POWER SYSTEMS I

CONTROL OF ELECTRICAL POWER SYSTEMS

Introduction

- Any power system is planned, designed and built to supply the consumers with electrical energy considering:
  - Economy
  - Quality
  - Supply security (Reliability)
  - Environmental impact

Electrical Power Quality

- Three important factors that decide the electrical quality are:
  - Frequency variations
  - Voltage variations
  - Waveform of voltage and current

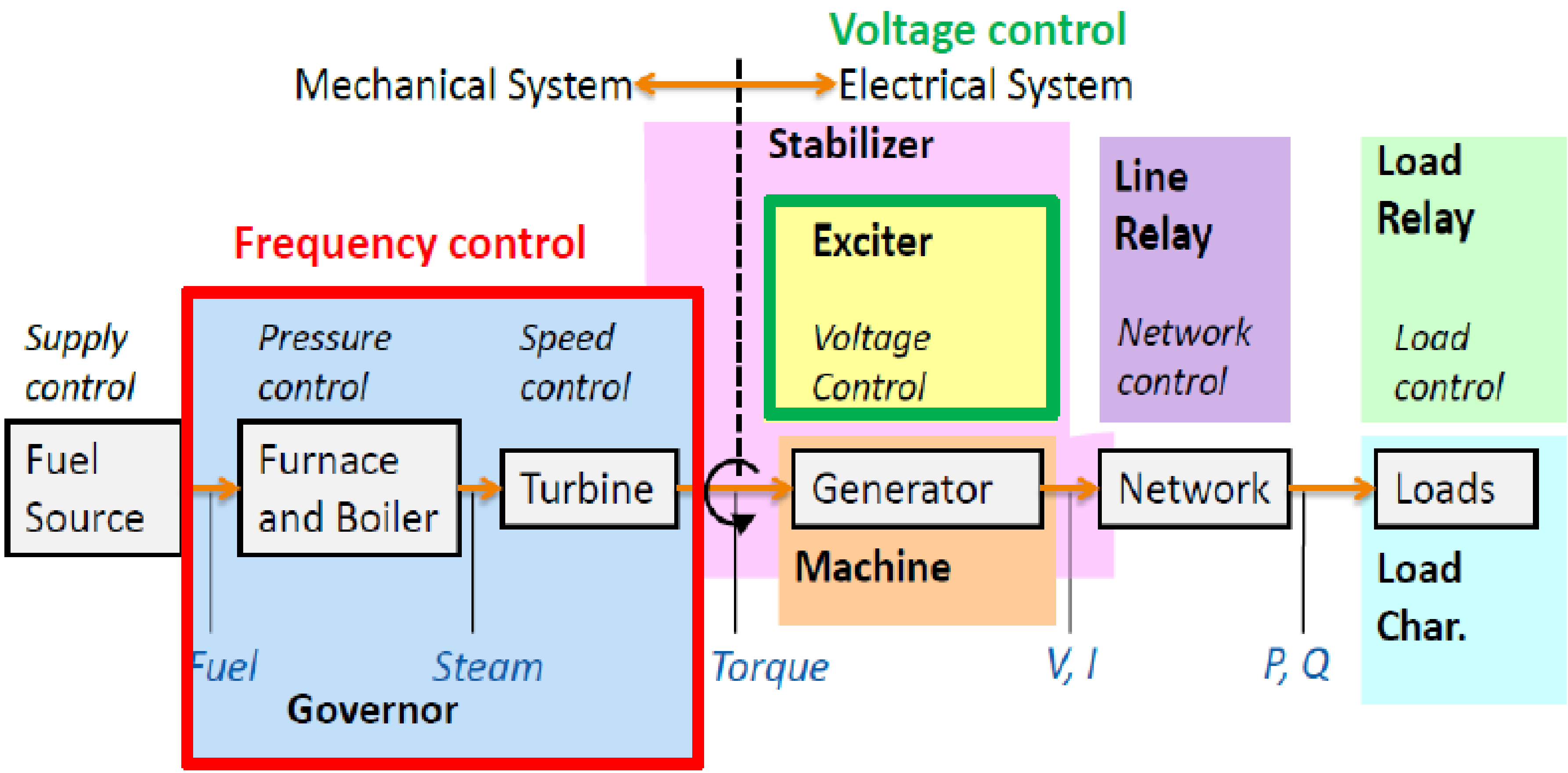
Power Flow Control

- The following means are used to **control** system power flows:
  - ✓ Generation Control;
    - ➢ Prime mover (speed control to maintain the frequency)
    - ➢ Excitation control (field current control to maintain the voltage).
  - ✓ Transmission Control;

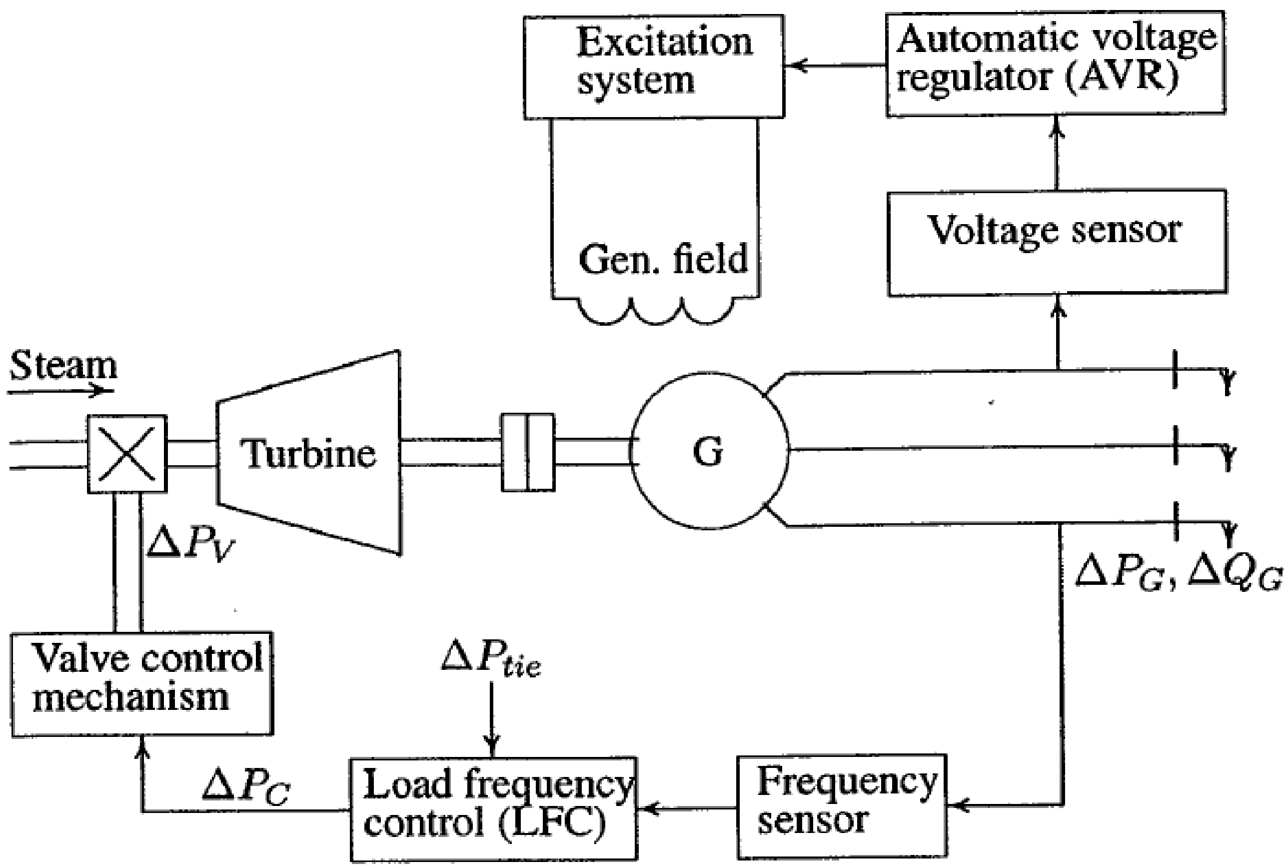
    Switching of shunt capacitor banks, shunt reactors, and static var compensators.
  - ✓ Distribution Control;

    The use of tap-changing and regulating transformers.

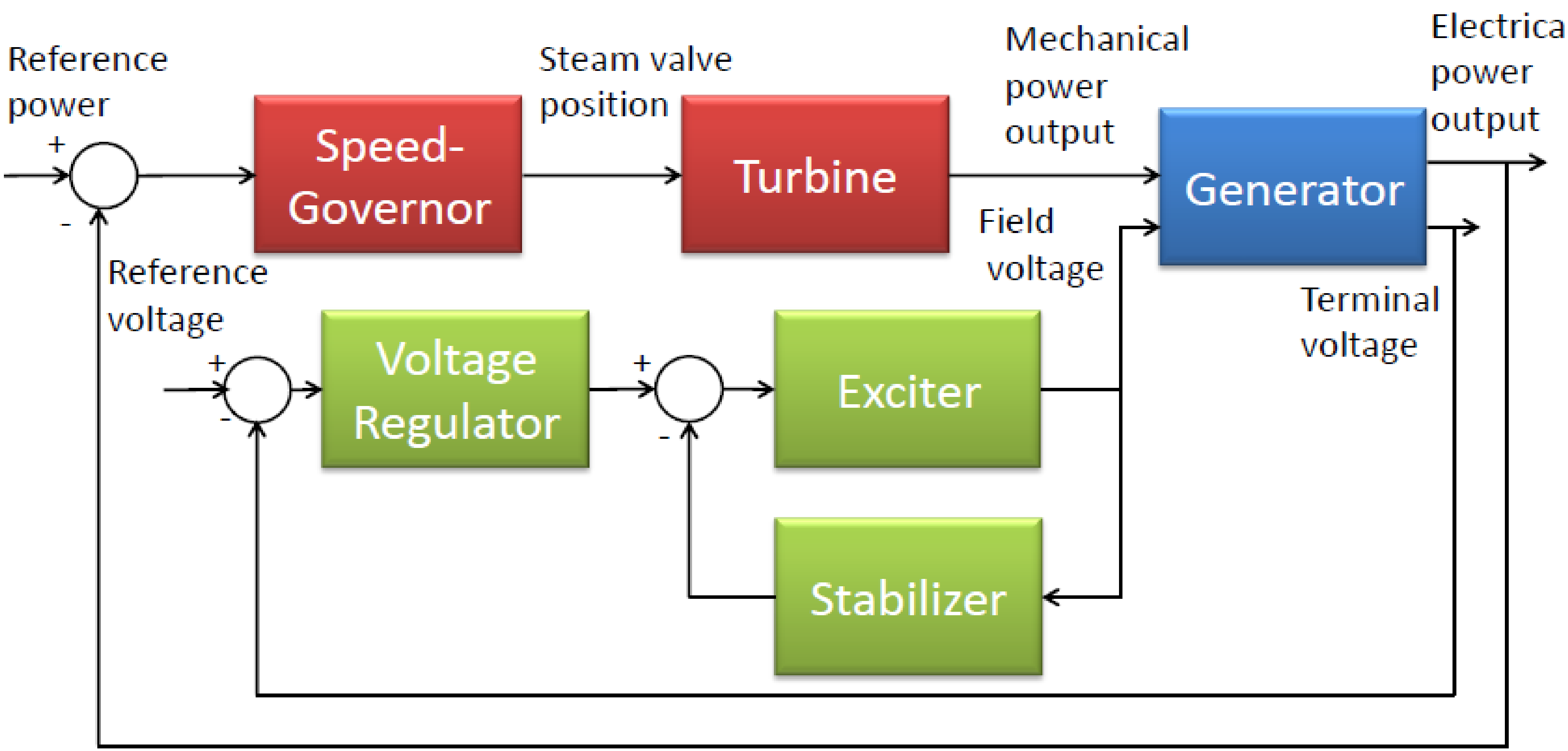
Physical Structures of Typical Power System



Simplified Physical Structures of Typical Power System



Basic Generator Control Loops



3.2 SYNCHRONOUS GENERATORS

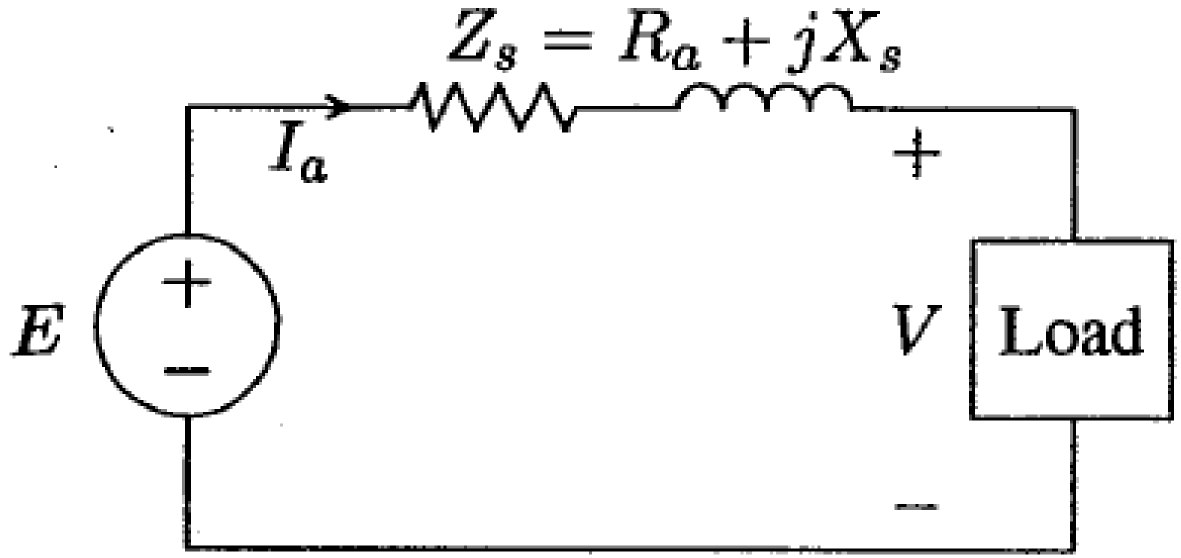


FIGURE 3.3
Synchronous machine equivalent circuit.

3.2 SYNCHRONOUS GENERATORS

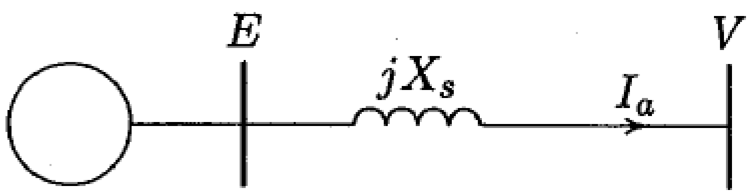


FIGURE 3.4
Synchronous machine connected to an infinite bus.

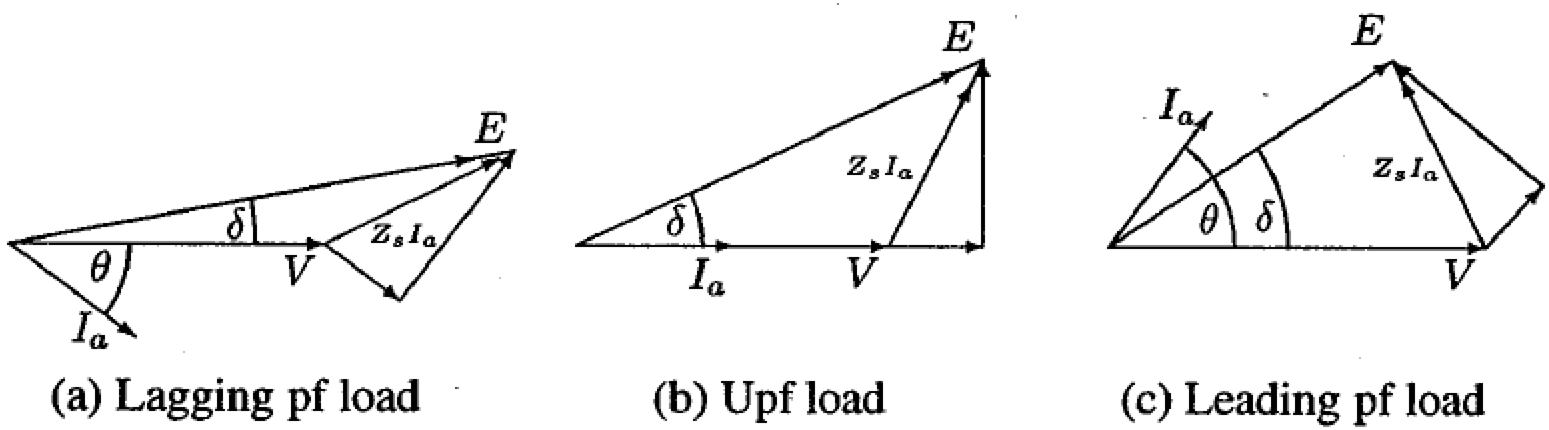


FIGURE 3.5
Synchronous generator phasor diagram.

3.3.2 POWER ANGLE CHARACTERISTICS

Consider the per-phase equivalent circuit shown in Figure 3.4. The three-phase complex power at the generator terminal is

$$S_{3\phi} = 3VI_a^* \tag{3.16}$$

Expressing the phasor voltages in polar form, the armature current is

$$I_a = \frac{|E|\angle\delta \ - |V|\angle 0}{|Z_s|\angle\gamma} \tag{3.17}$$

Substituting for I_a^* in (3.16) results in

$$S_{3\phi} = 3\frac{|E||V|}{|Z_s|}\angle\gamma - \delta \ - 3\frac{|V|^2}{|Z_s|}\angle\gamma \tag{3.18}$$

3.3.2 POWER ANGLE CHARACTERISTICS

Thus, the real power $P_{3\phi}$ and reactive power $Q_{3\phi}$ are

$$P_{3\phi} = 3\frac{|E||V|}{|Z_s|}\cos(\gamma - \delta) - 3\frac{|V|^2}{|Z_s|}\cos\gamma \tag{3.19}$$

$$Q_{3\phi} = 3\frac{|E||V|}{|Z_s|}\sin(\gamma - \delta) - 3\frac{|V|^2}{|Z_s|}\sin\gamma \tag{3.20}$$

If R_a is neglected, then $Z_s = jX_s$ and $\gamma = 90°$. Equations (3.19) and (3.20) reduce to

$$P_{3\phi} = 3\frac{|E||V|}{X_s}\sin\delta \tag{3.21}$$

$$Q_{3\phi} = 3\frac{|V|}{X_s}(|E|\cos\delta - |V|) \tag{3.22}$$

Active Power Control

$$P_{3\phi} = 3\frac{|E||V|}{X_s}\sin\delta \qquad (3.21)$$

Equation (3.21) shows that if $|E|$ and $|V|$ are held fixed and the power angle δ is changed by varying the mechanical driving torque, the power transfer varies sinusoidally with the angle δ. From (3.21), the theoretical maximum power occurs when $\delta = 90°$

$$P_{max(3\phi)} = 3\frac{|E||V|}{X_s} \qquad (3.23)$$

Active Power Control

The behavior of the synchronous machine can be described as follows. If we start with $\delta = 0°$ and increase the driving torque, the machine accelerates, and the rotor mmf F_r advances with respect to the resultant mmf F_{sr}. This results in an increase in δ, causing the machine to deliver electric power. At some value of δ the machine reaches equilibrium where the electric power output balances the increased mechanical power owing to the increased driving torque. It is clear that if an attempt were made to advance δ further than 90° by increasing the driving torque, the electric power output would decrease from the P_{max} point. Therefore, the excess driving torque continues to accelerate the machine, and the mmfs will no longer be magnetically coupled. The machine loses synchronism and automatic equipment disconnects it from the system. The value P_{max} is called the *steady-state stability limit* or *static stability limit*. In general, stability considerations dictate that a synchronous machine achieve steady-state operation for a power angle at considerably less than 90°. The control of real power flow is maintained by the generator governor through the frequency-power control channel.

Reactive Power Control

$$Q_{3\phi} = 3\frac{|V|}{X_s}(|E|\cos\delta - |V|) \quad (3.22)$$

Equation (3.22) shows that for small δ, $\cos\delta$ is nearly unity and the reactive power can be approximated to

$$Q_{3\phi} \simeq 3\frac{|V|}{X_s}(|E| - |V|) \quad (3.24)$$

From (3.24) we see that when $|E| > |V|$ the generator delivers reactive power to the bus, and the generator is said to be overexcited. If $|E| < |V|$, the reactive power delivered to the bus is negative; that is, the bus is supplying positive reactive power to the generator. Generators are normally operated in the overexcited mode since the generators are the main source of reactive power for inductive load throughout the system. Therefore, we conclude that the flow of reactive power is governed mainly by the difference in the excitation voltage $|E|$ and the bus bar voltage $|V|$. The adjustment in the excitation voltage for the control of reactive power is achieved by the generator excitation system.


Thanks


Any Questions...
Just Ask!