8. OPERATING, REACTIVE AND BLACK START RESERVES

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Operating reserves

Purpose of operating reserves

- Ensure power supply during disturbances and unnormal conditions

Classification of operating reserves

- Spinning reserves
  - Synchronised reserves
- Non-spinning reserve
  - Unsynchronised reserves
- Supplemental reserves
  - 30 – 60 minute reserves
- Slow reserves
  - 1 – 12 hours reserves

Spinning reserves

- Operating power plants which can change their output by ΔP in Δt
  - Called as ten minute spinning reserves in USA (Δt =10 min)

Spinning reserve Generation

- By internal combustion engine or gas turbine plants
- Can change their output from 40 % to 100 % in ten minutes

Spinning reserves Continued

- Spinning reserves = rotating reserves act immetiately by the rotating mass of the generator
- If the frequency starts dropping, the genertor intertia tends to resist the slowing down motion

Non-spinning reserves

Power plants, which can start up in Δt minutes to full output P

- Called as ten minute non-spinning reserves in USA (Δt= 10 min)
- Called as fast reserves in UK (Δt = 5 min) and Nordel (Δt = 15 min)

Non-spinning reserves, full power in

1 - 5 minutes	Diesel engines and hydro turbines
5 - 10 minutes	Gas engines and aero-derivative GT
10 - 15 minutes	Industrial gas turbines
60 - 120 minutes	Gast turbine combined cycles
2 - 12 hours	Steam turbine plants

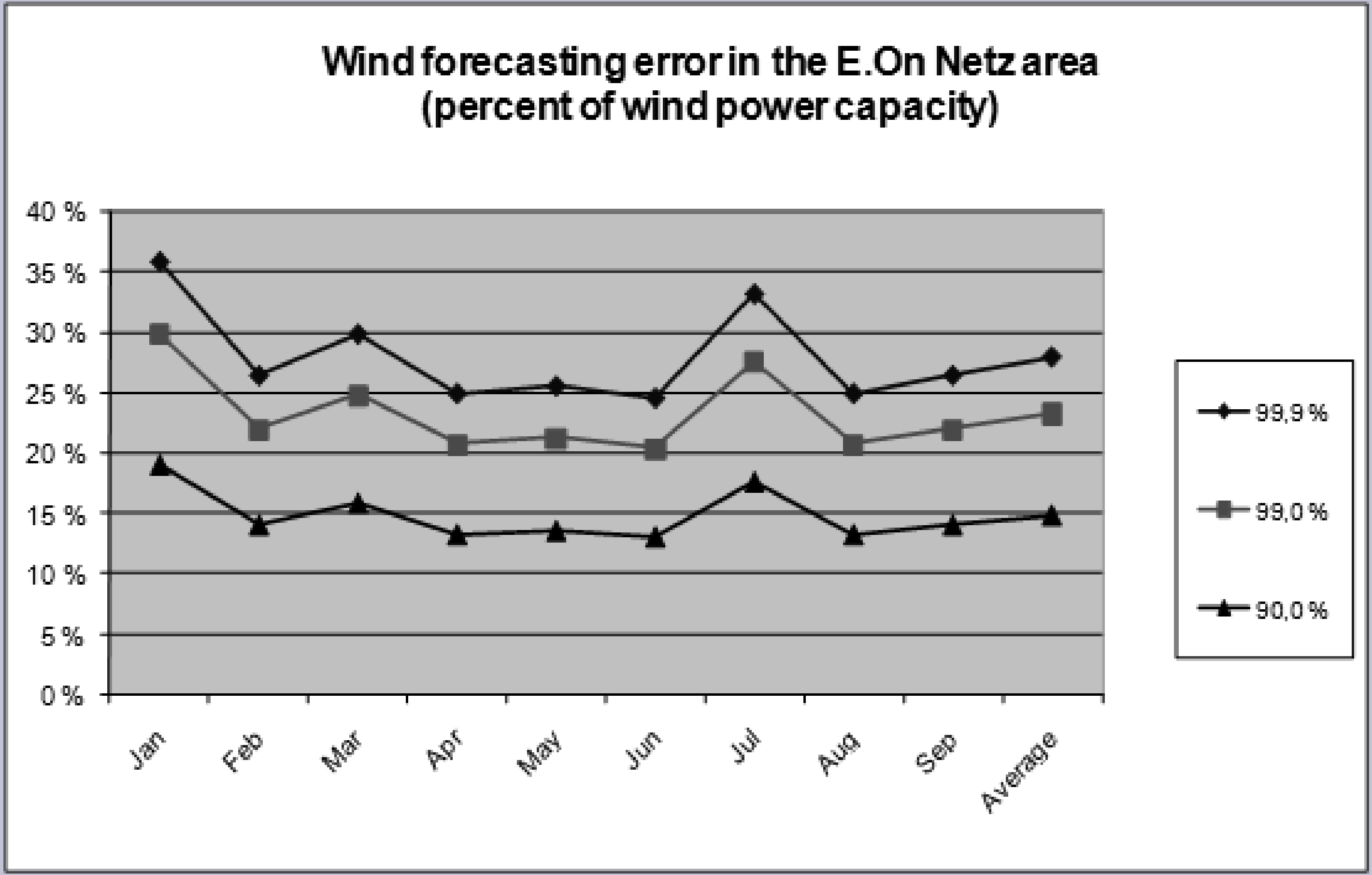
Dimensioning of spining and non-spinning reserves

Spin reserve + nonspin reserve > Lc

Spinning and non-spinning reserves shall compensate the largest contingency (Lc) in a system

Or 5 -7 % of load responsibility (California)

Wind power forecasting errors and need for reserves

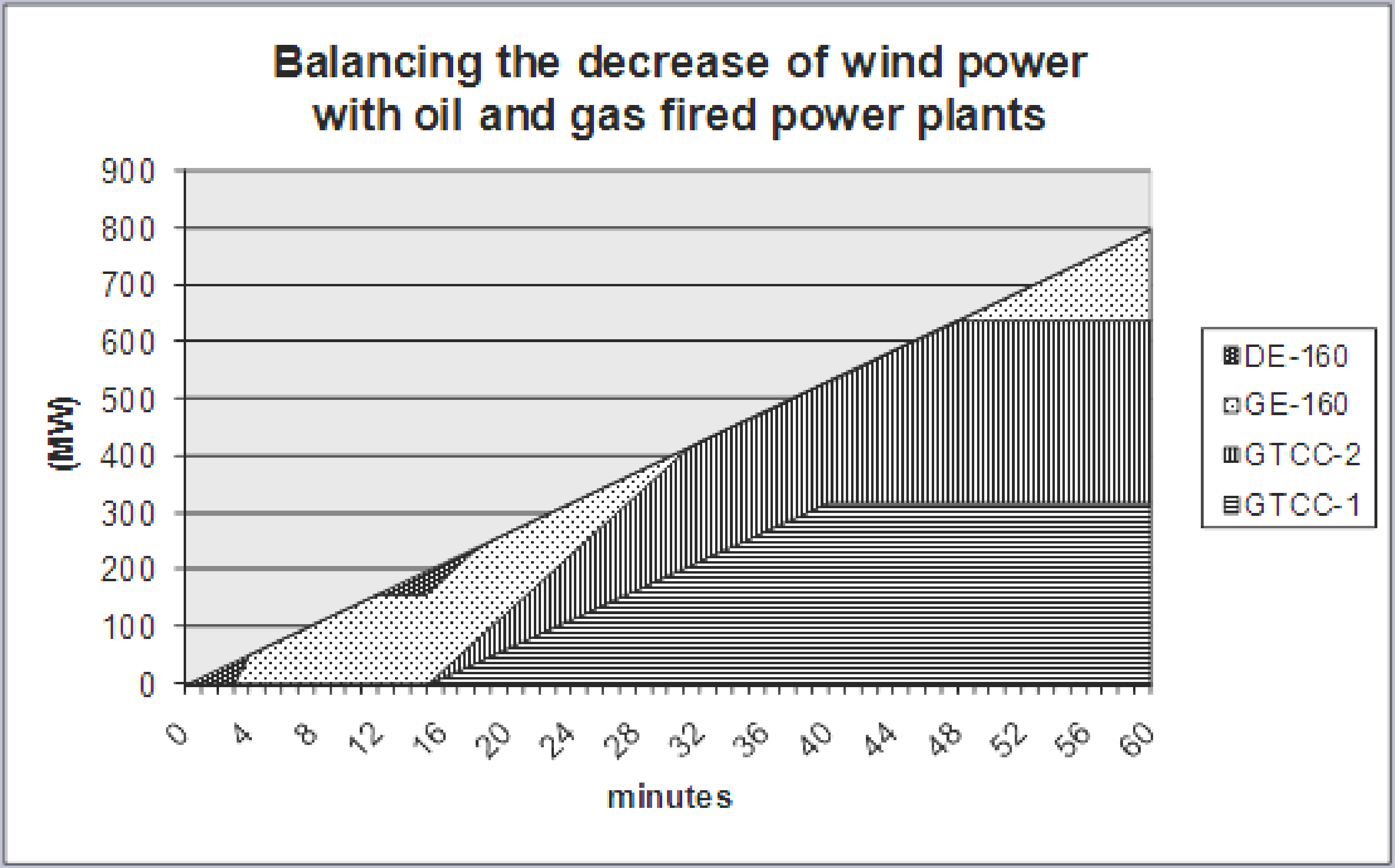


Maximim error is 28% from the installed wind capacity

Power plant alternatives for non-spinning reserves

Power plant		Diesel	Gas engine	Aero GT	Indust. GT	GTCC
Sychronisation	min	1	2	6	10	15
Full power	min	3	7	10	20	40
Output	MW	160	160	160	160	320
Ramp	MW/min	80	32	40	16	12,8
Energy in 15 min	MWh	36	29	20	4	0
Energy in 30 min	MWh	76	69	60	41	13

How to compensate 800 MW drop of wind power



Supplemental reserves

- Shall compensate loss of second largest contingency

- Dimensioning criteria
  - P > ½ x second contingency

Supplemental reserves

- Thirty minute reserves
  - New England, New York
  - ½ x second contingency loss
- Sixty minute reserves
  - California
  - ½ x second contigency loss

Slow reserves
Purpose

- Shall generate power during unnormal peak load conditions

Slow reserves, continued

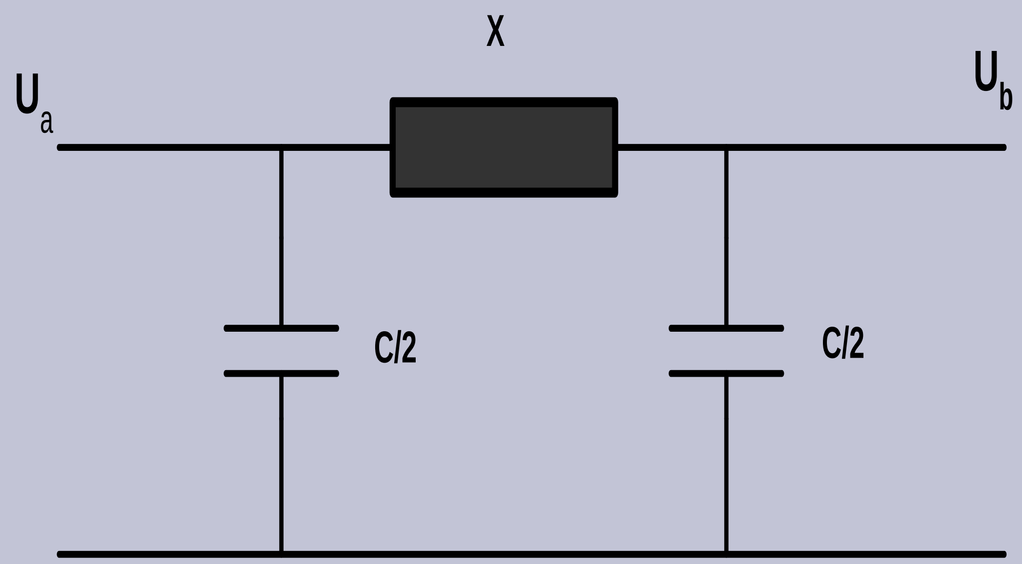
- Used in Nordel countries, which have no capacity oblications (Δt = 1 - 12 h) and very high winter peak load
  - 2000 MW (7 % of peak load) in Sweden
  - 600 MW (4 % of peak load) in Finland

Reactive reserves

Purpose of reactive reserves

- Compensate reactive losses in the transmission network
- Generate reactive power to electrical motors and other consumers

Single line diagram of a power line



Ua, Ub = voltages in the power line
X = reactive load of power line
C = capacitance

Near maximum load

$$P = \frac{U_a U_b}{X} \sin\delta$$

$$Q = P \tan\varphi = \frac{U_a U_b}{X} \cos\delta - \frac{U_{b2}}{X}$$

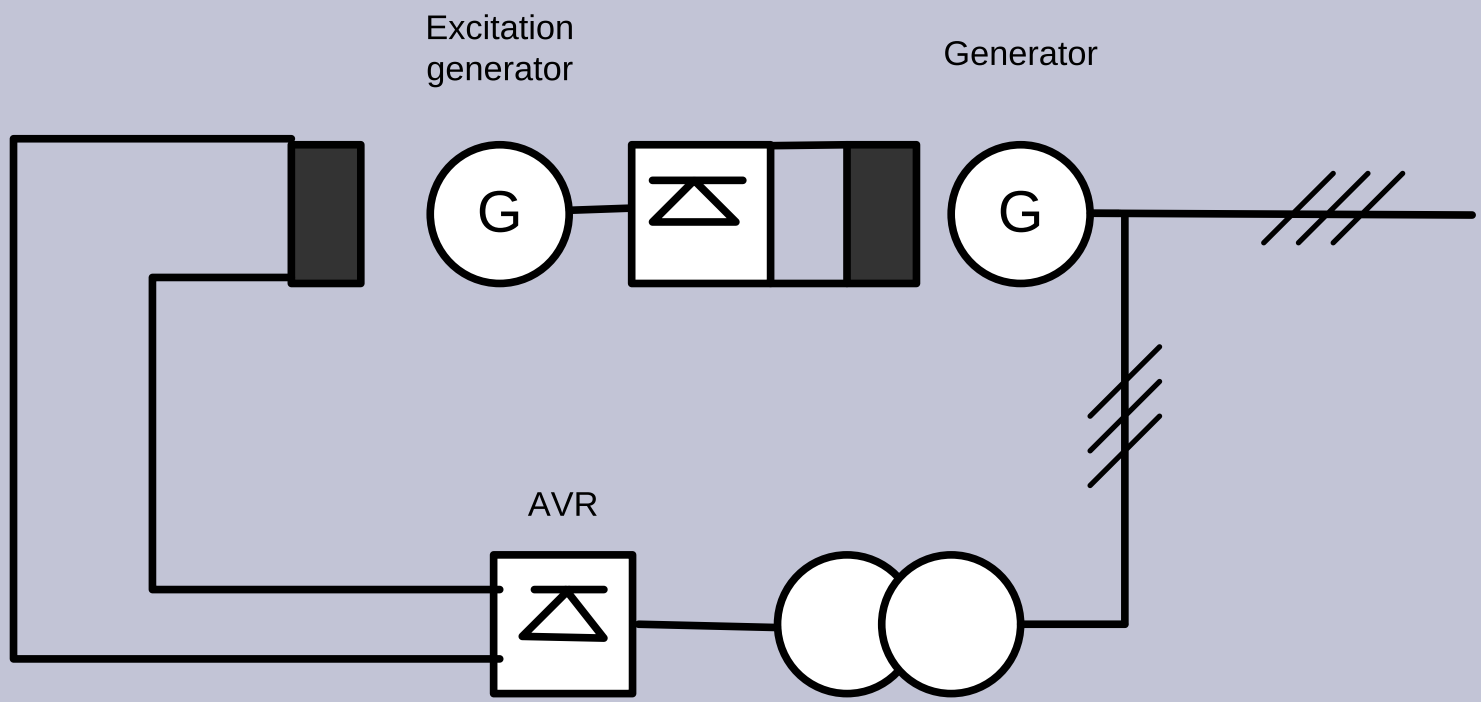
Maximum capacity of power line (=stability limit)

If $\delta = 90^o$, $\sin \delta = 1$

Then P = Pmax

Stability limit is reached

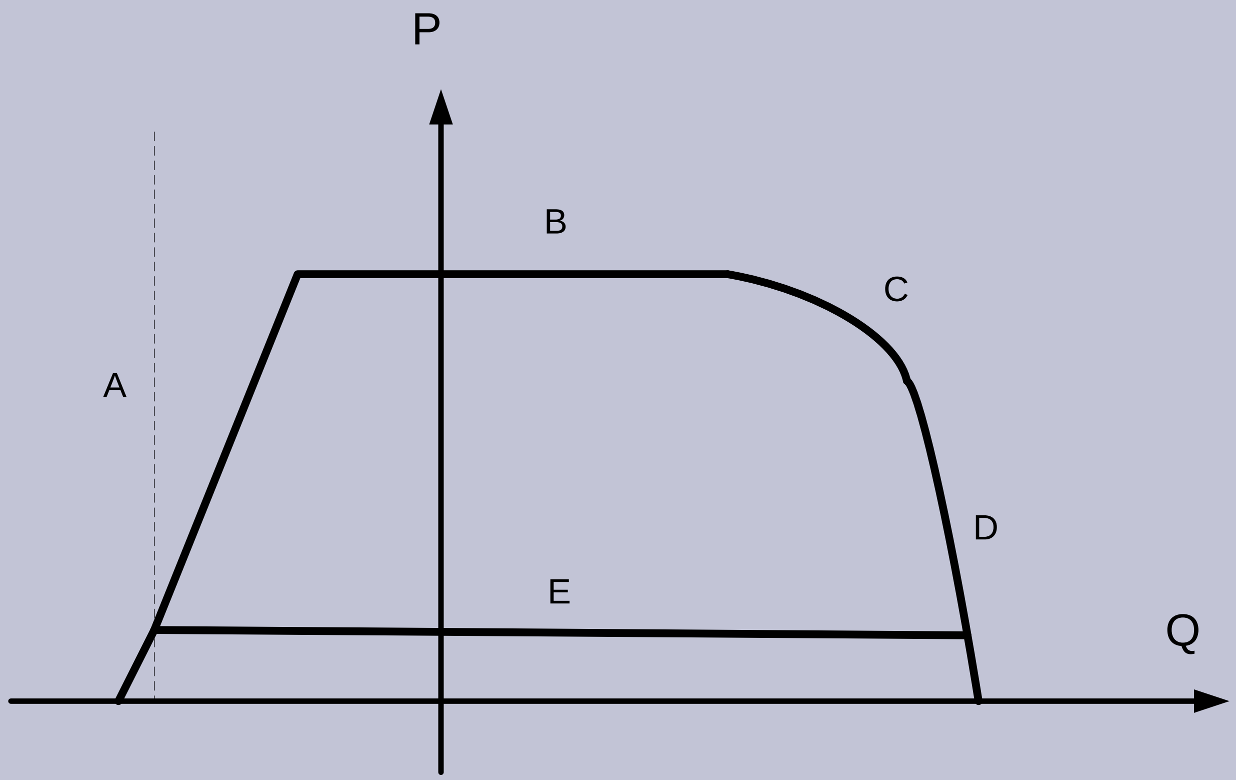
Reactive power generation



Reactive power generation, continued

- Generator voltage control system (AVR) increases excitation current in rotor
- Generator voltage will rise and reactive power will be generated

Reactive power generation



Reactive reserve generation

A Generator stability line

B Maximum mechanical output of engine

C Maximum current of generator

E Mimimum continuous mechanical output of engine

Apparent power (S)

$$S = \sqrt{(P^2 + Q^2)}$$

where

P = resistive power (MW)

Q = reactive power (MVar)

Determines the capacity of a generator in MVA

Recommendations

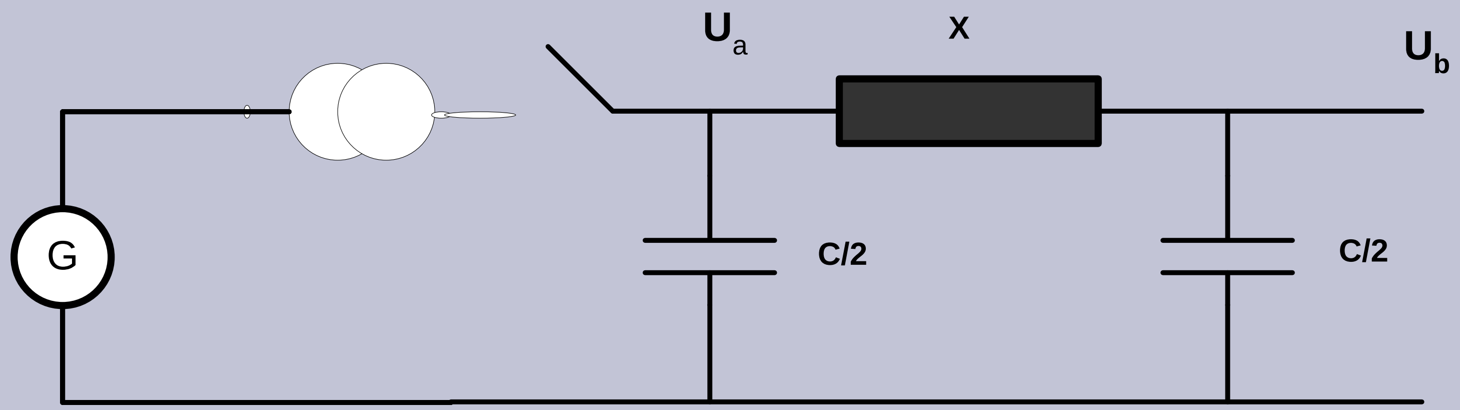
- Build power plants near consumpion centers to avoid consumption of reactive reserves
- Local power plants can generate the reactive power consumed by the appliances

Black start reserves

Black start reserves Purpose

- To energize power system after blackout
- To generate power for local needs when the power system is out of operation

Black start reserves
Energize power lines



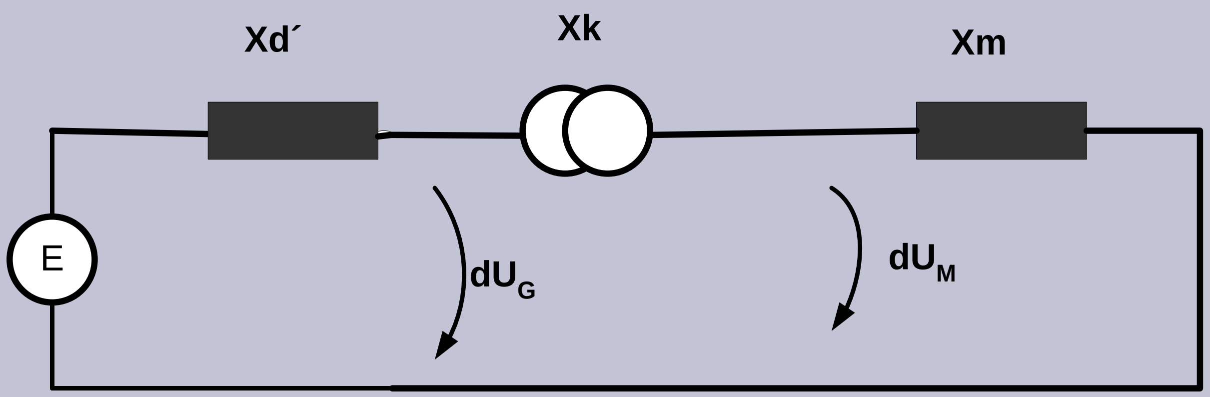
Black start generator (G) will energize power line after the switch has been closed

Capacitors (C/2) will consume the most of the current

Restoration approach

- Bottom up
  - Start local generators first and energize local power lines
- Top down
  - Use power lines to energize local generators

Starting of emergency motors



Induction motors consume reactive power (Xm) at the starting phase.
Starting current is typically 5 – 6 x I_n

Black start generators

- Small diesel engines
  - Started by batteries
- Large diesel or gas engines
  - Started using pressurised air
- Gas turbines
  - Started by diesel engines

For details see reference text book
”Planning of Optimal Power Systems”

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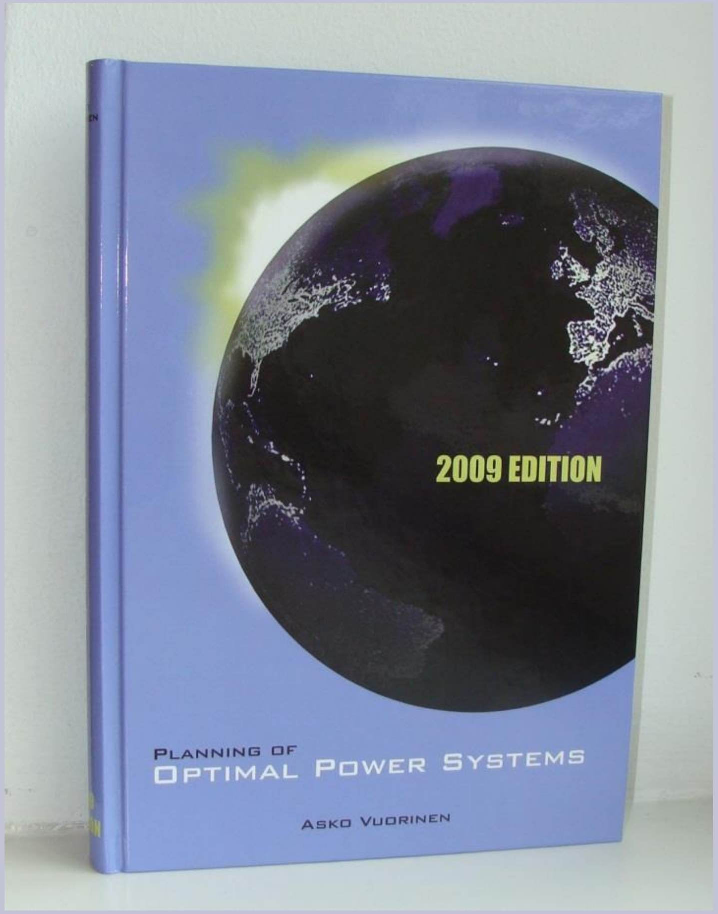
Publisher:
Ekoenergo Oy

Printed:
2008 in Finland

Orders click:



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