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ELECTRICAL POWER ENGINEERING

Study and Analysis of Machine Parameters Effect on Power System Stability

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Abstract— **The stability study of a power system is an important factor in the planning or increasing of facilities. The studies are helpful in determining such thing as nature of the relaying system needed, critical clearing time of circuit breakers, voltage level, and transfer capability between systems. In this paper, the effects of machine parameters (*inertia constant, damping constant and transient reactance*) on the critical clearing time of the power system stability have been analyzed. These parameters are the main contribution to the angular acceleration and power transfer capability that affected the power system stability. The analysis has been done for two types of power system: single machine infinite bus system and multi-machine system. From the analysis, it is found that the stability of the system is affected by studied parameters and important in the design of the improving power system stability and protection system..**

Keywords— **Power System Stability, Machine Parameters**

I. Introduction

Power system stability is that property of a power system which ensures that the operation of the system is within the specified limits of voltage and power angle during normal and abnormal changes in operating condition [1]. Since power systems rely on synchronous machines for the generation of electrical power, a necessary condition for the transmission and exchange of power is that all generators rotate in synchronism. The concept of power system stability relates to the ability of generators on a system to maintain synchronism and the tendency to return to and remain at a steady-state operation point following a system disturbance. The mechanism by which interconnected synchronous machines maintain synchronism with one another is through restoring forces, whenever there are forces tending to accelerate or decelerate one or more machines with respect to other machines [2]. If the forces tending to hold machines in synchronism with one another are sufficient to overcome the disturbing forces, the system is said to remain stable i.e., to stay in synchronism [2].

In order to maintain the stability, the fault must be removed from the system in a shorter time. Duration of fault clearing time is depends by the amount of power that may be transmitted to the system. If the system has a higher power limit, then a larger percentage of the transmission line capacity will have to be removed to clear the fault. If a smaller percentage of the transmission line capacity removed, then the system would be able to transmit a larger amount of power and the clearing time is increased. The benefit of studying the power system stability is to know the detailed knowledge of their transmission systems stability constraints and know the preventive control to improving the system operation reliability and increasing transfer capability.

This paper provides the machine parameters that effect on steady-state stability and transient stability of power system network. The model for single machine and multi-machine power system is described in section II. Effects of machine parameters are discussed in section III. Analysis of effect of machine parameter is demonstrated in section IV. And, a conclusion is made based on the simulation results of both single and multi-machine power systems.

II. Power System Models and Equations

A. *Synchronous Machine Model for Stability Study*

The simplest model for stability analysis is the classical model, where saliency is ignored, and the machine is represented by a constant voltage E' behind the direct axis transient reactance X_d' [2]. If V_g is the generator terminal voltage and I_a is the pre-fault steady state generator current, the model is represented by

$$E' = V_g + jX_d'I_a \qquad (1)$$

B. *Swing Equation*

The swing equation of the machine is given by

$$\frac{H}{pf}\frac{d^2d}{dt^2} = P_m - P_e \qquad (2)$$

where, P_e is the electrical power output and P_m is mechanical power input and δ is the load angle and then, H is inertia constant in terms of,

$$H = \frac{\text{kinetic energy in MJ at rated speed}}{\text{machine rating in MVA}} = \frac{W_K}{S_B} \qquad (3)$$

If damping is account for, assuming that the damping torque is introduced by a term proportional to the derivative of the angle, the swing equation becomes

$$\frac{H}{pf}\frac{d^2d}{dt^2} + D\frac{dd}{dt} = P_m - P_e \qquad (4)$$

The linearised differential equation is given by where, P_s is the synchronous power coefficient and D is the damping coefficient (ratio) which may be determined either from design data or by test. Additional damping torques is caused by the speed/torque characteristic of the prime mover and the load dynamic. When the synchronizing power is positive, because of the damping power, oscillations will damp out eventually, and the operation at the equilibrium angle will be restored. No loss of synchronous occurs and the system is stable. The presence of damper winding only influences the process of pulling out of synchronism by reducing the rate of increase of δ.

$$\frac{H}{pf}\frac{d^2Dd}{dt^2} + D\frac{dDd}{dt} + P_s Dd = 0 \qquad (5)$$

C. *Power System Model for Stability Study*

The stability of the power system was tested on two types of models with two different cases;

- Single machine infinite bus: application of disturbances with small perturbations (steady-state stability).
- Multi-machine system: studies the effects of various power system parameters on critical clearing time and transient stability.

The models are shown in Fig. 1 and 2, and each generator in the model is connected to a system consisting of transmission lines, transformer, loads and other machines. To a first approximation, the system can be represented by an infinite bus behind a system reactance $X_d^{'}$. An infinite bus is an ideal voltage source and maintains constant voltage magnitude, constant phase and constant frequency.

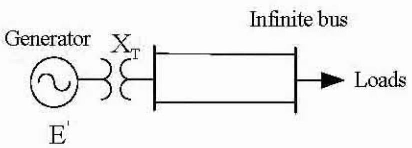

Fig. 1 Single machine infinite bus system

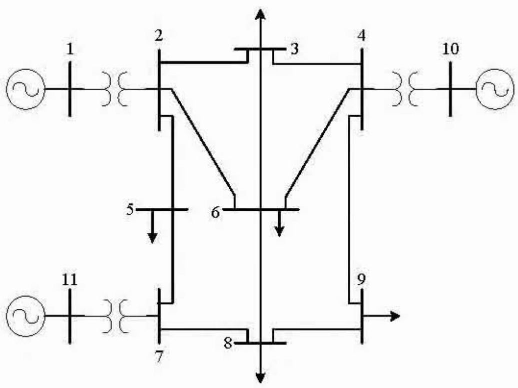

Fig. 2 Multi-machine test system with 11 buses

III. Effect of Machine Parameters to Power System Stability

Fault at the terminals of a synchronous generator will reduced the power output of the machine as it is supplying a mainly inductive circuit. If the fault continues, the rotor angle will increase and synchronism will lost, hence the operation time of the protection and circuit breakers is very important in maintaining the system stability.

The duration of fault clearing time of the system depends on the machine parameters. The machine parameters that affected the fault durations are inertia constant, damping ratio and transient reactance. The main contribution on stability of the power system stability is rotor angular swing [1]. The angular swing of the rotor is dependent on its inertia. Inertia constant is proportional to the synchronous angular velocity of the rotor. The changes of inertia constant will cause the changes of angular acceleration and this also affected the stability of the power system. The transient reactance of the machine is in series with the bus impedance. Power transfer capability of the generator is inversely proportional to the total reactance. So, the changes of machine transient reactance cause the changes of the fault duration clearing time and the system stability.

The other machine parameter is damping constant. The main source of damping in the synchronous generator is provided by the damper winding. The damper windings have a high resistance/reactance ratio. In the transient state, the air-gap flux, which at synchronous speed, penetrates the damper windings and induces e.m.f and current when the rotor speed is different from the synchronous speed [5]. Usually the damping of the rotor motion by mechanical losses is small and can be neglected for all practical consideration [5].

IV. Study and Analysis of Machine Parameters to Stability Problem

To study the effect of machine parameters on the critical clearing time, the 11 bus test system shown in Fig. 2 is analyzed. This power system consists of one generator as swing bus (reference bus) and the others are voltage regulated buses. Fig.3 and 4 are the swing curves of the system for the original value of machine and system parameters with fault cleared at 0.35 second and 0.73 second.

A. *Variation of Inertia Constant*

In this section, the variation of electric machine inertia constant (*H*) and its effect on the system stability has been investigated on the test system. Line impedance, damping and machine transient reactance were kept constant during the simulation. Below is the curve after increasing the inertia constant by double.

An increase in the inertia of the generators gives a slower clearing time without loss of synchronism because increasing the inertia will reduce the angular speed, so the angle between two machines takes more time to reach the maximum value and the critical clearing time will increase too. Fig. 6 and 7 shown that by increasing the inertia constant by double, the critical clearing time is increased compared with Fig. 3 and 4.

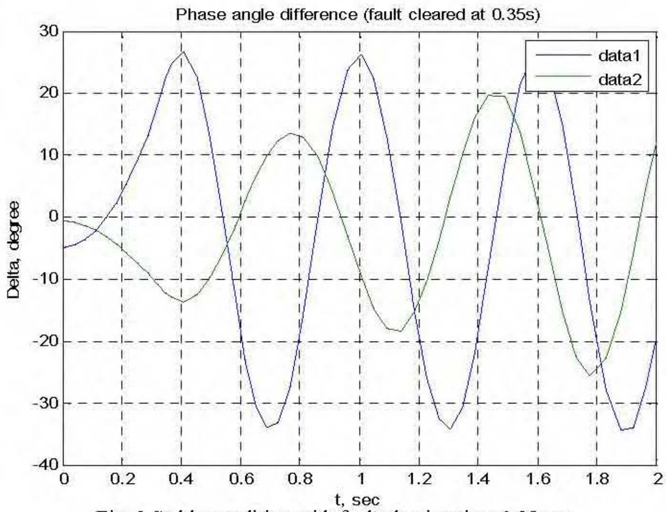

Fig. 3 Stable condition with fault clearing time 0.38 sec

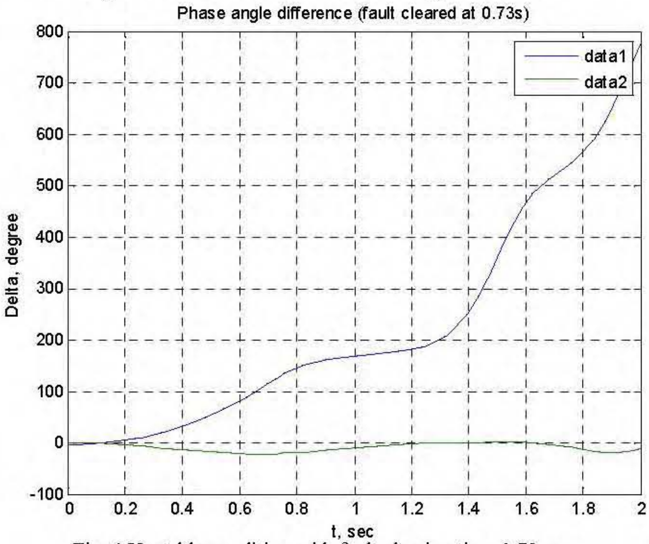

Fig. 4 Unstable condition with fault clearing time 0.73 sec

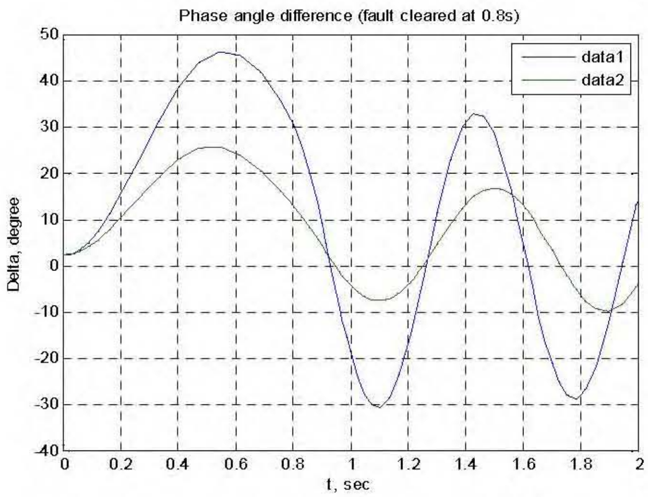

Fig. 5 Stable condition with fault clearing time 0.8 sec

The critical clearing time before increasing the inertia is 0.35 second and after increase the inertia, the critical clearing become 0.8 second. The oscillation over 5 seconds has been reduced by increasing the inertia. However, the peak of the first swing is increased a little bit when the inertia is increased because the clearing time of the fault is increased.

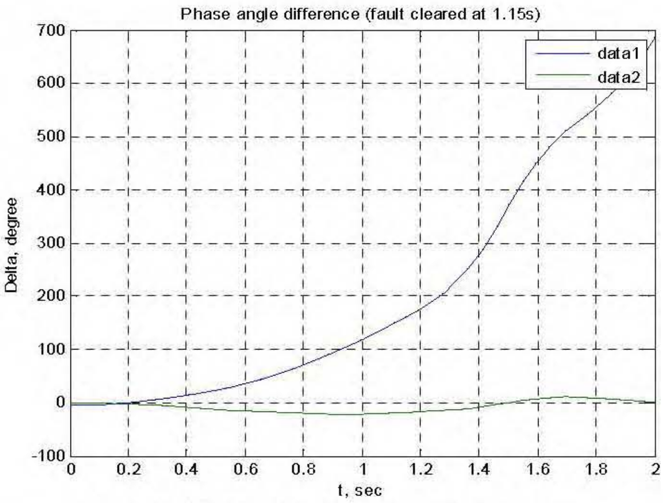

Fig. 6 Unstable condition with fault clearing time 1.15 sec

Practically, increasing the inertia of the generator meaning that, increase the weight of the rotor. This only can be done before installation of the generator because during running the system, the weight of rotor cannot be changed. Unfortunately, present day generator manufacturing trends are towards lower inertia, H constant, which are effect the stability.

B. *Variation in Machine Transient Reactance*

In this section, the effect of the variation in electric machine transient reactance has been investigated on the test system. Inertia and damping were kept constant during the simulation. Below is the swing curve after decreasing the machine transient reactance by half. It is found that, by decreasing the machine transient reactance, the critical clearing time is increased to 0.65 second. This means that a machine with a smaller transient reactance gives more stability properties. Stability can be improved by reducing the machine transient reactance. This is because the power transfer capability is increase when reducing the machine transient reactance.

C. *Variation of Machine Damping*

In this section, the effect of electric machine damping coefficient (*D*) on the system stability has been investigated for single machine system. For study with damping constant, only single machine system is tested because of damping power is negligible in transient stability analysis of multi-machine power system. Fig. 9 is the swing curve after including the damping constant 0.138. It is shown that, the rotor angle and frequency have been increasing by including the high value of damping constant to 0.5 (maximum value), which is shown in Fig. 10. This means that, the higher value of damping constant will increase the stability and system frequency.

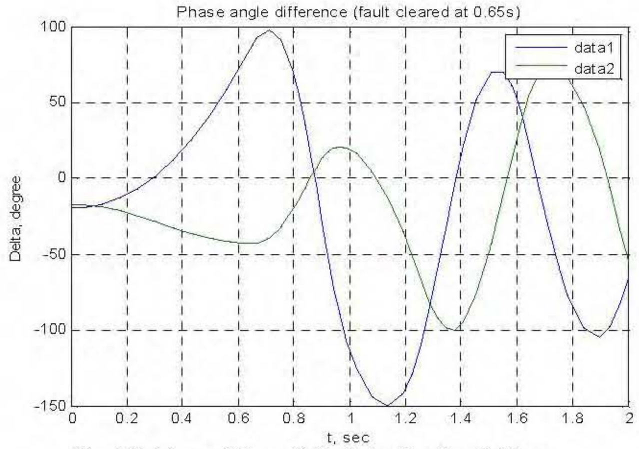

Fig. 7 Stable condition with fault clearing time 0.65 sec

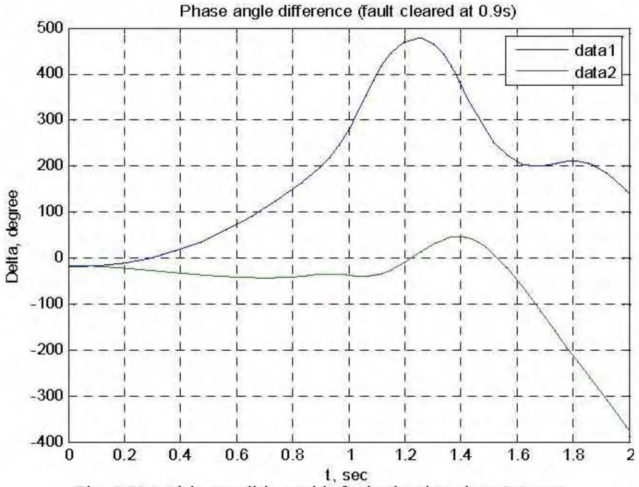

Fig. 8 Unstable condition with fault clearing time 0.9 sec

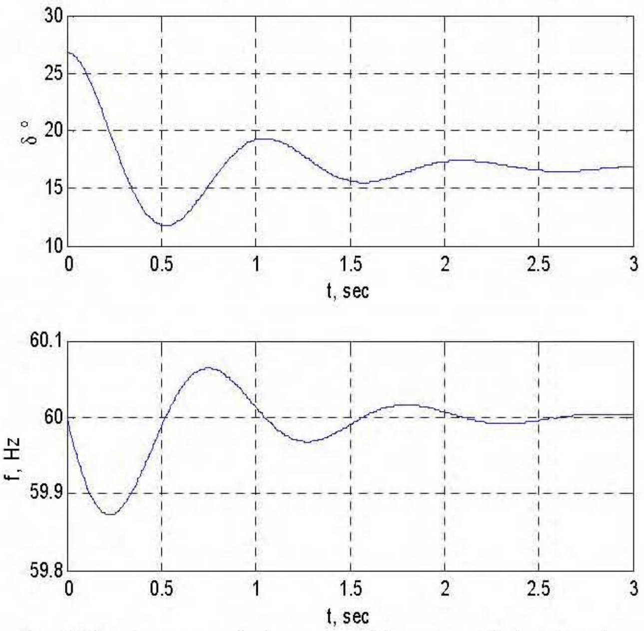

Fig. 9 Natural response of rotor angle and frequency with low damping constant

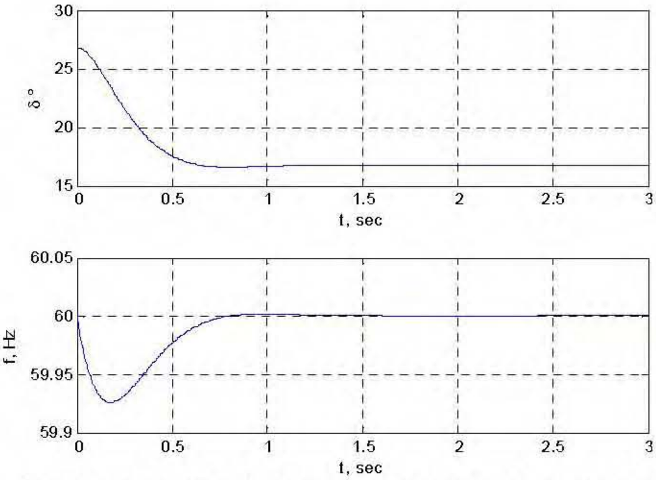

Fig. 10 Natural response of rotor angle and frequency with higher damping constant

V. CONCLUSION

From this analysis, found that, the importance of the various system parameters on the fault clearing calculations in the power system transient stability analysis. The stability analysis is on the behavioural of rotor during fault because it is the main contributor of the stability of the power system. By analyzing the stability of the power system, we can determine the relaying system needed, critical clearing time of circuit breakers, voltage level, and transfer capability between systems. And also know the transmission systems on stability constraints and the preventive control to improving the system reliability. Hence it is more effective and economic of performing engineering calculation that required in the planning, design and operation of a power system.

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