

# Power Plants

## A1M15ENY

### Lecture No. 5

*Jan Špetlík*

[spetlij@fel.cvut.cz](mailto:spetlij@fel.cvut.cz) - subject in e-mail „ENY“

Department of Power Engineering, Faculty of Electrical Engineering CTU, Technická 2,  
166 27 Praha 6

Peak short circuit current is:

$$i_{p3} = \kappa \cdot \sqrt{2} \cdot I''_{k3} = 1,7 \cdot \sqrt{2} \cdot 25 = 59,9 \text{ kA}$$

Force between main conductors for both cases:

$$F_{m3} = \frac{\mu_0}{2\pi} \cdot \frac{\sqrt{3}}{2} \cdot i_{p3}^2 \cdot \frac{l}{d_m} = \frac{4\pi \cdot 10^{-7}}{2\pi} \cdot \frac{\sqrt{3}}{2} \cdot 59,9^2 \cdot 10^6 \cdot \frac{1}{0,5} = 1,242 \text{ kN}$$

Factors:

$$\beta = 0,73 \quad V_\sigma \cdot V_r = 1 \quad q \cdot \sigma_{0,2} = 1,5 \cdot 120 = 180 \text{ MPa}$$

Force effects on conductors:

1) Vertical arrangement

$$Z = \frac{a \cdot b^2}{6} = \frac{0,010 \cdot 0,063^2}{6} = 3,97 \cdot 10^{-5} \text{ m}^3$$

$$\sigma_m = V_\sigma \cdot V_r \cdot \beta \cdot \frac{F_{m3} \cdot l}{8 \cdot Z} = 1,0,73 \cdot \frac{1,242 \cdot 10^3 \cdot 1}{8 \cdot 3,97 \cdot 10^{-5}} = 2,85 \text{ MPa}$$

Conductors are OK, because  $\sigma_{tot} < q \cdot \sigma_{0,2}$   $2,85 < 180$

## 2) Horizontal arrangement

$$Z = \frac{0,063 \cdot 0,010^2}{6} = 1,05 \cdot 10^{-6} \text{ m}^3$$

$$\sigma_m = V_\sigma \cdot V_r \cdot \beta \cdot \frac{F_{m3} \cdot l}{8 \cdot Z} = 1.0,73 \cdot \frac{1,242 \cdot 10^3 \cdot 1}{8 \cdot 1,05 \cdot 10^{-6}} = 107,9 \text{ MPa}$$

Conductors are OK, because  $\sigma_{tot} < q \cdot \sigma_{0,2}$   $107,9 < 180$

### Effects on supports:

#### 1) Vertical arrangement

$$\frac{0,8 \cdot \sigma_{0,2}}{\sigma_{tot}} = \frac{0,8 \cdot 120}{2,85} > 2,7 \Rightarrow V_F \cdot V_r = 2,7 \quad \alpha_{krit} = 1,1$$

$$F_D = V_F \cdot V_r \cdot \alpha \cdot F_{m3} = 2,7 \cdot 1,1 \cdot 1,242 = 7,18 \text{ kN}$$

$$T = 0,025 \text{ m}$$

$$\frac{7,18}{0,8} \cdot \frac{0,13 + 0,025}{0,13} = 10,7 \text{ kN} < P$$

Corresponding support is 16 kN

2) Horizontal arrangement

$$\frac{0,8 \cdot \sigma_{0,2}}{\sigma_{tot}} = \frac{0,8 \cdot 120}{107,9} = 0,889 < 1 \Rightarrow V_F \cdot V_r = 1 \quad \alpha_{krit} = 1,1$$

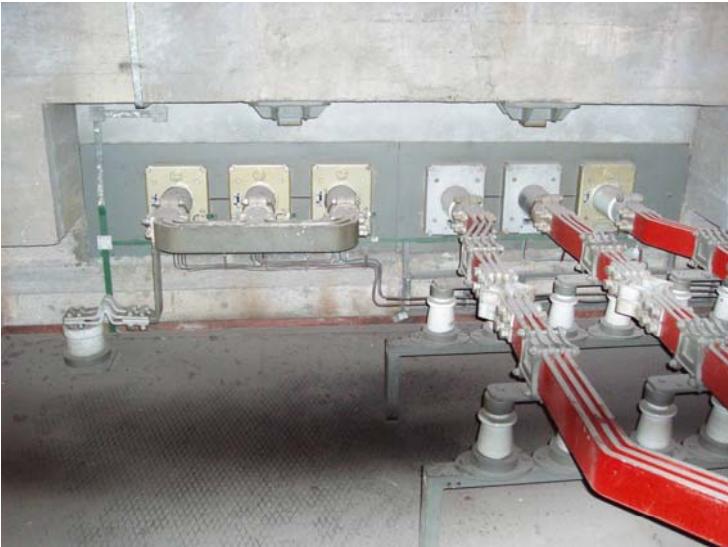
$$F_D = V_F \cdot V_r \cdot \alpha \cdot F_{m3} = 1,1 \cdot 1,1 \cdot 1,242 = 1,37 \text{ kN}$$

$$T = 0,052 \text{ m}$$

$$\frac{1,37}{0,8} \cdot \frac{0,13 + 0,052}{0,13} = 2,4 \text{ kN} < P$$

Corresponding support is 5 kN

Rem.



For power outlet from medium sized generator a multiple rigid conductor arrangement can be used (in this case 3 x Al 63x10 per phase)



multiple bundled ACSR conductors



High current resin insulated conductor system DURESCA

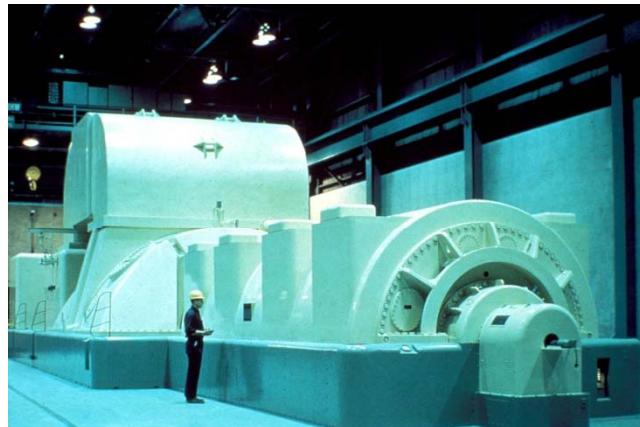


Aluminum enclosed bus ducts are used for the most heavy current demanding installations

# Generators

In power generation following types are used:

- Round synchronous machines (two or four poles) for steam turbines up to 1000 MW
- Salient pole synchronous machines (multipole) for hydroelectric power plants, power output hundreds of MW
- Cage induction machines
- Doubly Fed Induction Generators (DFIG), power output tens of MW for wind farms



Turbogenerator  
s



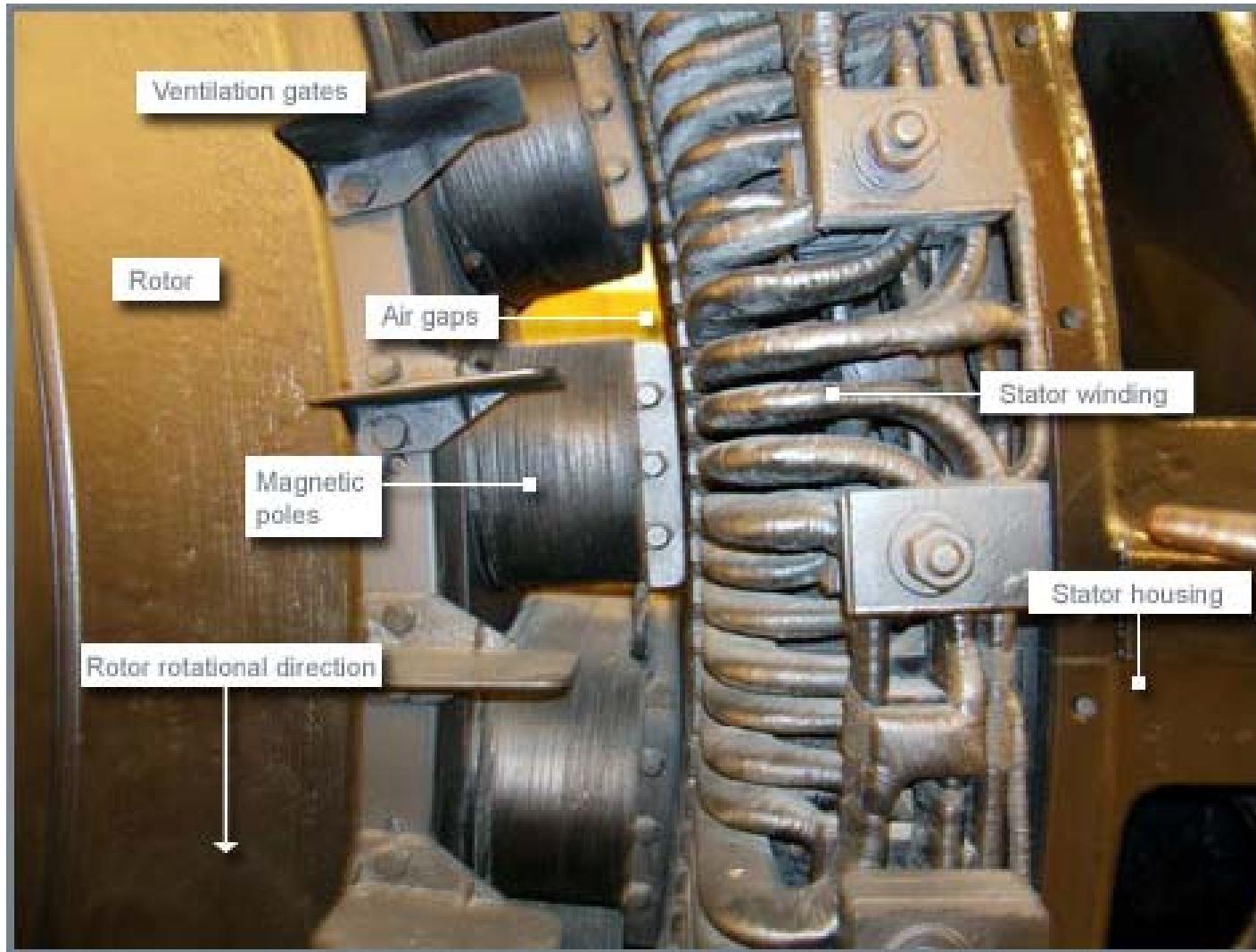
Hydrogenerators



DFIGs

# Generators

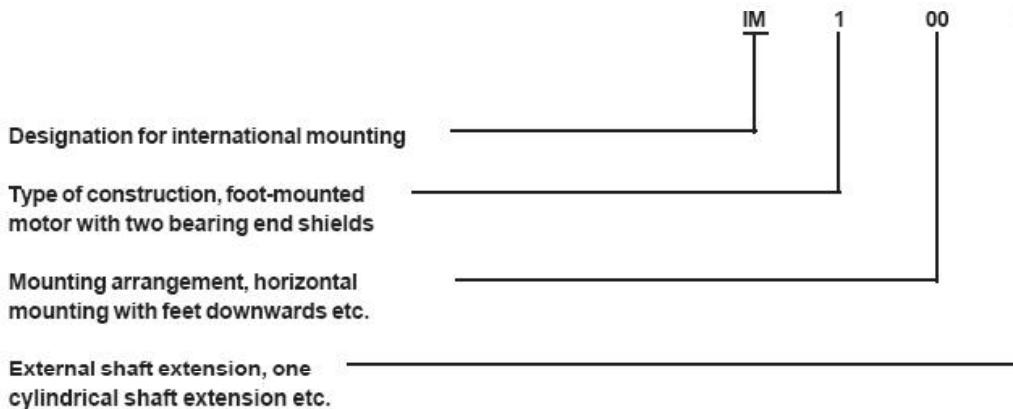
Construction:



# Generators

## IM code:

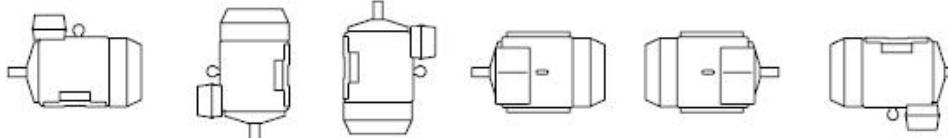
Mounting arrangement  
acc. to EN 60034-7  
(generators + motors)



## Examples of common mounting arrangements

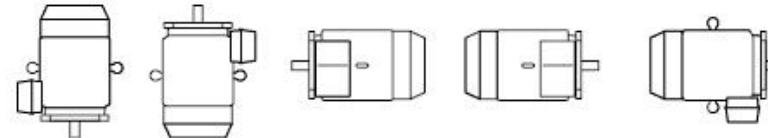
Code I	IM B3	IM V5	IM V6	IM B6	IM B7	IM B8
Code II	IM 1001	IM 1011	IM 1031	IM 1051	IM 1061	IM 1071

Foot-motor.



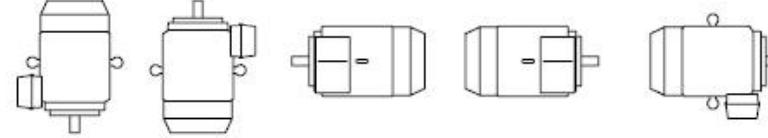
Code I	IM B5
Code II	IM 3001

Flange-mounted motor, large flange with clearance fixing holes.



Code I	IM B14
Code II	IM 3601

Flange-mounted motor, small flange with tapped fixing holes.



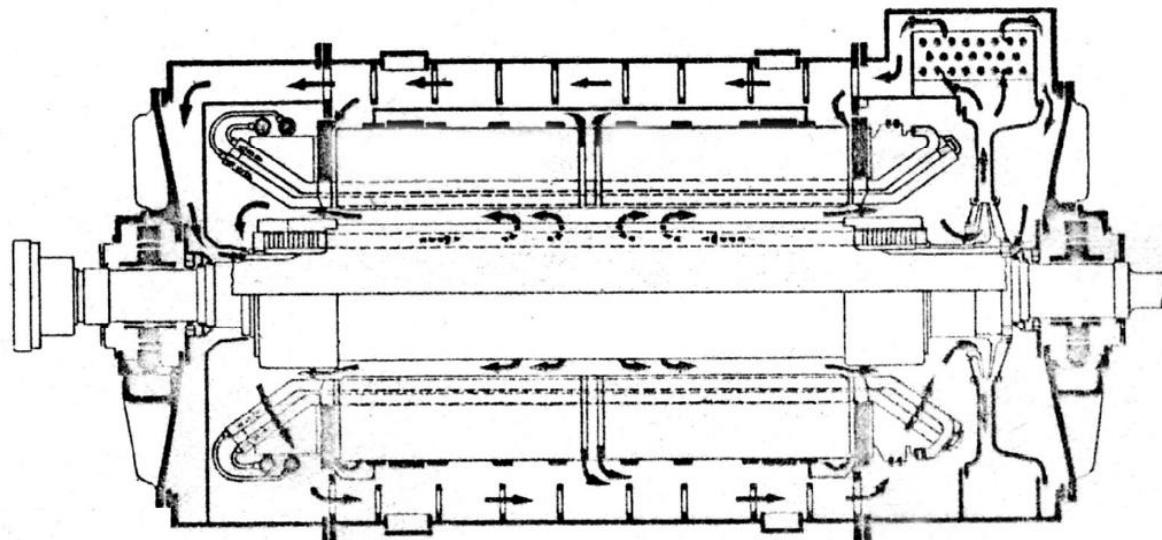
*\*) Not stated in IEC 60034-7*

# Generators

IC code: Cooling arrangement

Cooling arrangement of generators:

- Natural cooling - convection
- Forced internal cooling (a speed dependent fan located on shaft)
- Natural + forced internal cooling (two circuits convection + fan)
- Forced external cooling (speed independent fan/pump)



# Generators

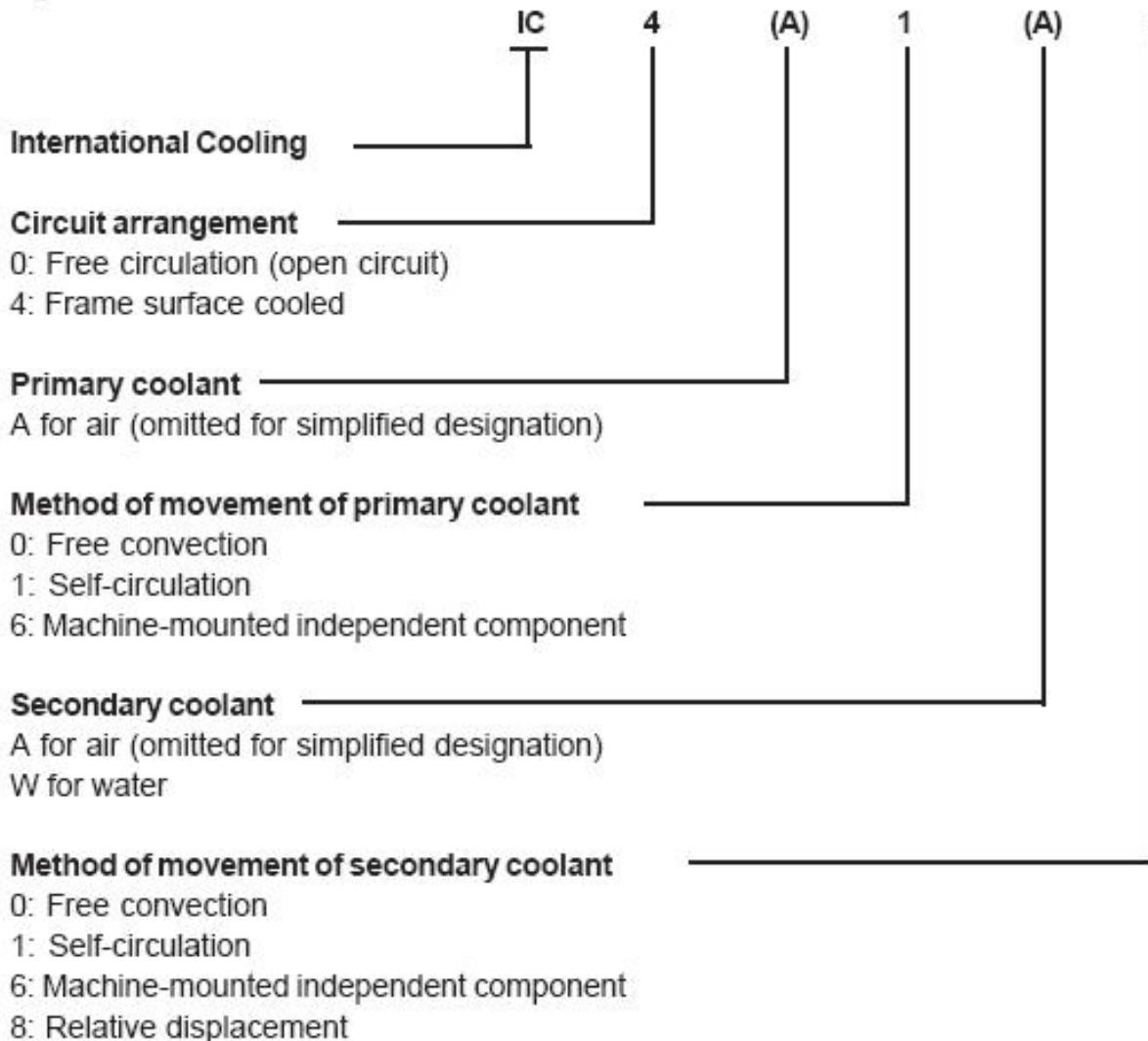
IC code: Cooling arrangement

Statorová drážka				
Chlazení	Vzduch	$H_2$	$H_2O$	$H_2O$
Rotorová drážka				
Chlazení	Vzduch	$H_2$	$H_2$	$H_2O$
Výkon v MVA	50	250	1000	2000

# Generators

IC code:

Example



# Generators

## Classes of the insulation system:

Expresses thermal withstand of (winding) insulation materials, typically:

Class A, E – cotton, silk, paper

Class B, F – mica, glass fiber, asbestos

Class H – silicone elastomer, porcelain, mica, glass fiber

Insulation Classes and Temperature Rating				
Insulation Class	A	B	F	H
Ambient	40° C	40° C	40° C	40° C
Rise by Resistance	60° C	80° C	105° C	125° C
Hot Spot Allowance	5° C	10° C	10° C	15° C
Max. Hottest Spot Temp.	105° C	130° C	155° C	180° C

Rem.:

Class B / F – most common for 60 Hz / 50 Hz motors

Materials for special insulation requirements (aerospace, nuclear, physics):

Ceramics, silicon resins, teflon, chrome-iron/nickel clad copper (over 200 – 600 °C)

# Main Parameters Selection

## Rated apparent power:

Dependent of turbine power output + rated power factor (~0,85)

Formerly used generator series: 63 MVA / 125 MVA / 235 MVA / 588 MVA / 1176 MVA

## Rated voltage:

Voltage selection with respect to  $I_n$ , insulation parameters, ability to protect the machine + outer network

Typical voltage level  $V_n$ :

$P_n$	$V_n$
do 50 MW	6 - 6,3 kV
50-100 MW	10,5 - 11 kV
100-200MW	13,8 kV
200-500 MW	15 - 15,75 kV
1000 MW Temelín	24 kV

# Basic Formulas for Steady State

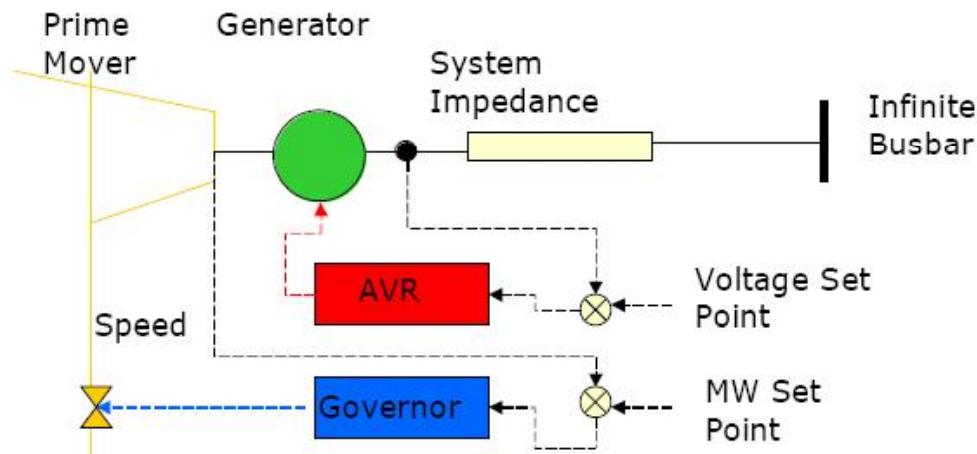
Steady state three phase power:

$$\hat{S} = P + j.Q = 3.\hat{U}_f.\hat{I}^* = 3.U_f.I.\cos\varphi + j.3.U_f.I.\sin\varphi$$

$$P = 3.U_f.I.\cos\varphi = \frac{U.E}{X_d}.\sin\beta + \frac{U^2}{2} \cdot \frac{X_d - X_q}{X_d.X_q}.\sin 2\beta$$

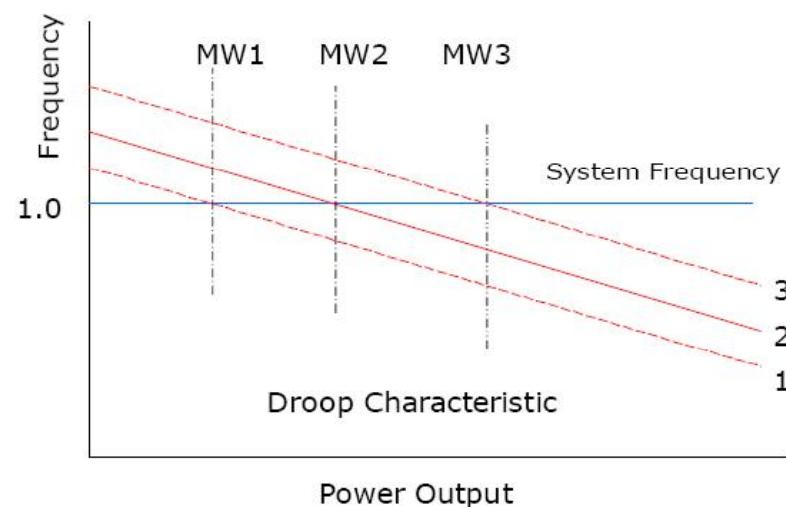
$$Q = 3.U_f.I.\sin\varphi = \frac{U.E}{X_d}.\cos\beta + \frac{U^2}{2} \cdot \frac{X_d - X_q}{X_d.X_q}.\cos 2\beta - \frac{U^2}{2} \cdot \frac{X_d + X_q}{X_d.X_q}$$

# Regulation Fundamentals



Governor: P-f regulation

$$f = f_{sys} + s_P \cdot (P - P_W)$$



AVR: Q-V regulation

$$V = V_{ref} + s_Q \cdot (Q - Q_W)$$

