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Steady State Stability Analysis Of A Single Machine Power System Using Matlab

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ABSTRACT--- ***This paper provides the stability of an interconnected power system is its ability to return to normal or stable operation after having been subjected to some form of disturbance. We have taken a single machine connected to a infinite busbar example to demonstrate the features of Steady state stability and the swing equation and its solution using MATLAB.***

***Keywords---*:** MATLAB, Modeling of a Power system, steady state Stability.

1. INTRODUCTION

The stability of power systems has been and continues to be of major concern in system operation. Modern electrical power systems have grown to a large complexity due to increasing interconnections, installation of large generating units and extra-high voltage tie-lines etc.

Successful operation of a power system depends largely on the engineer's ability to provide reliable and uninterrupted service to the loads. The reliability of the power supply implies much more than merely being available. Ideally, the loads must be fed at constant voltage and frequency at all times. The first requirement of reliable service is to keep the synchronous generators running in parallel and with adequate capacity to meet the load demand.

Synchronous machines do not easily fall out of step under normal conditions. If a machine tends to speed up or slow down, synchronizing forces tend to keep it in step. Conditions do arise, however, such as a fault on the network, failure in a piece of equipment, sudden application of a major load such as a steel mill, or loss of a line or generating Unit., in which operation is such that the synchronizing forces for one or more machines may not be adequate and small impacts in the system may cause these machines to lose synchronism.

There are two forms of instability in power system, the stalling of asynchronous loads and the loss of synchronism between synchronous machines. The synchronous stability is again divided into two regimes (i) Steady state stability and (ii) Transient state stability. The steady state stability is the stability of the power.

System under conditions of gradual or relatively slow change in load. The transient state stability refers to the maximum flow of power possible through a point without losing the stability with sudden and large changes in the network conditions such as brought about by faults, by sudden large increment of loads [1].

Transient stability is the ability of the power system to maintain synchronism when subjected to a severe transient disturbance, such as a fault on transmission facilities, sudden loss of generation, or loss of a large load. The system response to such disturbances involves large excursions of generator rotor angles, power flows, bus voltages, and other system variables. It is important that, while steady-state stability is a function only of operating conditions, transient stability is a function of both the operating conditions and the disturbance(s). [2]

This complicates the analysis of transient stability considerably. Repeated analysis is required for different disturbances that are to be considered. In the transient stability studies, frequently considered disturbances are the short circuits of different types. Out of these, normally the three-phase short circuit at the generator bus is the most severe type, as it causes maximum acceleration of the connected machine. [3]

Power systems over the global are becomingly increasingly complex and the requirements for providing stable, secure, controlled, economic, quality power, especially so in the deregulated environment are becoming vitally important. An overwhelming need is being felt for increasing the transmission capacity on transmission lines and controlling power flow in specific corridors, while assuring system reliability during any fault scenarios. Power transfer capacity along a transmission corridor is limited by several factors such as thermal limit, steady state stability limit, transient stability limit and system damping. In certain situations, a power system may have inadequate damping or even negative damping.

All mutual inductances between stator and rotor circuits are periodic functions of rotor angular position. In addition, because of the rotor saliency, the self inductances of the stator phases and the mutual inductances between any two stator phases are also periodic functions of rotor angular position. Therefore, the resulting circuit equations are awkward to handle. However, if certain reasonable assumptions are made, a relatively simple transformation of variables will eliminate the troublesome functions of angle from the equations.

The assumptions are:

1. The windings are sinusoidally distributed along the air gap as far as all mutual effects with the rotor are concerned.
2. The stator slots cause no appreciable variation of any of the rotor inductances with change in rotor position.
3. Saturation may be neglected. The effect of saturation can be accounted for separately.

If the magnitude of the disturbance is sufficiently small so that the system response in the initial stage is essentially linear, the stability may be classified as small - disturbance stability. Small disturbance stability is assured if the eigen values of the appropriate dynamic model, linearized about the equilibrium point, have negative real parts. If there is an eigenvalue with positive real part the system is unstable. Complex eighenvalues occur in conjugate pairs. They signify the oscillations. With negative real parts oscillations damp out.

2. STEADY STATE STABILITY

2.1 .Swing equation

Under normal operating conditions, the relative position of the rotor axis and the resultant magnetic field axis is fixed. The angle between the two is known as the power angle or torque angle. During any disturbance, rotor will decelerate or accelerate with respect to the synchronously rotating air gap mmf, a relative motion begins. The equation describing the relative motion is known as the swing equation.

By the law of rotation –

$$J\frac{d^2\theta_m}{dt^2} = T_a = T_m - T_e \qquad (1)$$

Where J is the combined movement of inertia of the prime mover and generator

$$\frac{H}{\pi f_0}\frac{d^2\delta}{dt^2}) = P_{m(pu)} - P_{e(pu)} = P_m - P_{\max}\sin\delta \qquad (2)$$

$$P_s = \frac{dp}{d\delta} = P_{\max} \cos \delta_0 \qquad (3)$$

Swing equation in terms of $\Delta\delta$

$$\frac{H}{\pi f_0} \frac{d^2 \Delta\delta}{dt^2} + P_m \cos \delta_0 \Delta\delta = 0 \qquad (4)$$

$$P_{\max} = \frac{EV}{X} \qquad (5)$$

Synchronizing Coefficient is

$$P_s = P_{\max} \cos \delta_0 \qquad (6)$$

Undammed natural frequency is

$$\omega_n = \sqrt{\frac{\pi f_0}{H}} p_s \qquad (7)$$

Damping ratio is

$$\eta = \frac{D}{2} \sqrt{\frac{\pi f_0}{HP_s}} \qquad (8)$$

Damped frequency of oscillation is

Rotor is suddenly is perturbed by a small angle

$$\Delta\delta = \frac{\Delta\delta_0}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t} \sin(\omega_d t + \theta) \qquad (10)$$

Rotor frequency is

$$\omega = \omega_0 - \frac{\omega_n \Delta\delta_0}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t} \sin \omega_d t \qquad (11)$$

The motion of rotor relative to the synchronously revolving field is

$$\delta = \delta_0 + \frac{\Delta\delta_0}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t} \sin(\omega_d t + \theta) \qquad (12)$$

2.2. Illustrative system example

We have considered the dynamic behavior of a one machine system connected to an infinite bus bar as shown in Fig1. These the system and the given data widely used in the literature. [4]

The generator is delivering real power 0.6 p.u, unity power factor lagging to the infinite bus at a voltage V=1 per unit. The system data are given in Appendix I. The equations written in Matlab commands.

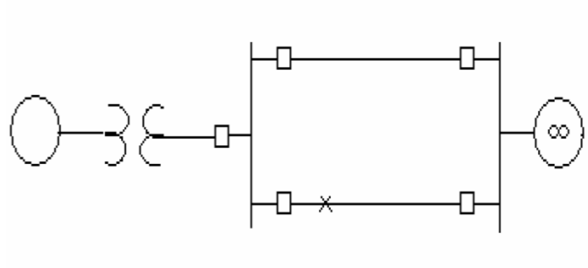

Fig 1 One – Line diagram for Steady State stability

Before applying the disturbance the rotor angle and frequency of the synchronous machine is 9.8^0 and 60 Hz in Fig 2.

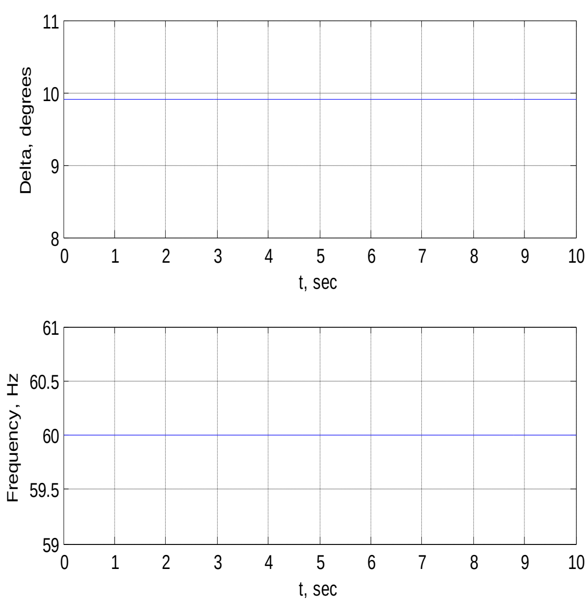

Fig 2. The Rotor angle and frequency for machine before disturbance.

By applying a small disturbance of per unit damping coefficient D=0.13 and a small disturbance of $\Delta\delta=12^0$ .The breakers open and quickly close to the Line diagram. The Synchronous machine will be followed by a slowly damped oscillation and comes to the steady state operation in7.714 seconds in Fig 3. The rotor locks back into synchronous speed, the generator will maintain its stability at 7.714 seconds. It is correlated with theoretical results.

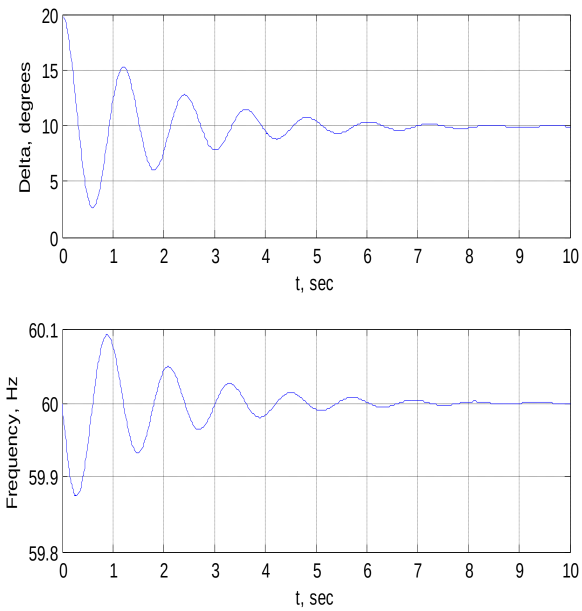

Fig 3. The Rotor angle and frequency for synchronous machine after disturbance

The motion of rotor relative to the synchronously revolving field in electrical radians becomes

$$\delta = \delta_0 + \frac{\pi f_0 \Delta P}{H\omega_n^{\ 2}}\left[1 - \frac{1}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t}\sin(\omega_d t + \theta)\right] \quad (13)$$

Rotor angular frequency in radian per second is

$$\omega = \omega_0 + \frac{\pi\ f_0 \Delta P}{H\omega_n \sqrt{1-\zeta^2}} e^{-\zeta\omega_n t}\sin(\omega_d t) \quad (14)$$

By applying the input power is increased by a small amount ΔP =0.3 per unit and the breakers open and quickly close to the Line diagram. The Synchronous machine will be followed by a slowly damped oscillation and comes to the steady state operation in7.714 seconds and a new steady state operating point is attained at $\delta=15^0$ in Fig 4. The rotor locks back into synchronous speed, the generator will maintain its stability at 7.714 seconds. The stability is entirely independent of the input, and for a positive damping coefficient the system is always stable as long as the synchronizing power coefficient is positive.

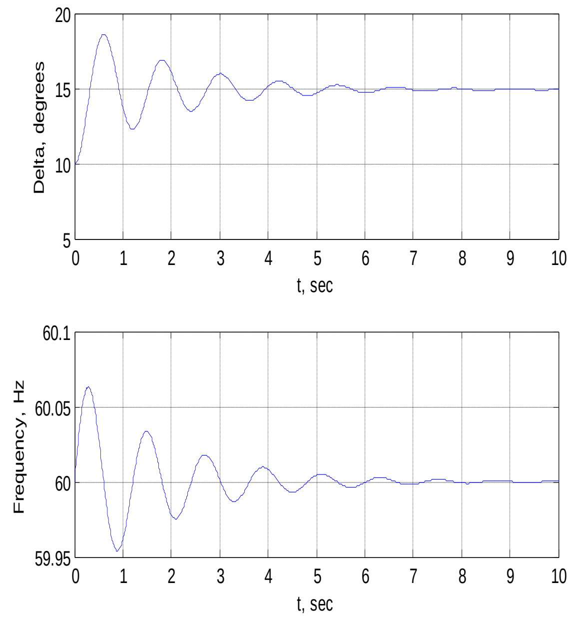

Fig 4. The Rotor angle and frequency for Synchronous machine after small power input

Conclusion:

The qualitative conclusions regarding system stability drawn from a two-machine or an equivalent one-machine infinite bus system can be easily extended to a multi machine system. Any parameter within Matlab programming can be easily modified through simple MATLAB commands to suit the changes in the original power system network due to fault or a corrective action. By applying a small disturbance the breakers open and quickly close to the Line diagram. The Synchronous machine will be followed by a slowly damped oscillation and comes to the steady state operation the rotor locks back into synchronous speed, the generator will maintain its stability it is correlated with theoretical results.

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Appendix I (generator data)

Generator	RATING
Power Factor	1.0
H(S)	23.64
X'_d	0.0608
Xt	0.2
X12	0.0608
$\Delta\delta$	12 Degrees
f0	60