



Impact of Fusion Reactor on Electricity Grids

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Nuclear Fusion Reactor

Nuclear fusion reactor is one of candidates for sustainable energy source in the future without carbon dioxide emission.

In conceptual studies,

fusion reactor is assumed to be used as a base load machine in industrial countries with unit capacity of $> 1\text{GWe}$,

- continuous operation with maximum power
- $> 200\text{MWe}$ startup/operation power

Startup scenario with inductive current drive requires very large dP/dt value and large Q

Our question is

can the fusion reactor be installed in the small electric grid ?

→ calculate the influence of startup power in the small electric grid



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- The diagram illustrates the energy balance of a tokamak system. The components and their associated power flows are as follows:
- Plasma (Q)**: Represented by a red oval on the left. It receives power $P_i = \eta_d P_d$ (60MW) from the Driving System and outputs $P_f + P_i$ (3060MW) to the Blanket.
 - Blanket (M)**: Represented by a purple rounded rectangle. It receives $P_f + P_i$ (3060MW) from the Plasma and outputs $P_\alpha = P_f / 5$ to the Plasma. It also outputs $P_c = P_i + P_\alpha$ to the Generator.
 - Generator (η_e)**: Represented by a green rounded rectangle. It receives $P_{th} = P_c + MP_n$ (3372MW) from the Blanket and outputs $P_{net} = (1 - \epsilon) P_e$ (1250MW) to the Grid. It also outputs P_d (120MW) to the Driving System and P_{aux} (~5% 80MW) to the Auxiliary System.
 - Driving System (η_d)**: Represented by a pink rounded rectangle. It receives P_d (120MW) from the Generator and outputs $P_i = \eta_d P_d$ (60MW) to the Plasma.
 - Auxiliary System (η_{anc})**: Represented by an orange rounded rectangle. It receives P_{aux} (~5% 80MW) from the Generator.
 - Grid**: Represented by a large red vertical oval on the right. It receives $P_{net} = (1 - \epsilon) P_e$ (1250MW) from the Generator.
 - Intermediate Power Flows**:
 - P_n flows from the Plasma to the Blanket.
 - MP_n flows from the Blanket to the Generator.
 - $P_e = \eta_e P_{th}$ (1450MW) flows from the Generator to the Grid.
 - $P_{cir} = \epsilon P_e$ (200MW) flows from the Generator back to the Grid (indicated by a dashed arrow).
- Efficiency values are provided for the Blanket ($M = 1.13$), Generator ($\eta_e = 0.4$), Driving System ($\eta_d = 0.5$), and Auxiliary System (η_{anc}).



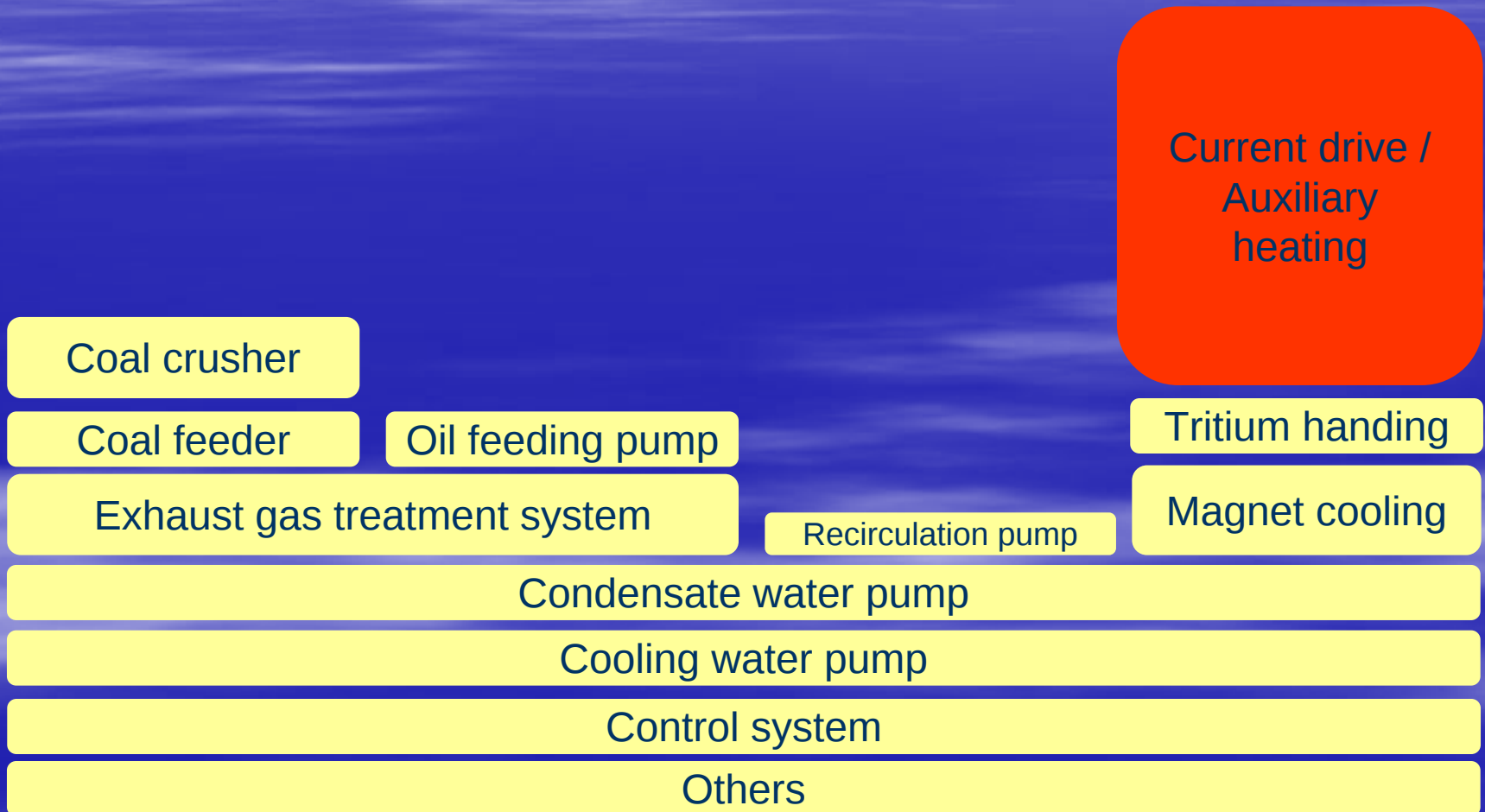
Auxiliary power in power plants

Coal

Oil

Nuclear

Fusion



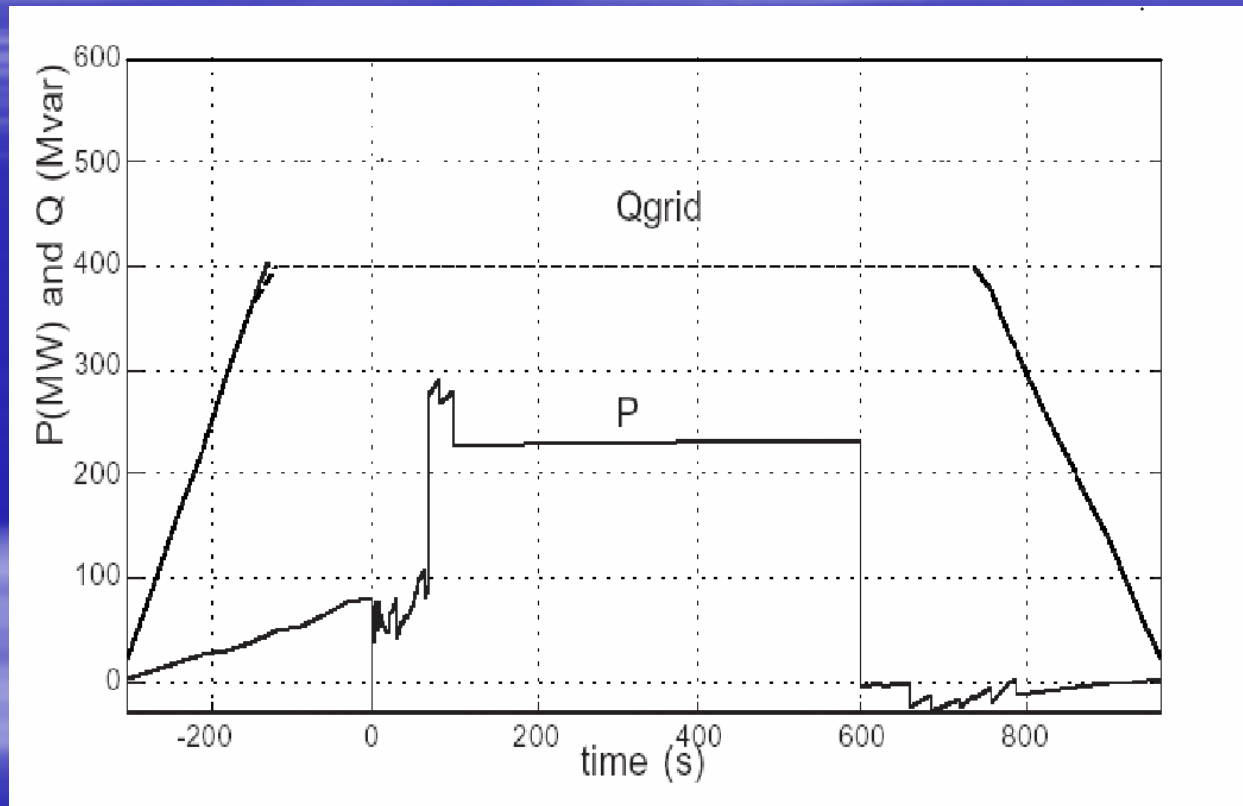
Auxiliary power ratio of various system

System	Capacity [MW]	utilization of facilities [%]	Auxiliary power ratio [%]
Fusion	1,000	75	~13.0
Nuclear Fission	1,000	75	3.4
Oil thermal	1,000	75	6.1
LNG thermal	1,000	75	3.5
Coal thermal	1,000	75	7.4
Hydro	10	45	0.25
geothermal	55	60	7.0
wind power	0.1	20	10
Photovoltaic			
utility	1.0	15	5
home	0.003	15	0

Source : 内山洋司 ; 発電システムのライフサイクル分析 , 研究報告 , (財) 電力中央研究所(1995)

Influence to the electric grid

Power demand in ITER standard operation scenario



Active power

$$P = \sim 300 \text{ MW}$$

$$dP/dt = \sim 230 \text{ MW/s}$$

Reactive power

$$Q > 600 \text{ MVA}$$

by on-site compensation

$$Q_{\text{grid}} = \sim 400 \text{ MVA}$$



Influence to the electric grid

- Power generation is controlled by

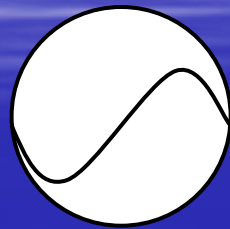
Time scale	method
$> \sim 10\text{min}$	ELD or manual
$3\text{min} < t < 10\text{min}$	AFC
$< \sim 3\text{min}$	governor of each UNIT (spinning reserve)

In Japan, usual value of spinning reserve is 3% of total generation

Influence to the power grid

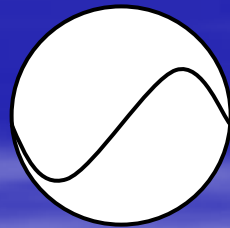
■ Calculation model

Thermal Generator



10km

Hydroelectric Generator



10km

100km Transmission Line

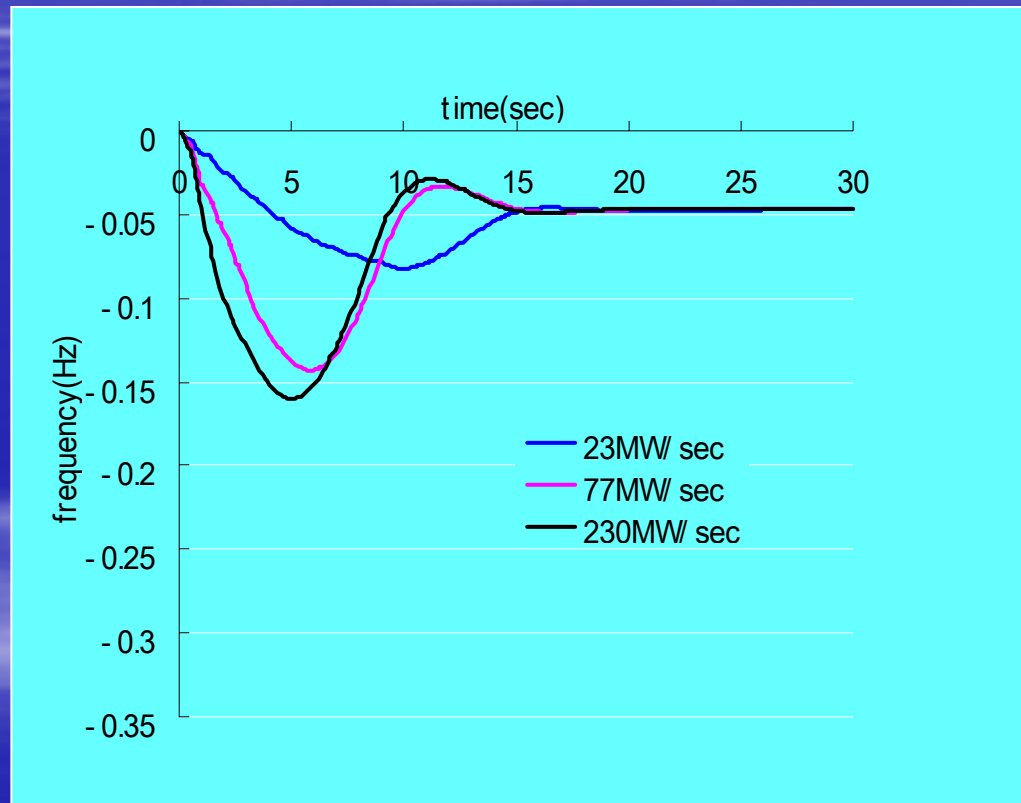
Demand

Fusion Reactor

Reference Capacity	: 1000MVA
Transmission Voltage	: 115kV
System capacity	: 7-15GWe
Impedance per 100km	: $0.0023 + j0.0534$ [p.u.]
Capacitance	: $jY/2 = j0.1076$ [p.u.]

Influence to the power grid

- Frequency fluctuation



Influence to the power grid

- Maximum Frequency Fluctuation [Hz] for 7GW grid

		Load change rate [MW/s]		
		23	77	230
Peak Load [MW]	130	0.05	0.07	0.08
	230	0.08	0.15	0.16
	330	0.11	0.30	0.33

- Maximum Frequency Fluctuation [Hz] for 15GW grid

		Load change rate [MW/s]		
		23	77	230
	330	0.03	0.05	0.06

Influence to the power grid

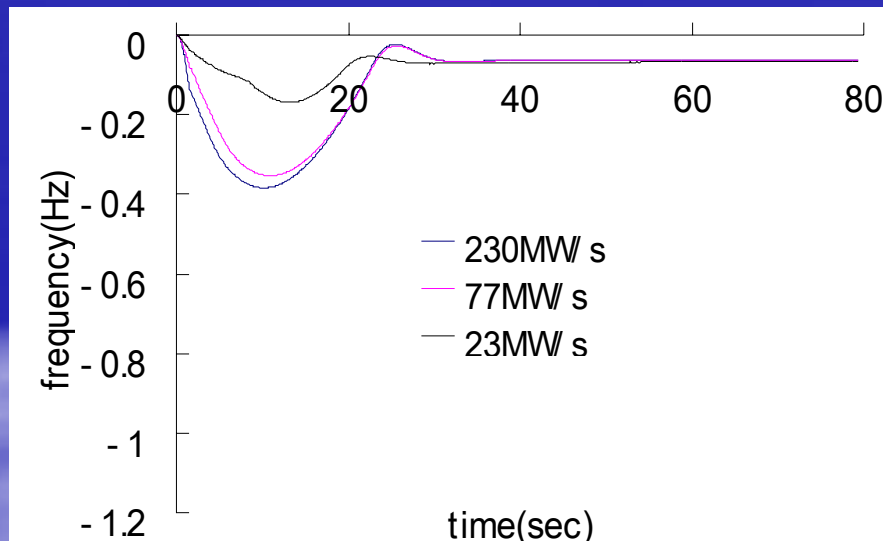
- The grid capacity of 10-20GW is required to supply startup power of ITER like fusion reactor. In the small grid, more than the usual value (3% of total capacity) of spinning reserve is required
- The influence also depends on the grid configuration, as response time of each power unit is different.

	Response speed
Hydro	fast 10~50%/min
Oil	5%/min
Coal	slow 1%/min
Nuclear	not allowed now in Japan
Solar/Wind	No response

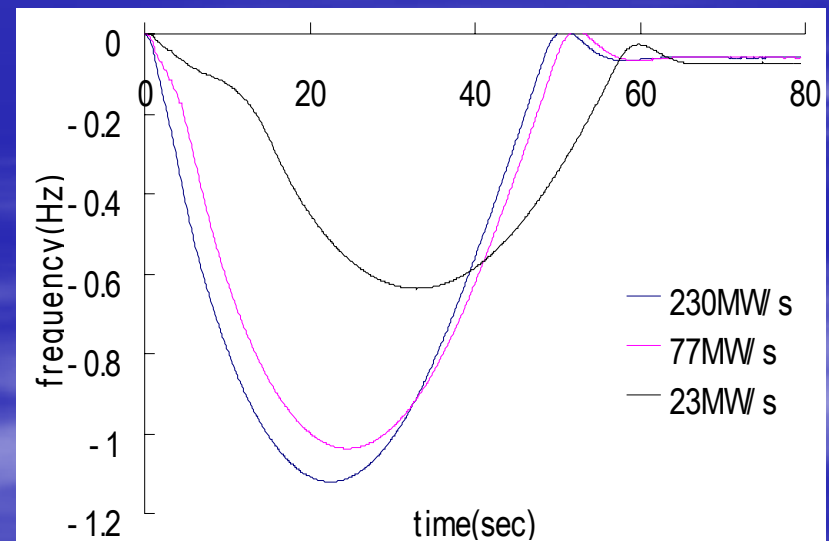
Influence to the power grid

- 8GW Grid with plant capacity ratio
Nuclear:Thermal:Hydro = 28:58:14

- 230MW



- 330MW



Electric Grid in Japan

Comb structure due to geographical reason

Utility Name
Max. demand (~2003)
Largest Unit (Nuclear)

✕ DC connection

West Japan Grid
60Hz, ~100GW

Kyushu
17,061MW
1,180MW

Chugoku
12,002MW
820MW

Shikoku
5,925MW
890MW

Kansai
33,060MW
1,180MW

Hokuriku
5,508MW
540MW

Chubu
27,500MW
1,380MW

Hokkaido
5,345MW
579MW

Tohoku
14,489MW
825MW

Tokyo
64,300MW
1,356MW

East Japan Grid
50Hz, ~80GW

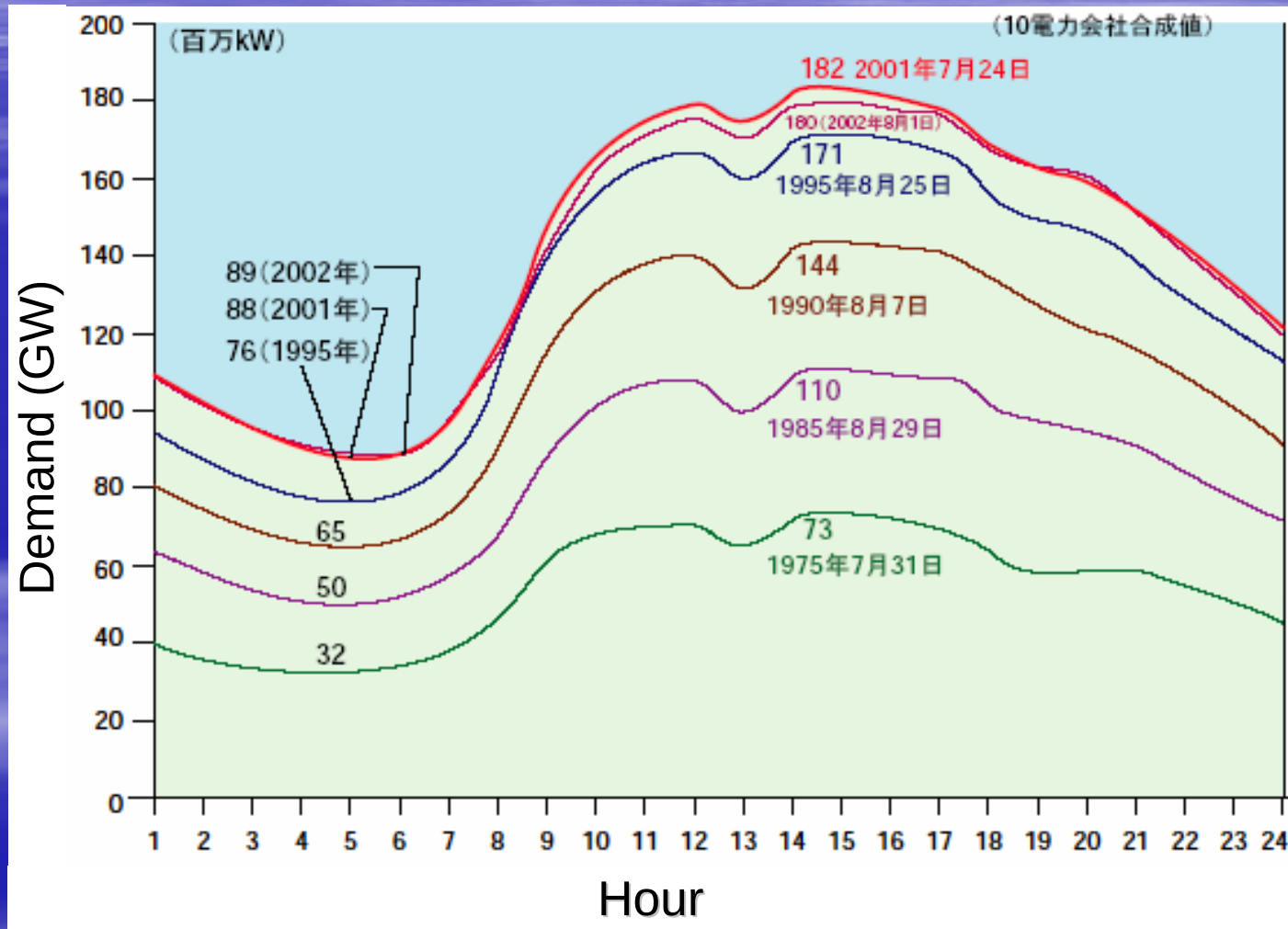
600MW

600MW

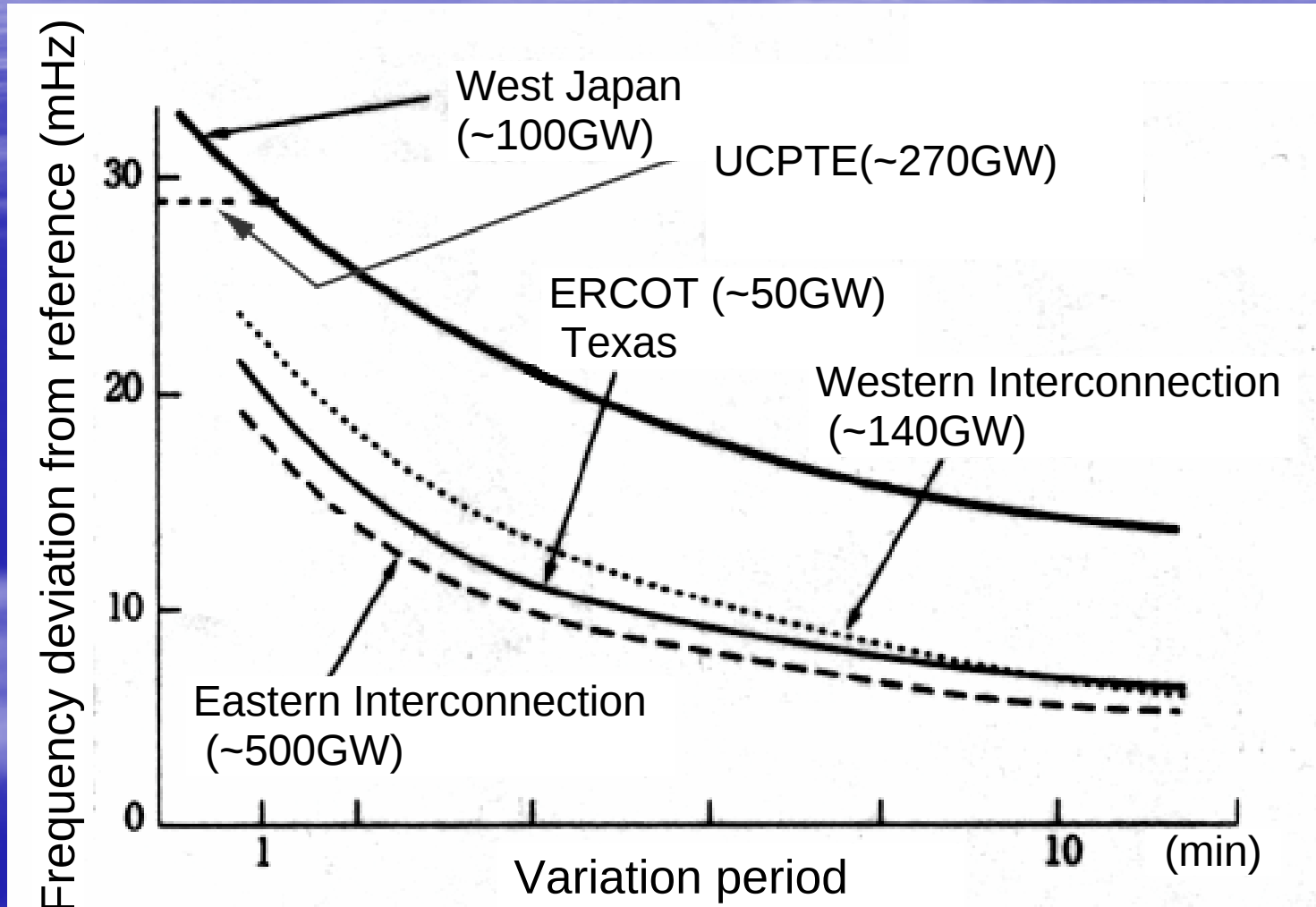
300MW

Demand change within the day in the summer

- Grid capacity is almost a half of maximum at early morning



Frequency deviation and grid capacity



Conclusion

- The rate of change of active power requirement for additional heating is faster than the response time of electric grid.
- For a Fusion reactor with 1GWe output, the grid capacity of 10~20GWe is required for safely supplying startup power.
- By develop the slower increase of additional heating power (NBI, ECH, ICRF ...) and L-H transition scenario, which matches the response time of electric grids, fusion reactor can be installed into more smaller grids.
- Developing above scenario also help the fusion reactor can be used as middle load plants in the countries where there are many nuclear fission reactors for base-load plants.
- In current calculation, reactive power is assumed to be supplied locally. We will estimate the influence of it.