Power System Stability

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Power system stability can be defined as the ability of alternators maintaining synchronism after the disturbance, which are working parallel. Power system stability problem is appearing in power system due to large variation in inertia of electrical machine.

Stability Limit

The maximum amount of power that can be transfer to the point of disturbance, to maintain the stability is known as stability limit.

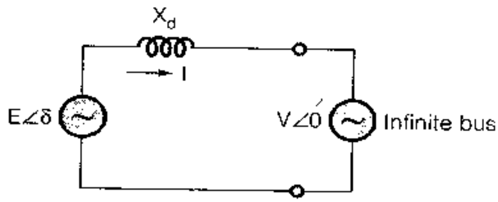
Note:

- Steady state stability limit is always more than transient stability limit.
- Transient stability limit can be improved maximum upto steady state stability limit.
- A system with high steady state stability limit is not guarantee for high transient stability limit, however a system with high transient stability limit is guarantee for high steady state stability limit.

Generator Power Output

Complex Power Output of Generator

$$S = \frac{|E||V|}{X_d}\sin\delta + j\left[\frac{|E||V|}{X_d}\cos\delta - \frac{|V|^2}{X_d}\right]$$



where, X_d = Direct axis synchronous reactance of synchronous machine

$E = |E|\angle\delta$ = voltage behind direct axis synchronous reactance of generator

V = Terminal Voltage of generator

Real Power Output of Generator

$$P_e = \frac{|E||V|}{X_d}\sin\delta = P_m \sin\delta$$

Reactive Power Output of Generator

$$Q_e = \frac{|E||V|}{X_d}\cos\delta - \frac{|V|^2}{X_d}$$

$$P_r = \frac{|E||V|}{X_d}\cos\delta$$

where, P_r = Synchronizing power coefficient

Note: ....

Maximum value of δ for successful operation is 90°.

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Swing Equation

It describes rotor dynamics of alternator. When ever there is an imbalance between mechanical input and electrical power output the rotor of the alternator either accelerate or deccelerate.

$$M\frac{d^2\delta}{dt^2} = P_a = P_i - P_e$$ ... Swing equation

where,
$M = I\omega$ = Angular momentum
$P_i = T_i\omega$ = Mechanical power input
$P_e = T_e\omega$ = Electrical power output
$P_a = P - P_e$ = Accelerating power
T_i = Mechanical input torque
T_e = Electromagnetic output torque
I = Moment of inertia

Stored Kinetic Energy of a Rotating Body

$$K.E. = \frac{1}{2}I\omega^2 = \frac{1}{2}M\omega$$

Inertia Constant

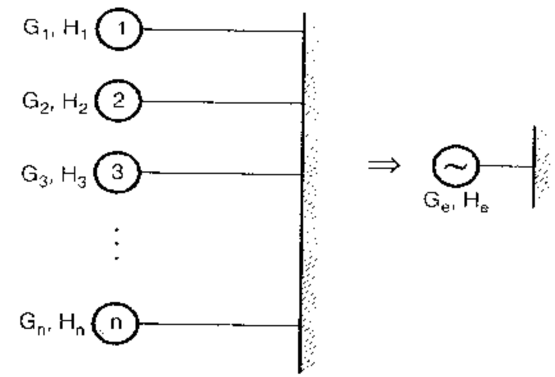
$$H = \frac{\text{Stored energy in mega-joules}}{\text{Machine rating in MVA. (G)}}$$

Angular Momentum

$$M = \frac{GH}{\pi f} \quad \frac{\text{MJ-sec}}{\text{Elec-rad}}$$

$$M = \frac{GH}{180° f} \quad \frac{\text{MJ-sec}}{\text{Elec-degree}}$$

For Multi-Machine System



$$G_e H_e = G_1 H_1 + G_2 H_2 + G_3 H_3 + \cdots G_n H_n$$

If $G_e = G_{base}$

then,
$$H_{e(p.u.)} = \frac{G_1 H_1}{G_{base}} + \frac{G_2 H_2}{G_{base}} + \cdots + \frac{G_n H_n}{G_{base}}$$

(a) If n Machine Swing Together

$$M_{eq} = M_1 + M_2 + M_3 + \cdots + M_n$$

(b) If n Machine Do Not Swing Together

$$\frac{1}{m_q} \quad M_{eq} = \frac{1}{M_1} + \frac{1}{M_2} + \frac{1}{M_3} + \cdots + \frac{1}{M_n}$$

Steady State Stability Limit (P_{SSSL})

$$\boxed{P_{SSSL} = \frac{EV}{X_{eq}}}$$

Note:

For better steady state stability margin a power system maintain $\delta = 30$ to $40°$.

Method to Improve Steady State Stability

- Operate system at high voltage. A 400 kV line has highest steady state power limit.
- Reduce the transfer reactance (X_{eq}) by
  - (a) using parallel lines
  - (b) using bundle conductor
  - (c) using series capacitor

Transient Stability

It is the ability of synchronous machine to deliver maximum power to the load, without losing synchronism for sudden and large disturbance, which is characterised as 3ϕ S.C. fault for few cycles.

Transient Stability Evaluation Using Equal Area Criteria

(a) Equal area criteria is a graphical method.

(b) It gives absolute stability of the machine.

(c) It can applied only for single machine connected to infinite bus system.

(d) It can not use for multi machine system.

For stability

$$\boxed{\text{Accelerating area} = \text{Decellerating area}}$$

Note:

A power system can not have steady state stability beyond $\delta = 90°$, however it can have transient stability beyond $\delta = 90°$ as long as the condition of equal area criteria is satisfy.

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