Introduction

Modern power systems are three-phase ac systems operating essentially at constant voltage. The major components are

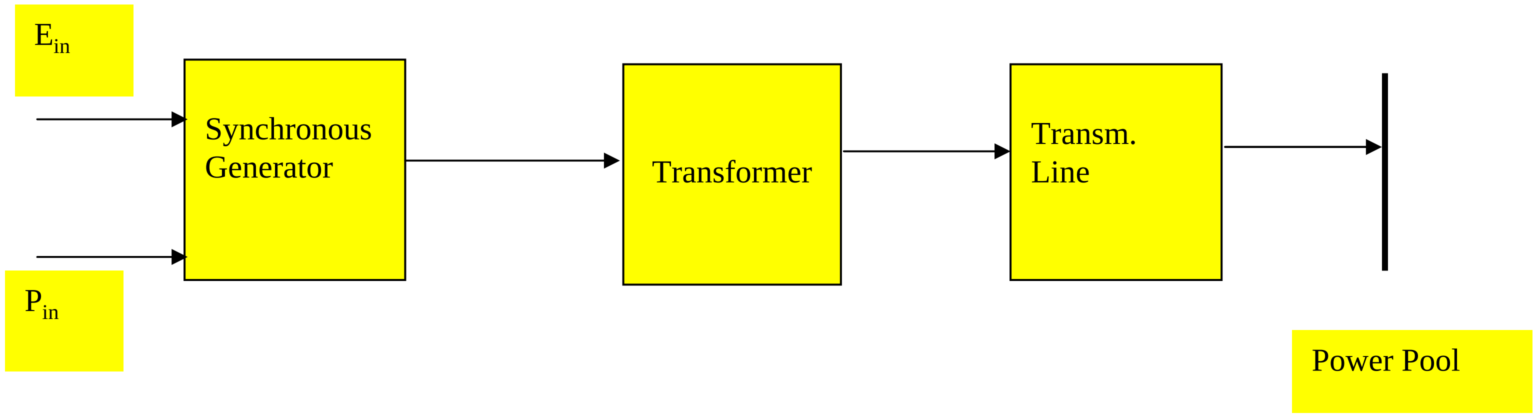
- Generation (synchronous machines)
- Transmission (including transformers)
    1. Transmission system (230KV and above)
    2. Sub-transmission system (69-138 KV)
    3. Distribution system (4-34.5KV)
- Load (industrial, residential)

A properly designed and operated power system should meet the following fundamental requirements:

1. It should be able to meet the continually changing load demand for real and reactive power
2. Should supply energy at minimum cost
3. The quality of power should meet certain standards with regard to the following factors:

   Constancy of frequency
   Constancy of voltage
   Level of reliability

The complexity of connection of the elements increases with the size of the system. The most important component of a power system is the synchronous generator. A simple single machine system connected to a power pool represented through block diagram would be,



Two inputs to the generator

- Electrical - coming from an excitation system
- Mechanical - coming from governor/turbine system

Excitation systems

- DC generator
- Brush less excitation
- Static excitation

Turbines

- Steam → (components) high pressure, low pressure, condenser, reheater, etc.
- Hydraulic → (types) Kaplan, Francis, Pelton wheel, etc.

Governor: The function is to maintain constant speed.

- Mechanical hydraulic governor
- Electrical hydraulic governor

Power System Operating States

- *Normal* state: all variables are within normal range, no equipment overload. The system is secure and can withstand a contingency without violating constraints.

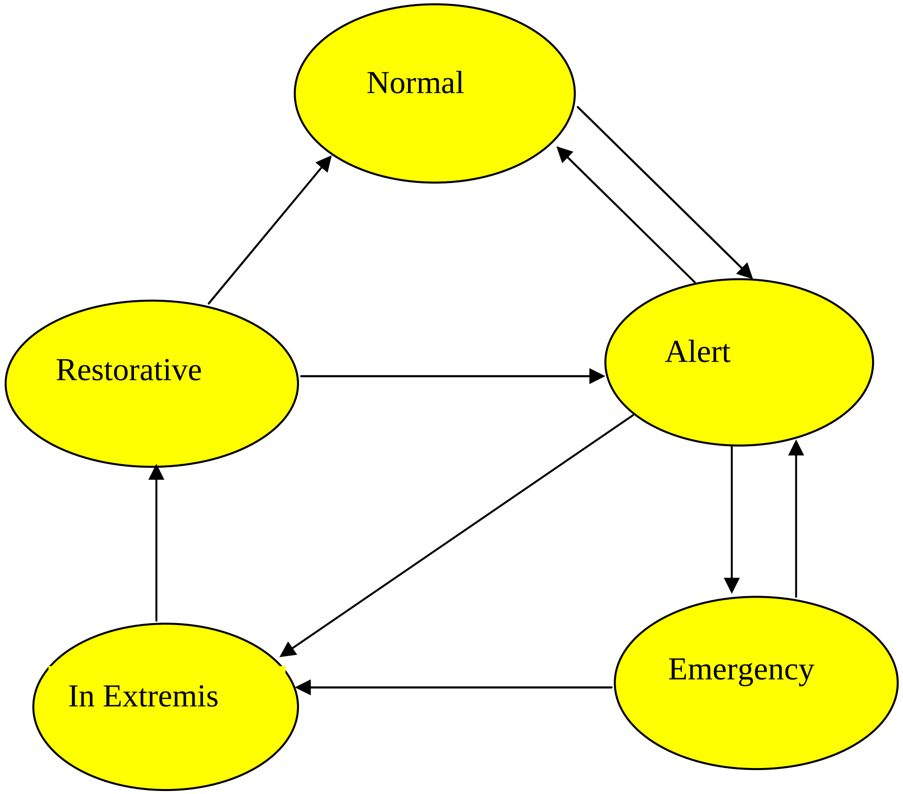
- *Alert* state: security level falls below a certain level of adequacy. All variables are within acceptable range. However, system has been weakened to a level where a contingency may cause trouble.

- *Emergency* state: if a sufficiently severe disturbance occurs when the system is in alert state then it enters emergency state. Voltages at some buses are low and loadings exceeded short-term emergency ratings. The system is still intact. It can be brought back to alert and normal state by taking appropriate control action.

- *In Extremis*: if controls are not applied or are ineffective, the system is in extremis; the result is cascading outages and possibly shut down of a major part of the system. Actions like load shedding, controlled system separation may save a widespread blackout.

- *Restorative* state: represents a condition in which controlled action is being taken to reconnect all the facilities and restore system load. The system transits from this state to either alert state or the normal state depending on the system conditions.

The following diagram can summarize transition between all these operating states.



Material already covered in earlier courses

➢Load flow: study of voltage current relationship under steady state conditions. Solved equations of the type

$$F(x,y)=0$$

System is in *Normal state*

➢Fault calculation: solution of current –voltages for some emergencies. Steady state equations of the above type.

➢Economic power dispatch problems: determining optimum share of each generator for a particular loading. Solution of algebraic equations. System is in *Normal state.*

Nature of problems in the present course

In this course we are interested in the dynamic aspect of a power system – how the current voltage frequency change with time when the system is perturbed. The disturbance on the system may appear when the system is in Normal, or Alert state. The dynamic equations are written in the form

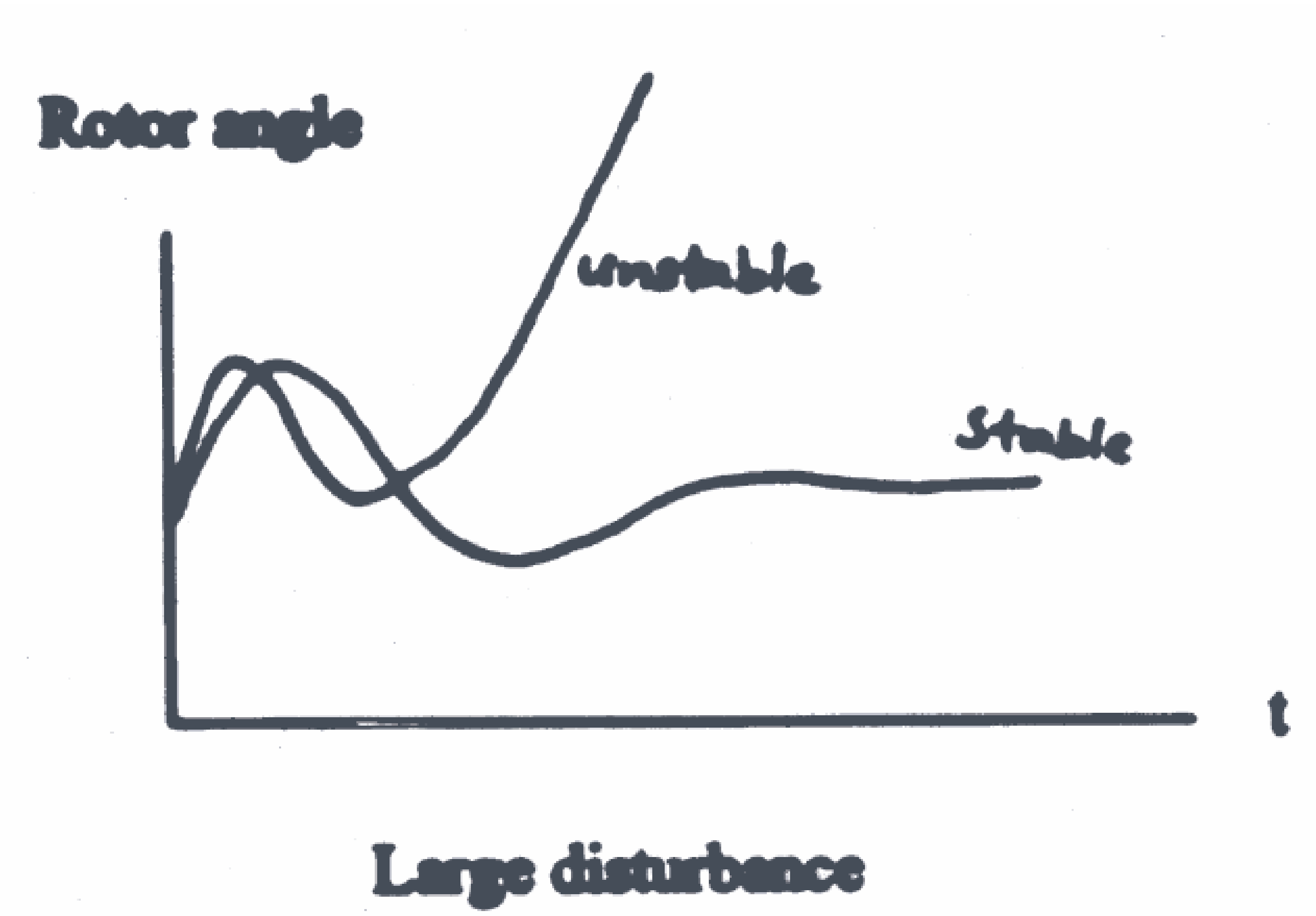
$$\dot{x} = f(x,u) \qquad (1)$$
$$y = g(x,u)$$

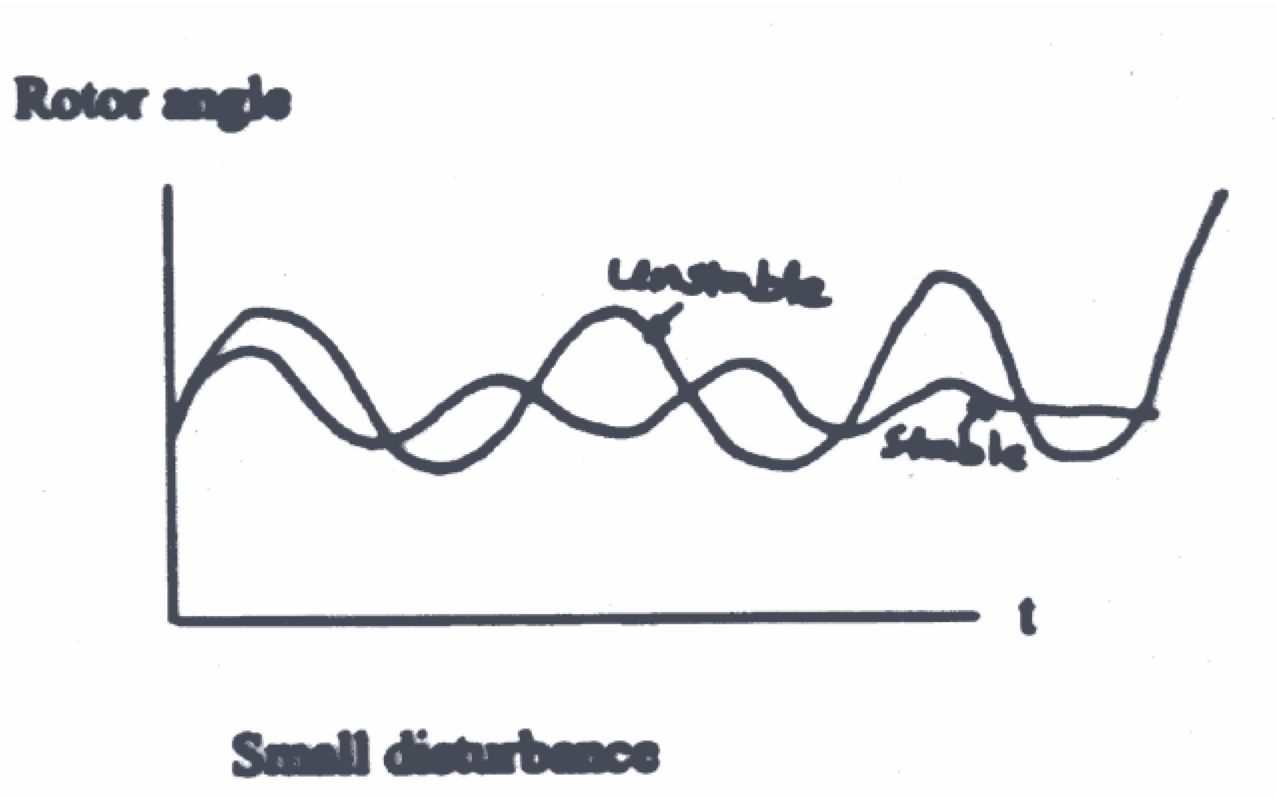
x is the state variable (like speed, rotor angle, current, etc.)
y is the output vector (like terminal voltage, power output, etc.)
u is the control (like PSS, governor control, braking resistor, etc.)

If the perturbation or the disturbance is small, the above equations can be linearized to:

$$\dot{x} = Ax + Bu \qquad (2)$$
$$y = Cx + Du$$

The response is studied for some perturbations.





Power System Stability

Power system stability may be broadly defined as the property of a power system that enables it to remain in a state of operating equilibrium under normal operating condition and to regain an acceptable state of equilibrium after being subjected to a disturbance.

➢Traditionally, the stability problem has been one of maintaining synchronous operation. The synchronous machines in the system should remain in synchronism or in step. This aspect is influenced by the dynamics of rotor angles and the power-angle relationships. The “rotor angle stability” is one of the major issues in this course.

➢Instability may also be encountered without loss of synchronism. For example, a system consisting of a synchronous generator feeding an induction motor through a transmission line can become unstable because of collapse of load voltage. This type of instability is called voltage instability.

The following definitions are related to rotor angle stability.

•*Steady state stability*: is the ability of the machines to remain in synchronism when the system is subjected to small and gradual change of load.
•*Dynamic stability (small signal stability*) refers to stability/instability of the system when a relatively smaller disturbance results in growing oscillations. Linear analysis is valid.
•*Transient stability* refers to the stability of the power system subjected to large and sudden changes in the system (such as, line switching, faults, etc.). Nonlinear dynamic model is required for the study.

Conventional way of ascertaining stability is through step-by- step (numerical) calculations of differential equations. However, this is computationally expensive.

Alternative proposition is to determine stability through direct method (*Lyapunov* method). This does not involve solution of differential equations.