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EFFECT OF FAULT LOCATION AND LOAD INCREMENT ON TRANSIENT STABILITY OF POWER SYSTEM

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ABSTRACT

This paper is aimed at investigating the effect of some parameters on transient stability analysis of electric power system. The analysis was carried out using the 3-machine 9-bus Western System Coordinate Council (WSCC) test system. The effects of parameters like fault location and load increment were tested on the system. The result show that when faults close to the generating station are cleared, the system returns to stability more rapidly than those on lines further away from the station and load increment also lead to loss of synchronism of generators, thereby the instability of the system.

KEYWORDS: fault location; load increment; stability.

INTRODUCTION

The transient stability is one of important items in the planning and maintaining security of power system operation. A power system at a given operating state is stable if following a given disturbance, or a set of disturbances, the system state stays within specified bounds and the system reaches a new stable equilibrium state within a specified period of time.

These disturbances can be faults such as: a short circuit on a transmission line, loss of a generator, loss of a load, gain of load or loss of a portion of transmission network.[1,2]

Power system stability is a multifaceted problem depending upon a variety of factors, such as: the time span that must be taken into consideration in order to assess stability/instability; the size of the disturbance considered; the physical nature of the resulting instability.

This sudden disturbance affects the system's performance such as large variations in generator's rotor angles, power (real and reactive) flows, bus voltages and other system parameters.

The transient stability limits refers to the amount of power that can be transmitted through some point in the system with stability when the system is subjected to sever disturbance. The transient stability limits depends on duration and location of fault, construction parameters of the network and generators, and dynamic characteristics of loads. In this order the main objective of this paper is to know the effects of parameters such as fault location, fault clearing time, load increment and the effect of fault on synchronous speed in transient stability system.

METHODOLOGY

A. Stability

Power-system stability is a term applied to alternating current electric power systems, denoting a condition in which the various synchronous machines of the system remain in synchronism, or "in step," with each other. Readjustment of voltage angles of synchronous machine is required because power system operating under steady load condition is perturbed. If this condition occurs and creates an unbalance between the load and system generation, new steady state operating condition is established with subsequent adjustment of voltage angles. The perturbation may be in the form of major disturbance like: small load, random load changes under normal conditions, loss of generator, fault or loss of line or both. To establish the correct condition, fresh adjustment is needed with the new operating condition called transient period. The major criterion of stability is to maintain synchronism at the end of the transient period for the synchronous machines.

For stability, the system oscillations must be damped, so that, the inherent forces in the system tends to reduce oscillations. After a disturbance, the stability problem is concerned with the behavior of synchronous machines. The stability problem can be categorized into steady state and transient state. The voltage behind the transient reactance is determined from the following equation.[3]

$E_i = V_i + jX_d I_i$........................ (1)

Where

$E_i = voltage\ behind\ transient\ reactance$

$V_i = machine\ terminal\ voltage$

$X_d = direct\ axis\ transient\ ractance$

$I_i = machine\ terminal\ current$

Swing Equation

Applying the laws of mechanics to the rotational motion of a synchronous machine

$$I\frac{d^2\theta}{dt^2} = T_a \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2)$$

Where I is the moment of inertia of the rotor system, θ is the mechanical angle of the rotor in radians with respect to a fixed reference, and T_a is the net torque acting on the machine.

The net torque is the accelerating (or retarding) torque given by

$T_a = T_m - T_e$.......................... (3)

Where T_m is the shaft mechanical torque, corrected for rotational losses, and T_e is the electromagnetic torque

In the steady state T_a= 0. If we measure the angular position and velocity with respect to a synchronously rotating reference axis instead of with respect to a stationary axis,

$\delta = \theta - \omega_o t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4)$ From which

$$\frac{d\delta}{dt} = \frac{d\theta}{dt} - \omega_o \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (5)$$

and

$$\frac{d^2\delta}{dt^2} = \frac{d^2\theta}{dt^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots (6)$$

$therefore\ equation\ (2) becomes$

$$I\frac{d^2\delta}{dt^2} = T_a \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (7)$$

Equation (7) can be written as

$$I\omega_o \frac{d^2\delta}{dt^2} = T_a\omega_o \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (8)$$

Or

$$M\frac{d^2\delta}{dt^2} = T_a\omega_o$$

Where $M = I\omega_o$ is the angular momentum at normal speed $\omega_o, the\ value\ of\ M\ is\ called$

$the\ inertia\ constant\ of\ the\ machine.$

The rotor mechanical dynamics are represented by the following equations

$$2H\frac{dw}{dt} = T_m - T_e - D\omega$$

$$\frac{d\delta}{dt} = \omega$$

Where

H= per unit inertia constant

D= damping coefficient

$\omega = rotor\ angle\ of\ the\ generator$

$\delta = angular\ speed\ of\ the\ generator$

$T_m = mechanical\ torque\ input$

$T_e = electrical\ torque\ output$

Numerical integration techniques are used to solve the swing equation for multi-machine stability problems. The modified Euler's method is used to compute machine power angles and speeds in this research work. The real electrical power output of each machine is computed by the following equations.

$P_e = Real[E_n I^*{}_n]$, n= 1,2…………m.

$$P_e = \sum_{j=1}^{n} /E_i//E_j//Y_{ij}/\cos(\theta_{ij} - \delta_i - \delta_j)$$

The equations given above are very crucial for transient stability studies, because they are used to calculate the output power of each machine in the power system. The individual models of the generators and the system load given by the differential and algebraic equations have been stated. These equations, together, form a complete mathematical model of the system, which, when solved numerically, simulate the system behaviours.

SIMULATION OF RESULTS

This section presents computer simulations with the program developed in the Powerworld software environment. The analysis has been carried out on a 3-Machine 9-Bus WSCC test power system for an electric utility company shown in Figure 1. It consists of nine (9) buses, tree (3) synchronous generators, three (3) loads and nine (9) transmission lines.[4,6]

Appendix

i. Generator Data

Generator	H	X'_d
1	23.64	0.0608
2	6.4	0.1198
3	3.01	0.1813

ii. Transformer Data

Transformer	X_t
1	0.0576
2	0.0625
3	0.0586

iii. Line Data

Us No.		Half line charging Admittance (p.u)	Admittance(p.u.)	Reactance (p.u)
From Bus	To Bus			
1	4	0.0	0.0576	0.0
4	6	0.079	0.092	0.017
3	9	0.0	0.0586	0.0
6	9	0.179	0.17	0.039
5	7	0.153	0.161	0.032
7	8	0.0745	0.072	0.0085
2	7	0.0	0.0625	0.0
8	9	0.1045	0.1008	0.0119

iv. Load Data

Bus No	P_G	Q_G	P_L	Q_L	V_{spc}
1	0.0	-	0.0	0.0	1.04
2	1.63	0.0	0.0	0.0	1.025
3	0.85	0.0	0.0	0.0	1.025
4	0.0	0.0	0.0	0.0	-
5	0.0	0.0	1.25	0.5	-
6	0.0	0.0	0.9	0.3	-
7	0.0	0.0	0.0	0.0	-
8	0.0	0.0	1.0	0.35	-
9	0.0	0.0	0.0	0.0	-

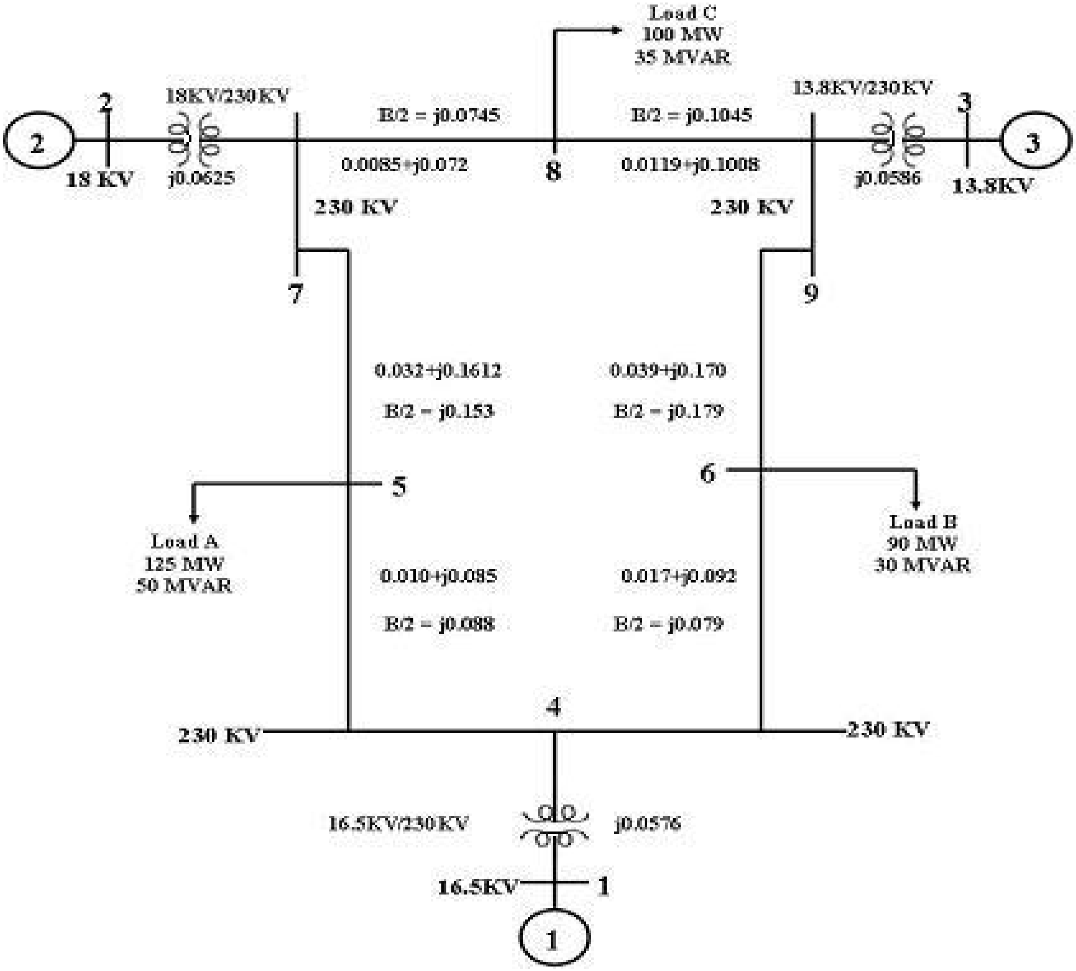

Fig. 1: 3-Machine 9-Bus WSCC test power system single line diagram.

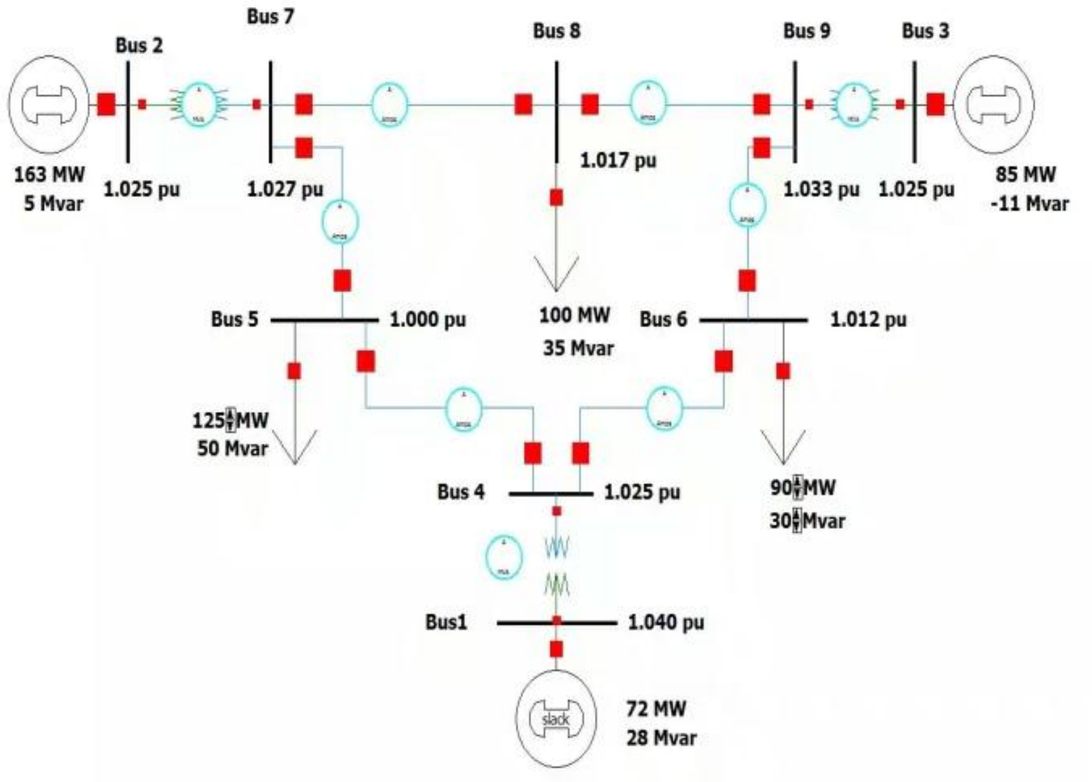

Fig. 2: 3-Machine 9-Bus WSCC test power system at run mode in Powerworld simulator.

Effect of Fault Location

This sub-section analyzes the effect of fault location in transient stability. A three-phase fault is simulated at two different locations, one close to the generating station and the other one far from the generating station.

Figure 3 shows the angular positions of the generators with the generator at bus 1 as reference, when a three phase fault occurred at bus 4 and the fault was cleared at the critical clearing time by removal of line 4-5. The critical clearing time for this case is 232ms (see Table 1). The generators swing together to show stable equilibrium. Figure 4 shows the angular positions of the machines when a three phase fault occurred at bus 6 and the fault was cleared at the critical clearing time by removal of line 4-6. The Critical clearing time for this case is 261ms (see Table 1). The generators swing together to show stable equilibrium. It is observed that the critical clearing time of the fault on bus 4 is lower than that of bus 6 with reference to bus 1. This shows that when faults close to the generating station are cleared, the system returns to stability more rapidly than those on lines further away from the station.

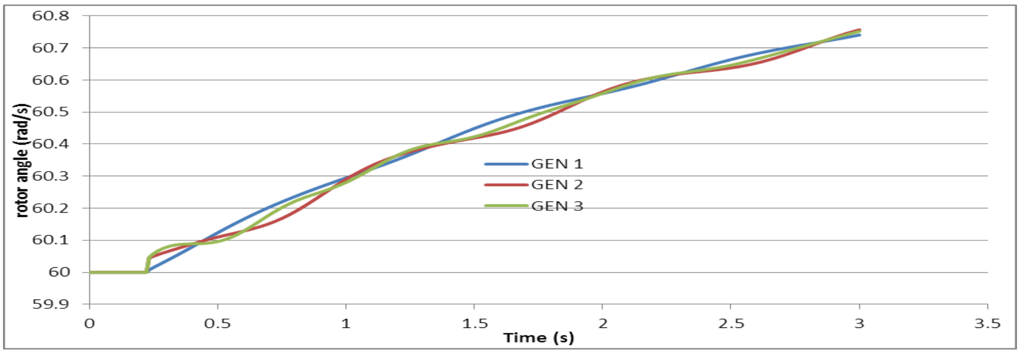

Fig. 3: Rotor angle response with fault on bus 4.

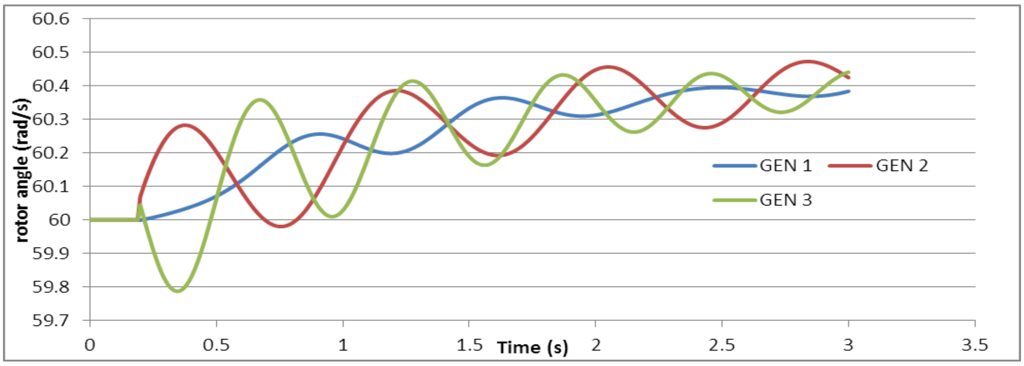

Fig. 4: Rotor angle response with fault on bus 6.

Effect of Load Increment

The objective of this sub-section is to investigate the impact of load increment on the Critical Clearing Time (CCT). For this reason, active load at all buses in the 9-bus system are increased from the base value by 10%, 20%, 30% and 40%. Real example of this case is electrical peak load of energy consumption. In order to evaluate the effects of load variation on the transient stability of the system, a three-phase fault was simulated at bus 1 with the opening of line 1–4 to clear the fault. Table 2 shows the impact of the load increment on the Critical Clearing Time. It was observed for this particular case that as the load increased within certain range, the Critical Clearing Time decreased. Increment of the load beyond certain limit caused the machines' rotor angle to diverge continuously leading to loss of synchronism and hence, instability. In order to maintain the stability of the system within certain range of the load increment, power generation has to increase while the voltage at all buses has to drop.

Table 2: Critical clearing times with load increment.

Load increment (%)	**Base value**	**10**	**20**	**30**	**40**
Total load increment (MW)	72	79.2	95.04	123.55	173
Critical clearing time (MS)	347	309	271	237	199

CONCLUSION

Transient Stability Analysis is a major investigation into the operation of power systems due to the increasing stress on power system networks. The main goal of this analysis is to gather critical information on the effect of location of fault within a power system network and effect of load increment on the system. This information can aid protection engineer make an informed decision when designing protection scheme for a power system. This paper presents a transient stability analysis of a 3-Machine 9-Bus WSCC test power system using the Powerworld software package. To analyze the effects of these parameters on the system stability, a three-phase fault was applied at different locations in the system. The stability of the system has been observed based on the simulation graphs of the generators' swing curves and generators' synchronous speed. The simulation results showed that the critical clearing time decreases as the fault location becomes closer to the power generating station and load increment also lead to loss of synchronism of generators, thereby the instability of the system. The results obtained from this study, confirmed and established the findings in previous stability studies regarding these parameters.

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