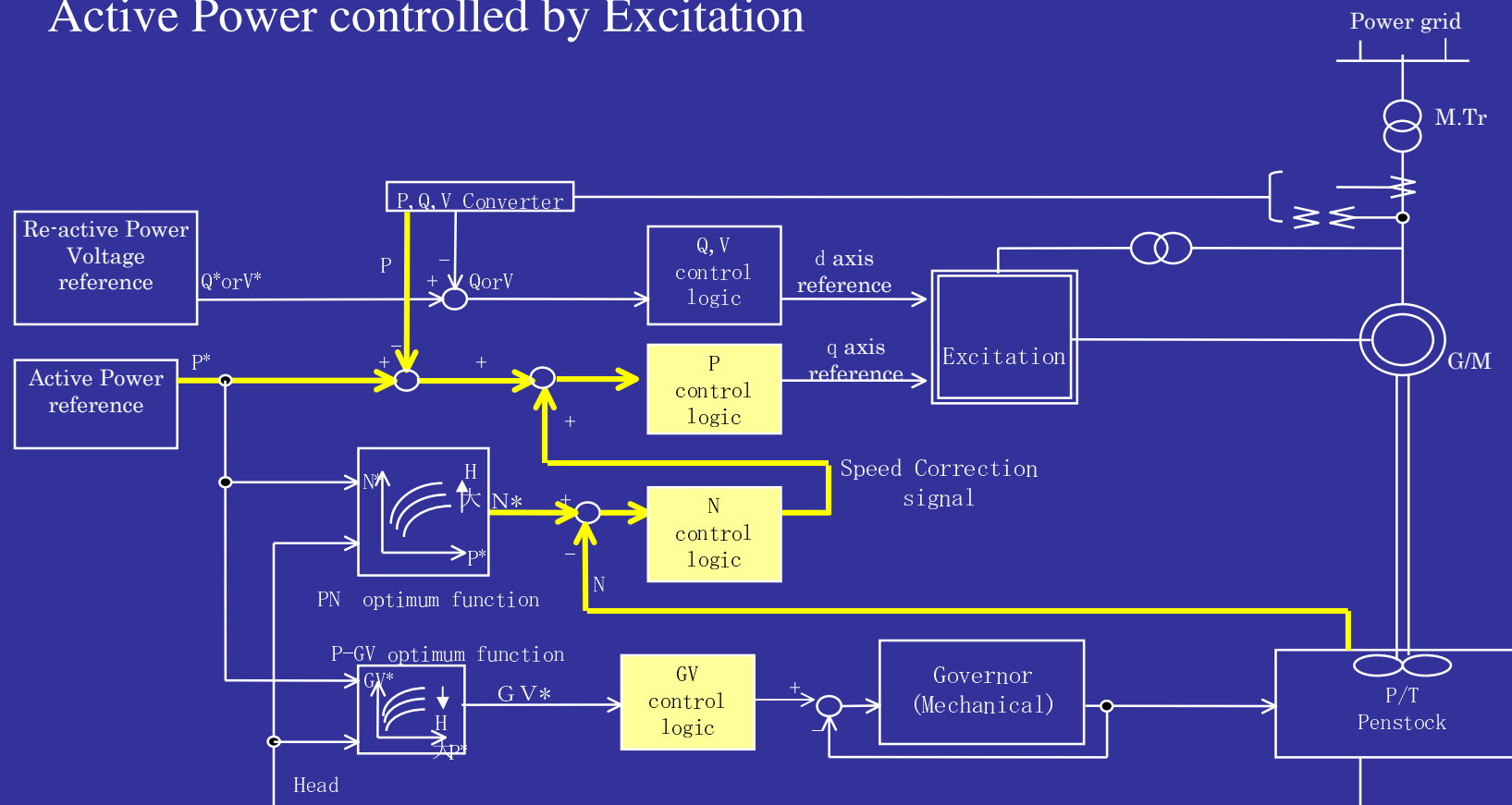


# Adjustable Speed Control Block Diagram



## Pumping Mode

Active Power controlled by Excitation

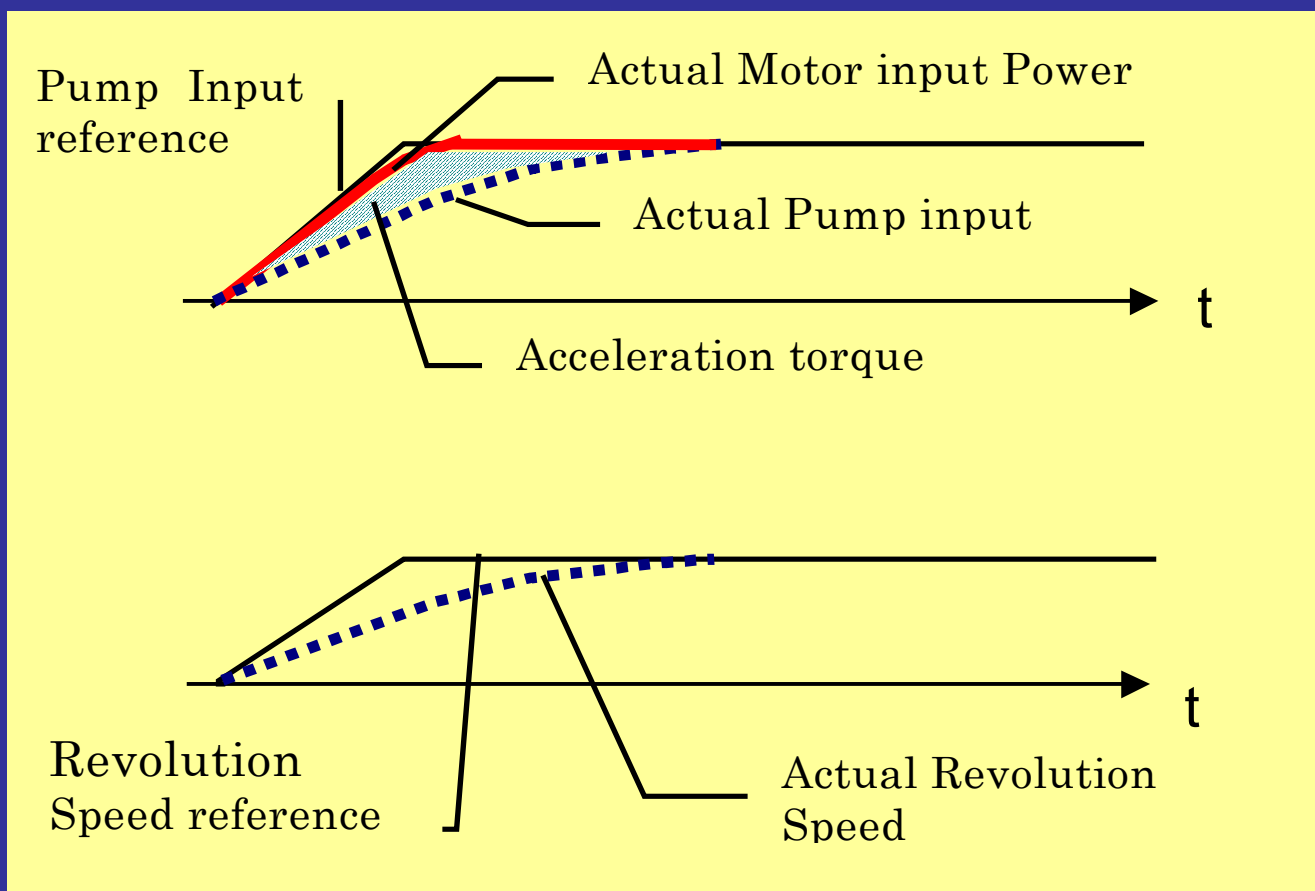


# Behavior of Adjustable speed control



## Pumping Mode

### Active Power controlled by Excitation (Pump Mode)



### **3. Operating Zone of Adjustable Speed Pumped-Storage Project**

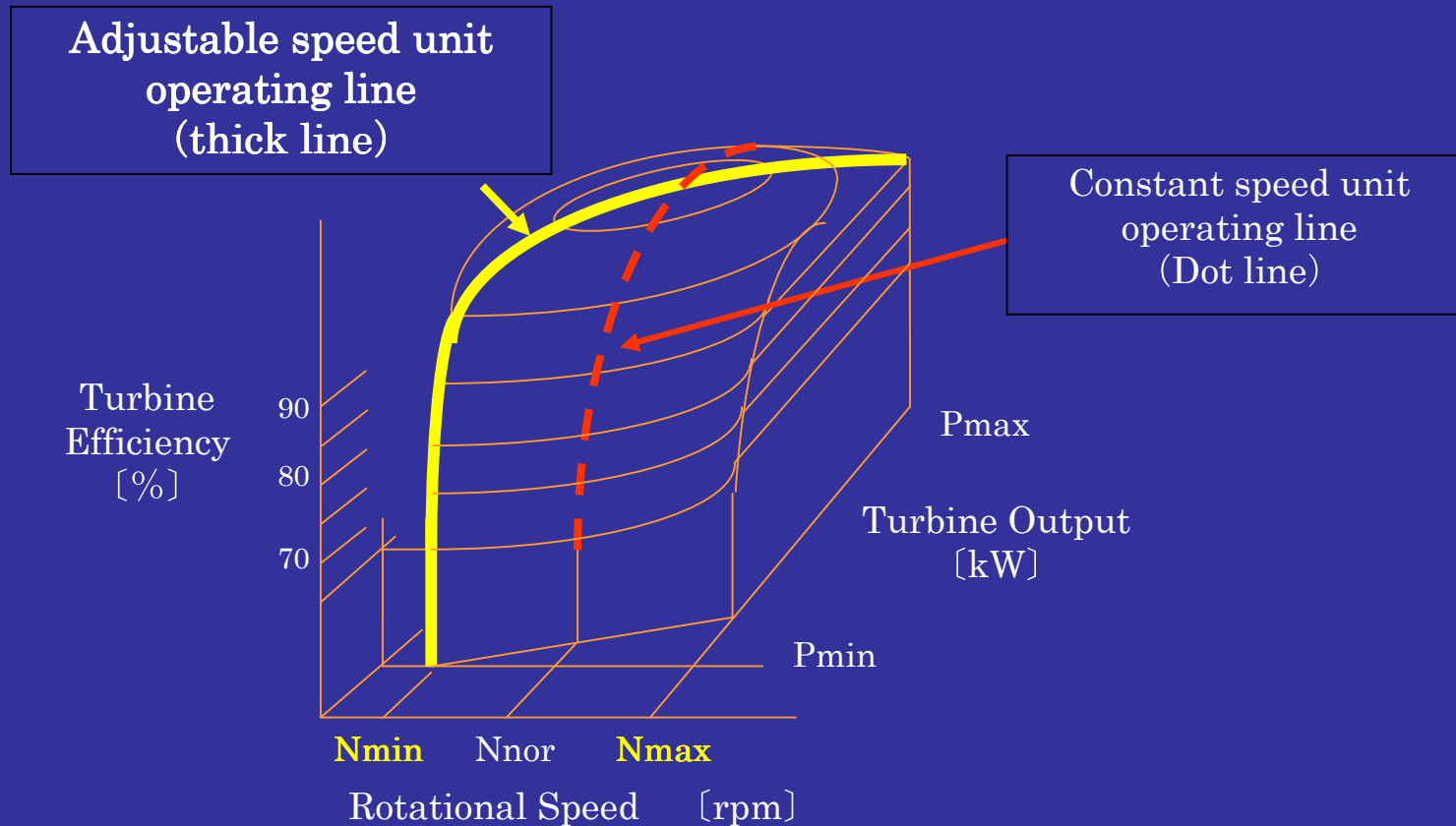


	Variable	Constant or <b>Two Speeds</b>
Rotational Speed	Rated $\pm \alpha$	Rated or <b>Two Speeds</b>
Pump Input	Adjustable	Not Adjustable
Pump Cavitation	Generally severer (depending upon the operation range)	Generally less severe
Turbine Cavitation	Better	-
Turbine efficiency	Better	-
Turbine Operating Condition such as <b>Head Fluctuation</b>	<b>Better</b>	-

# Operating range in turbine operation

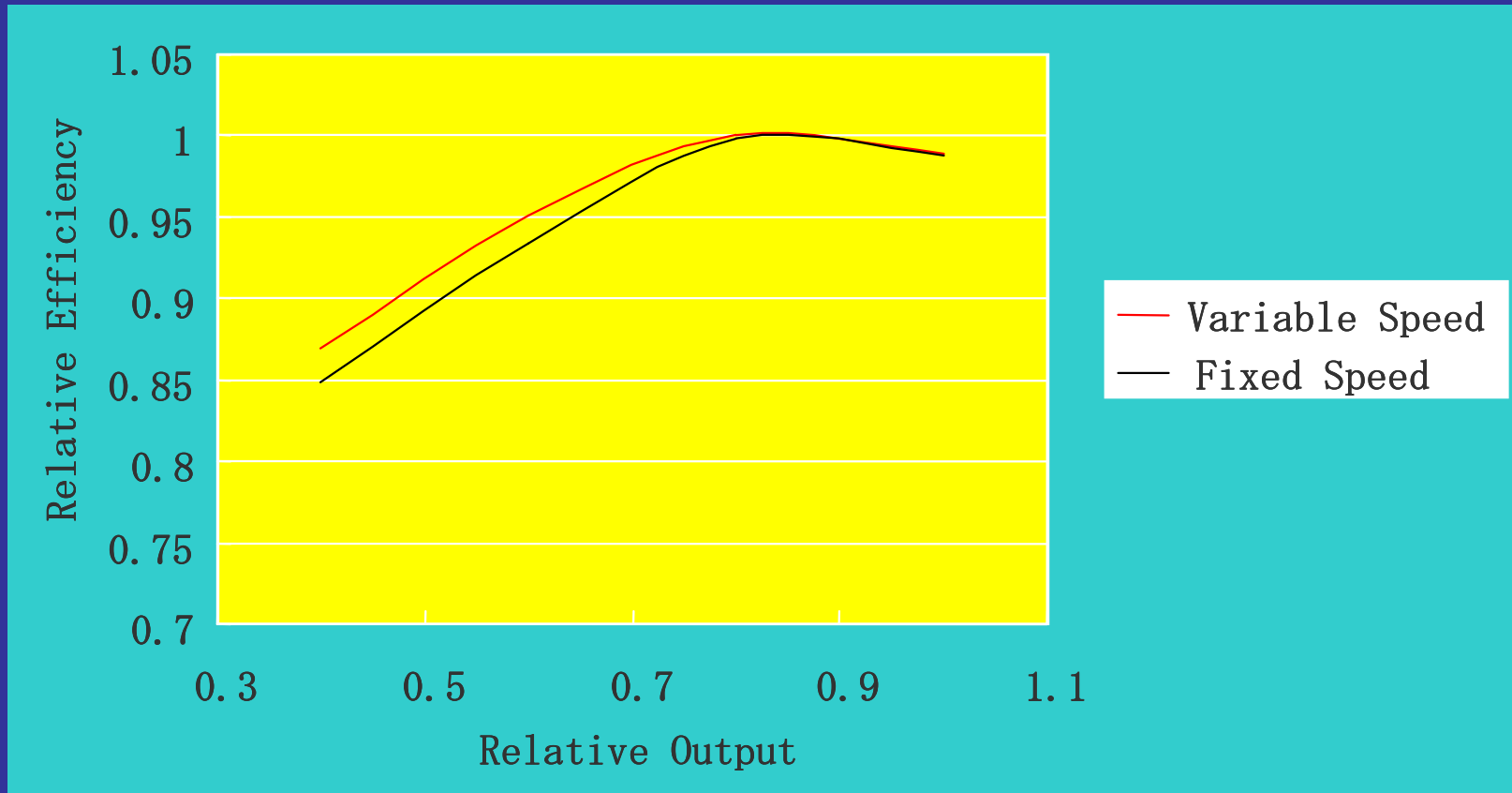


## Highest efficiency line operation



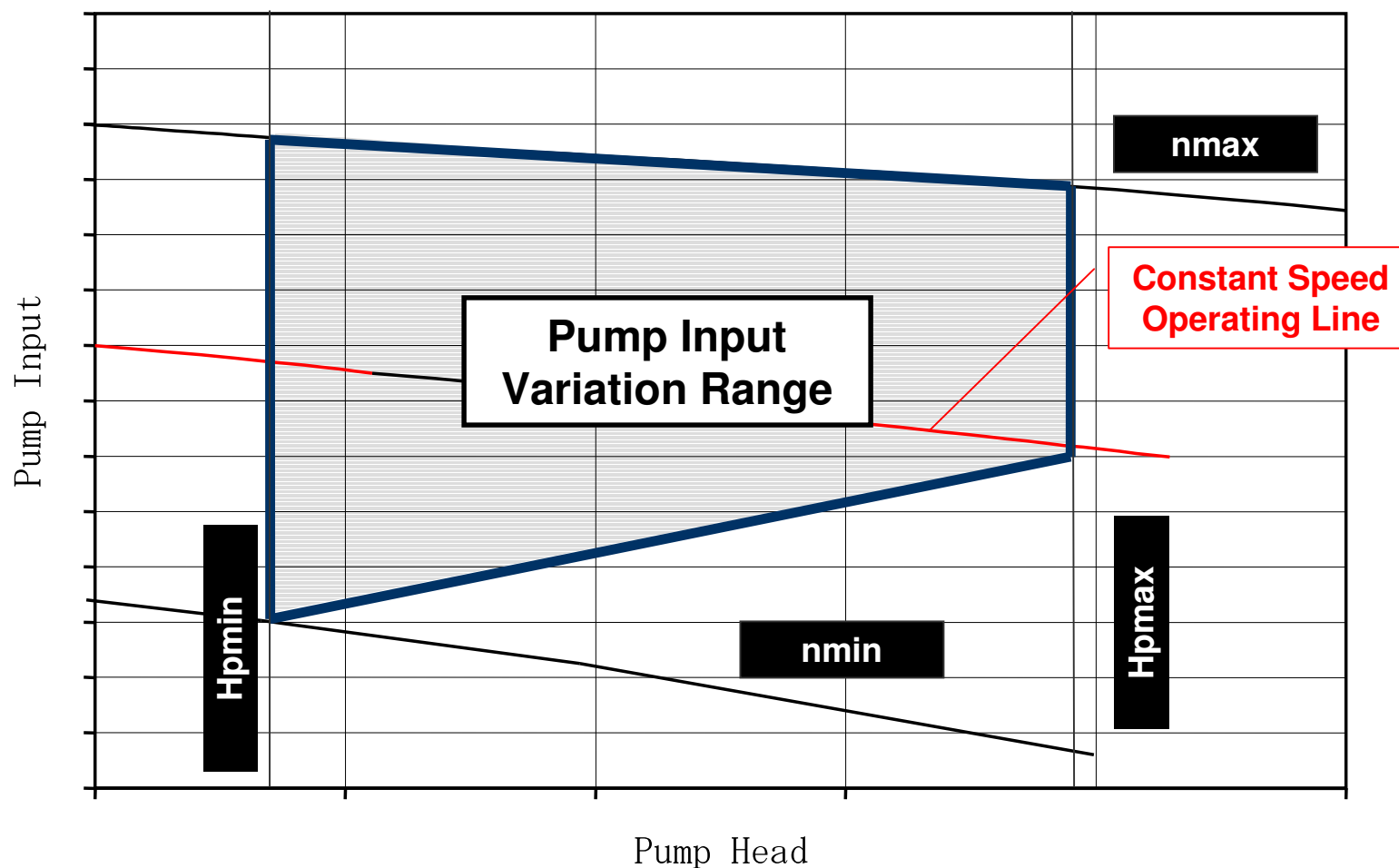
- The turbine efficiency at partial load is improved
- Lower limit of turbine operation range is expanded.

# Turbine Efficiency



- **Increase Turbine Operating Condition Especially in Partial Operation  
(Improve Turbine Efficiency, Turbine Runner Inlet Cavitation Characteristics etc.)**

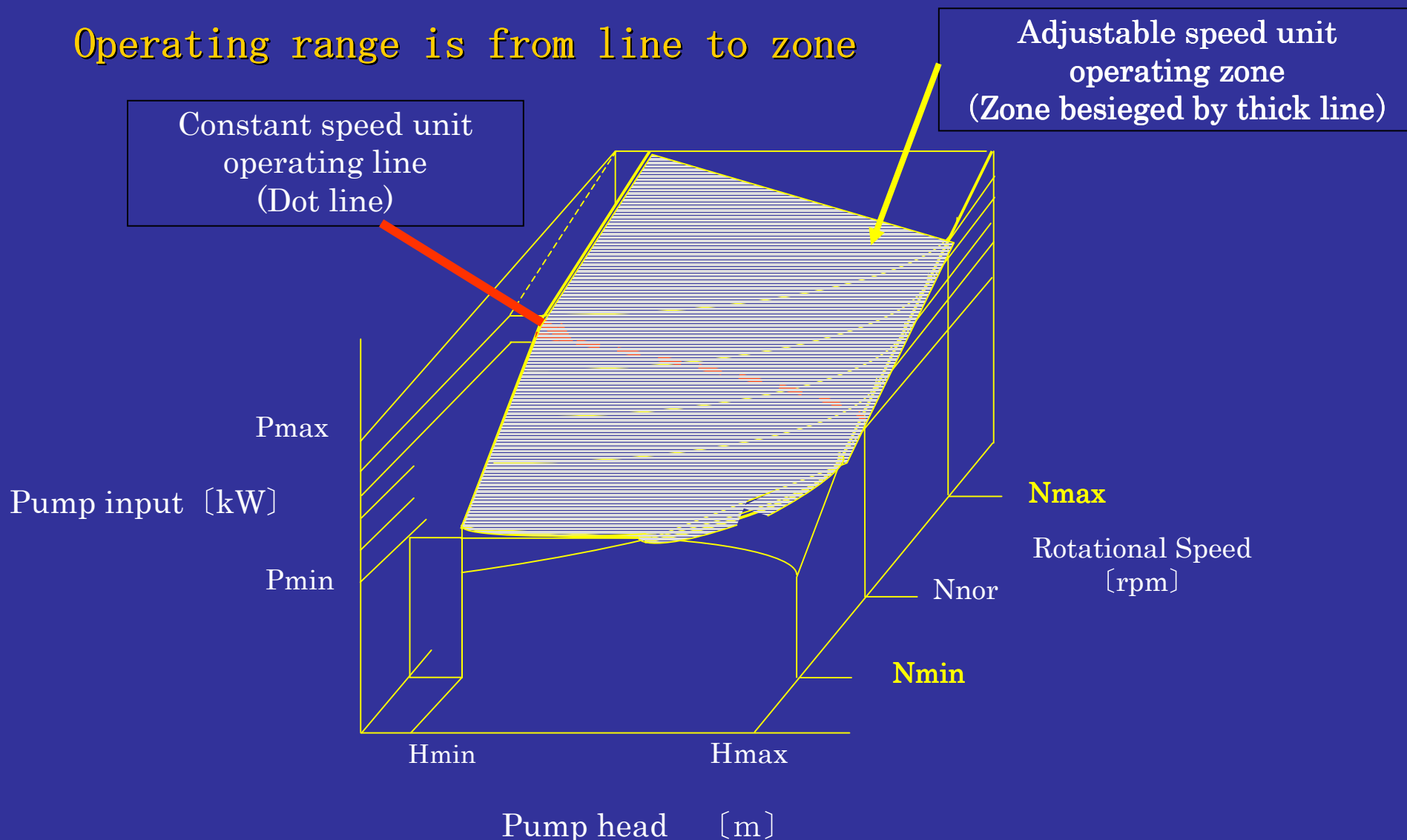
# Operating range in Pumping mode



# Operating range in pumping operation



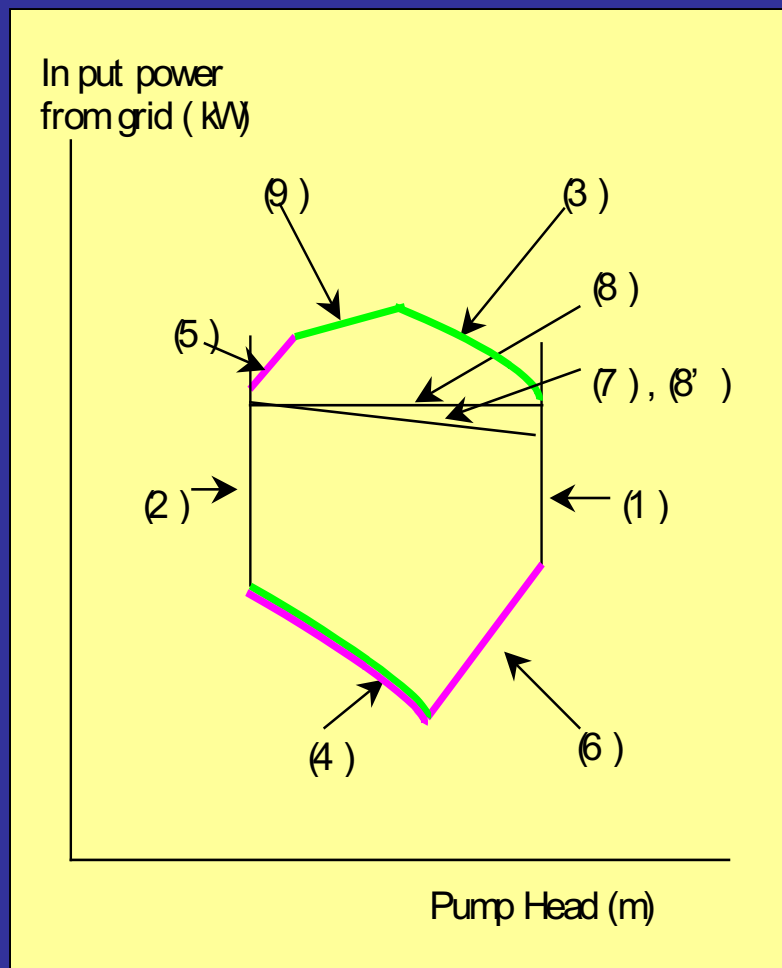
Operating range is from line to zone



# Limitation and Operating zone in pumping mode



## Limitation of Adjustable speed system



- (1) maximum head
- (2) minimum head
- (3) maximum rotational speed  
= maximum output voltage of inverter
- (4) pump cavitation limit  
= minimum rotational speed  
= maximum output voltage of inverter
- (5) pump stability and cavitation limit
- (6) pump cavitation limit
- (7) maximum output of the stator capacity
- (8) maximum output of the main-transformer capacity in case of synchronizing at high voltage side of main-transformer
- (8') maximum output of the main-transformer capacity in case of synchronizing at low voltage side of main-transformer
- (9) maximum output current of inverter



# **Development & Manufacture of KAZUNOGAWA #2 Pump-Turbine**

# Kazunogawa Power Station



\*TEPCO : Tokyo electric power company

- 👤 Kazunogawa Power Station, which located in Yamanashi Pref., is the eighth of TEPCO\*'S pumped storage power plants.
- 👤 Kazunogawa #2 P/T & G/M has been operated in good condition since the commercial operation began on 2000/6/8.

Yamanashi Pref.  
(Otsuki city)



Upper reservoir

Over all view of the power station

# Kazunogawa Power Station



## Pump Turbine

412MW(turbine)/ 438MW(pump)  
Effective heads 714m

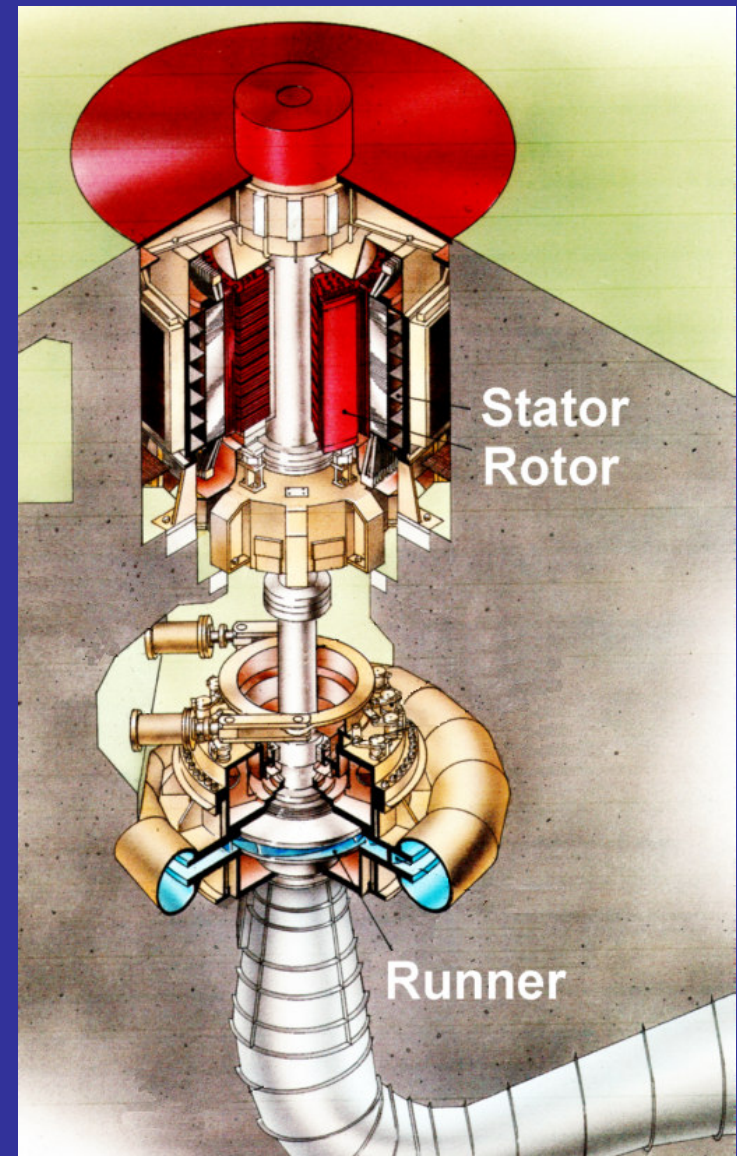
## Generator motor

475MVA(gen.)/438MW (motor)  
Rated speed 500min<sup>-1</sup>

Exciter Thyristor type

## Main Transformer

950MVA (475×2) 525/18kV  
Oil-immersed water-cooled type



# **TAKAMI Unit-2**

## **Variable Speed Generator-Motor**



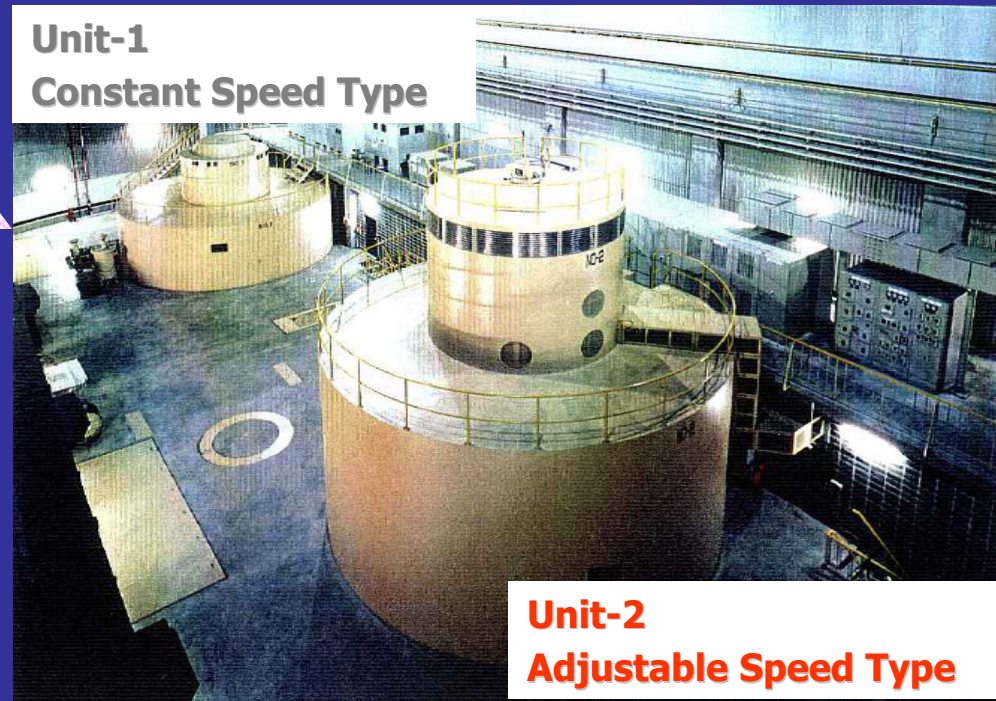
# Takami Power Station



\*HEPCO : Hokkaido Electric Power Co. Inc.

- ❧ Takami Power Station, which is located in Hokkaido Govt., is the first variable speed pumped storage power plant of HEPCO.
- ❧ Takami #2 P/T & G/M has been operated for 15 years in good condition since the commercial operation began on 1993/4/26.

Hokkaido Govt.  
(Shin-Hidaka town)



**Over the view of the power station**



# **OMARUGAWA Unit-3**

## **Variable Speed Generator-Motor**



# Omarugawa Power Station



-  Omarugawa Power Station, which is located in Miyazaki Pref., is the first variable speed pumped storage power plant of Kyusyu Electric Power.
-  Omarugawa #3 P/T & G/M is now at the site installation stage. Commercial operation will be started in Jul. 2008.

Miyazaki Pref.  
(Kijyou town)



# Omarugawa Power Station



## Spec. of system

	Generator	Motor
Active power [MW]	300	330
Reactive Power [MVar]	50	60

## Spec. of each components

### Pump Turbine

310MW(turbine)/330MW(pump)

Max. head 688.4 m

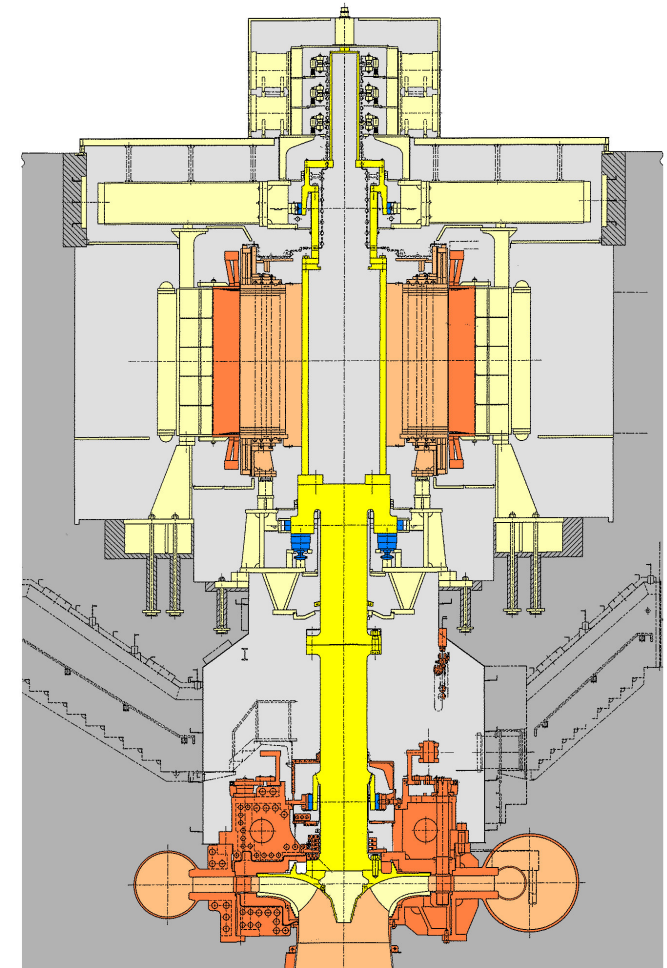
Max. pump head 720.3 m

### Generator motor

319MVA(gen.)/330MW(motor)

Rated speed  $600\text{min}^{-1} \pm 4\%$

Exciter GCT Converter type



# **AVCE**

## **Variable Speed Generator-Motor**

# AVCE Power Station



- 📍 AVCE Power Station, which is located in Slovenia.
- 📍 AVCE P/T & G/M is now at the designing and manufacturing stage. Commercial operation will be started in April 2009 .



# AVCE Power Station



## Spec. of each components

### Pump Turbine

185.4MW(turbine)  
/185.25MW(pump)

Max. head 498.2 m

Max. pump head 508.8 m

### Generator motor

195MVA(gen.)/185.25MW(motor)

Rated speed 600min<sup>-1</sup>[-4%~+4.4%]

Exciter GCT Converter type