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Effect of Power System Parameters on Transient Stability Studies

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ABSTRACT: *Transient stability studies play a vital role in providing secured operating configurations in power system networks. This paper shows an investigation of the effects of some key power system parameters on transient stability. The parameters for which this analysis is carried out include fault location, load increment, machine damping factor, fault clearing time and generator synchronous speed. The analysis has been carried out on a 7-bus test system for an electric utility company. From this analysis, the impact of these parameters on power system transient stability has been highlighted.*
Keywords*-fault location; load increment; machine damping factor; fault clearing time; generator synchronous speed.*

I. INTRODUCTION

The definition of stability includes a number of factors that may be involved: the load carried before a fault occurs, the type of fault and its location in the system, the time required to clear the fault, the change in steady state operating angles when the faulted portion of the system is removed from service, and the moment of inertia of the rotating machines at each end of the system. Stability, then, is the ability of a system to continue to operate without loss of load when any reasonable system change or disturbance occurs. The transient stability is one of the important constraints in the planning and maintenance of a secured power system operation. Transient stability is concerned with the ability of the power system to maintain synchronism when subjected to severe perturbations. These perturbations can be faults such as: a short circuit on a transmission line, loss of a generator, loss of load, gain of load or loss of a portion of transmission network [1][2].

II. BACKGROUND OF STUDY

Transient stability analysis is used to investigate the stability of power system under sudden and large disturbances, and plays an important role in maintaining security of power system operation. Some studies have been carried out to evaluate the effects of parameters that influence transient stability in a power system.

Adepoju [3] carried out a study to evaluate the Critical Clearing Time (CCT) of the Nigerian 330kV transmission system. This research work demonstrated that determination of appropriate CCTs for the Nigerian power system will enhance the operation of the system by limiting the effects of faults on the power system. The CCTs for three-phase faults of circuit breakers installed on the Nigerian 330kV transmission grid, which can serve as reference data for the use of power system experts and researchers,were established. Investigationof the damping of electromechanical oscillations using Power System Stabilizers (PSS) was carried out [4]. The study simulated the behavior of PSS on Automatic Voltage Regulator (AVR) and excitation system. It also developed an algorithm to investigate the transient and dynamic stability of the power systems. This was with a view to providing information of damping rotor oscillations of synchronous generators. Baseer [5] focused on the improvement of the transient stability of the Western System Coordinating Council9-Bus System with fixed compensation on various lines and optimal location using trajectory sensitivity analysis for better results. In order to improve the transient stability margin further series Flexible AC Transmission System (FACTS) devicewas implemented. A fuzzy controlled, Thyristor Controlled Series Compensation (TCSC) devices were used and the results highlighted the effectiveness of the application of a TCSC in improving the transient stability of power systems especially with regards to damping of the system.

Singh [6] focused on the comparative performance of Static Var Compensator (SVC) and Unified Power Flow Controller (UPFC) for the improvement of transient stability of multi-machine system. The UPFC is more effective FACTS device for controlling active and reactive power flow in a transmission line and power oscillation damping by controlling its series and shunt parameters. Simulations were carried out in MATLAB /Simulink environment for multi-machine system to analyze effects of SVC and UPFC on transient stability performance of the system. The performance of UPFC was compared with SVC. The simulation results demonstrate the effective and robustness of the proposed UPFC for transient stability improvement of the system. This paper, however, investigates the effects of some key power system parameters on transient stability of the system. These parameters include the effect of fault location within the system, effect of load increment on the system, effect of damping factor of the synchronous machines within the system and effect of the fault clearing time on the stability of the system.

III. METHODOLOGY

The initiation of fault and its removal by circuit breakers in a power system shows that the system is going through a fault with change in the system configuration in three stages: pre-fault, fault and post-fault stages. The dynamics of the power system during fault and post-fault periods are nonlinear and the exact solution is too complex. In transient stability studies, particularly, those involving short periods of analysis in the order of a second or less, a synchronous machine can be represented by a voltage source behind transient reactance that is constant in magnitude but changes its angular position [7]. This representation neglects the effects of saliency and assumes constant flux linkage and small change in speed. The voltage behind the transient reactance is determined from the following equation [8].

$$E_i = V_i + jX_d I_i \tag{1}$$

where

E_i = voltage behind transient reactance

V_i = machine terminal voltage

X_d = direct axis transient reactance

I_i = machine terminal current

The rotor mechanical dynamics are represented by the following equations

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

$$\frac{d\delta}{dt} = \omega \tag{3}$$

where

H = per unit inertia constant

D = damping coefficient

ω = rotor angle of the generator

δ = 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.

$$P_e = \text{Real}\left[E_n I_n^*\right], n = 1,2,\ldots, m \tag{4}$$

$$P_e = \sum_{j=1}^{n} |E_i||E_j||Y_{ij}| \cos\left(\theta_{ij} - \delta_i - \delta_j\right) \tag{5}$$

Equations (1) to (5) 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 behaviors.

IV. SIMULATION OF RESULTS

This section presents computer simulations with the program developed in the MATLAB software environment. The analysis has been carried out on a 7-bus test system for an electric utility company shown in Figure 1. It consists of seven (7) buses, three (3) synchronous generators, four (4) loads and seven (7) transmission lines.

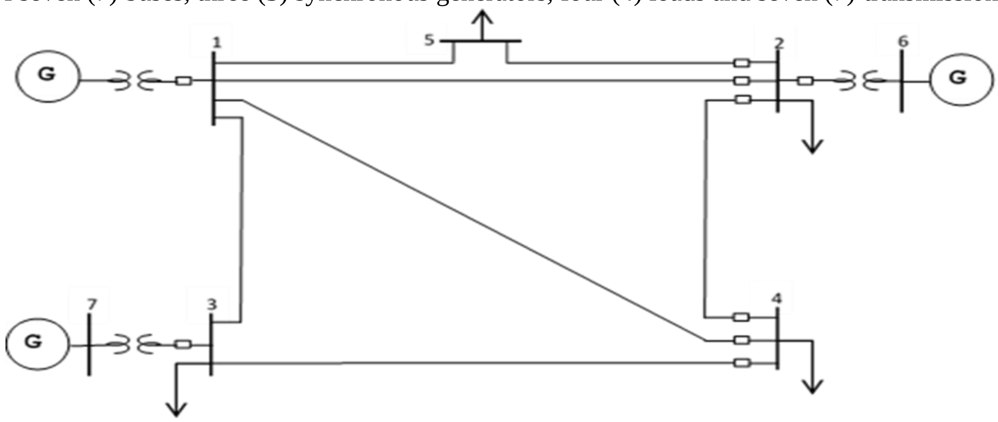

Figure 1: Single-line diagram of the test system for an electric utility company

4.1 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 2 shows the angular positions of the generators with the generator at bus 1 as reference, when a three phase fault occurred at bus 1 and the fault was cleared at the critical clearing time by removal of line 1-2. The critical clearing time for this case is 242ms(see Table 1). The generators swing together to show stable equilibrium. Figure 3 shows the angular positions of the machines when a three phase fault occurred at bus 4 and the fault was cleared at the critical clearing time by removal of line 2-4. The CCT for this case is 271ms(see Table 1). The generators swing together to show stable equilibrium. It is observed that the critical clearing time of the fault on bus 1 is lower than that of bus 4. 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.

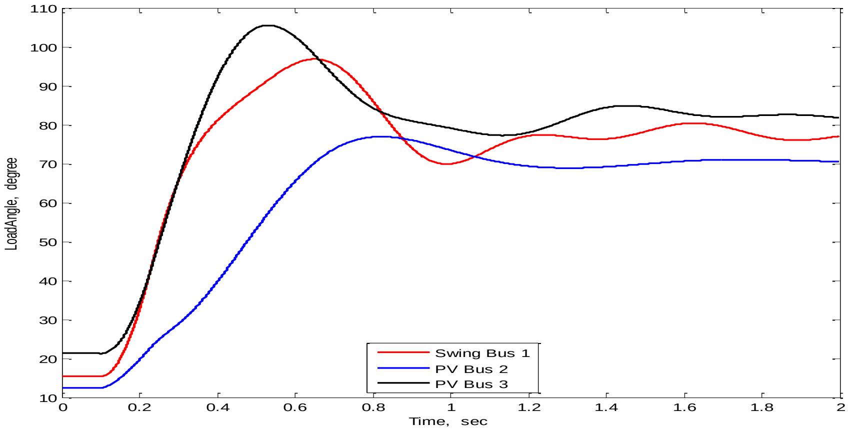

Figure 2. Rotor angle response with fault on bus 1

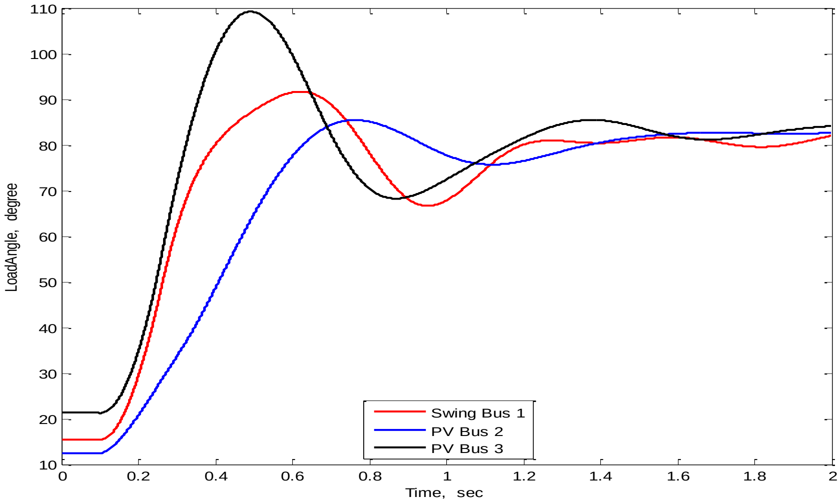

Figure 3. Rotor angle response with fault on bus 4

4.2 Effect of damping factor on the system stability.

The machine damping factor represents the natural damping of the system. This sub-section considers the effect of damping factor on the transient stability evaluation. Figure 4 and Figure 5 show the rotor angle behavior with and without damping coefficient for a three phase fault on bus 1. When a fault occurs, the rotor angles of the generators will begin to oscillate and will eventually either converge or diverge depending on the system configuration. The damping factor prevents the growth of oscillations. Machines within the system that are properly damped regain synchronism when the fault is cleared. However, those that are poorly damped wereobserved to be unstable with their rotor angles continuously diverging. When the fault is cleared, the speed is continuously increasing and system is not able to retain stability due to the lack of proper damping.

4.1 **Effect of fault clearing time**

In order to know the effect of fault clearing time on transient stability, a disturbance in the form of a three phase fault was simulated at some buses and different lines removed to determine the stability or otherwise of the power system. The critical clearing time, which is a measure of the stability, was determined by varying the fault clearing times. The stability and instability of the power system at a given fault is determined by the behavior of the generators in the system. If the rotor angles of the generators diverge, the system is unstable and if otherwise, the system is stable.

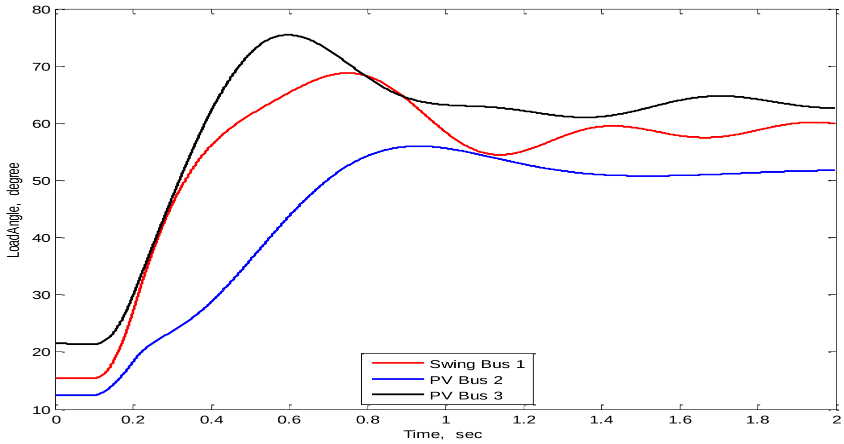

Figure 4. Rotor angle oscillations when the system is properly damped

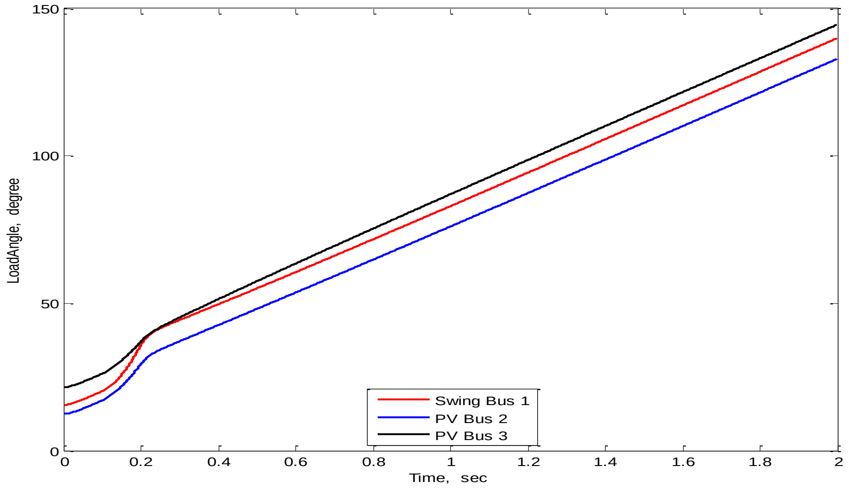

Figure 5. Rotor angle oscillations when the system is poorly damped

Figure 6 show the angular positions of the generators with the generator at bus 1 as reference when a three phase fault occurred at bus 2 and the fault was cleared at the critical clearing time by the removal of line 2-4. The generators swing together to show stable equilibrium. Figure 7 shows the angular positions of the machines for a clearing time greater than the critical clearing time. In this case, the clearing time increased beyond the critical clearing time and the machines lost synchronism as seen in the figure.

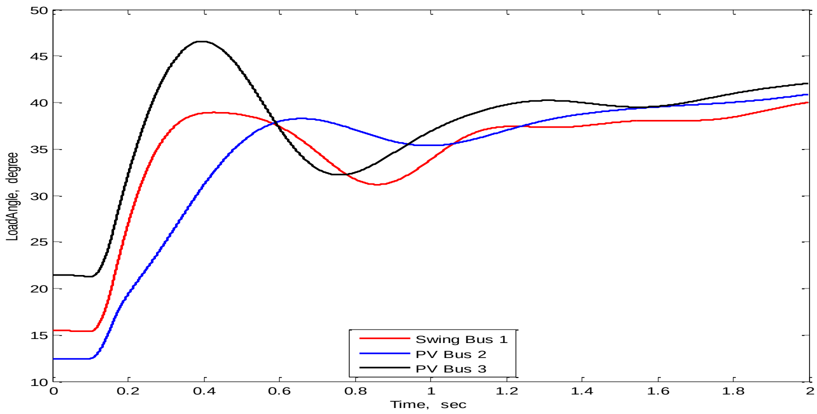

Figure 6. Generator rotor angle response for fault cleared at the critical clearing time

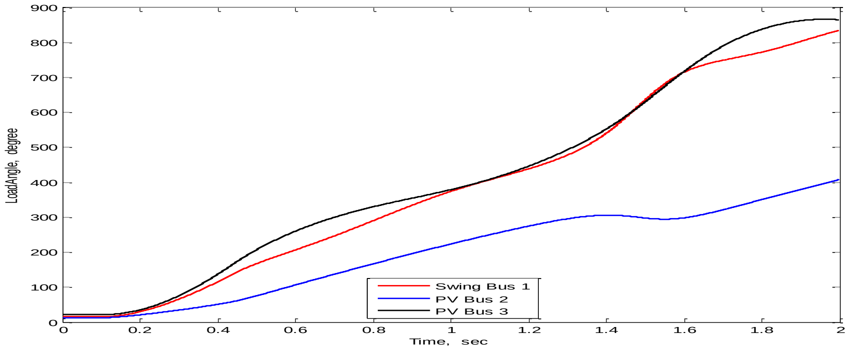

Figure 7. Generator rotor angle response for fault cleared after the critical clearing time

Further simulations were carried out at different locations and it was observed that if faults are cleared rapidly the angular deviation is less and the system stability is assured. The angular deviation increases if the fault clearing time increases and ultimately if the fault is cleared after the critical clearing time, the system will lose synchronism. Table 1 shows the critical clearing times in millisecond for different fault location in the 7-bus test of the electric utility company.

Table 1: Critical clearing times for faults at different locations in the 7-bus test system

Faulted bus	Line opened	Critical clearing time (ms)
1	1-2	242
2	2-4	271
3	1-3	225
4	1-4	315

4.2 **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 7-bussystem are increased from the base value by 10%, 20%, 30% and 40%. Real example of this case is electrical peak load ofenergy 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 1–2 to clear the fault. Table 4.2 show the impact of the load increment on the CCT. It was observed for this particular case that as the load increased within certain range, the CCT 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)	1400	1540	1680	1820	1960
Critical clearing time (ms)	347	309	271	237	199

4.3 Effect of fault on the synchronous speed

This sub-section is aimed at investigating the response of the generator synchronous speed in relation to the mechanical power input, electrical power output, power angle and the damping of the generator when a fault occurs in the system. Consider a three phase fault on bus 1, which is cleared by opening line 1-2.

In the steady-state, the generators in a power system network operate at equilibrium corresponding to the mechanical power input P_m being equal to the electrical power outputP_e. When a fault occurs in the system, the initial configuration of the system will be lost and since P_m is constant, thenP_m will become greater thanP_e. An excess of the mechanical input P_m over the electrical output P_e accelerates the rotor, thereby storing excess kinetic energy, and the power angle increases. With increase in the power angle, the electrical power P_e will begin to increase until it matches the mechanical power inputP_m. At this point, with the fault cleared, the accelerating power becomes zero but the rotor is still running above synchronous speed; hence the power angle and the electrical power P_e will continue to increase. Now$P_m < P_e$, causing the rotor to decelerate toward synchronous speed until the power angle reaches its critical value. The rotor angle will continue to oscillate back and forth at its natural frequency and the damping present in the generators will cause the oscillations to eventually subside. Figure 8 depicts the deviation from the synchronous speed when the system is perturbed and the eventual return to synchronous speed when the fault was cleared.

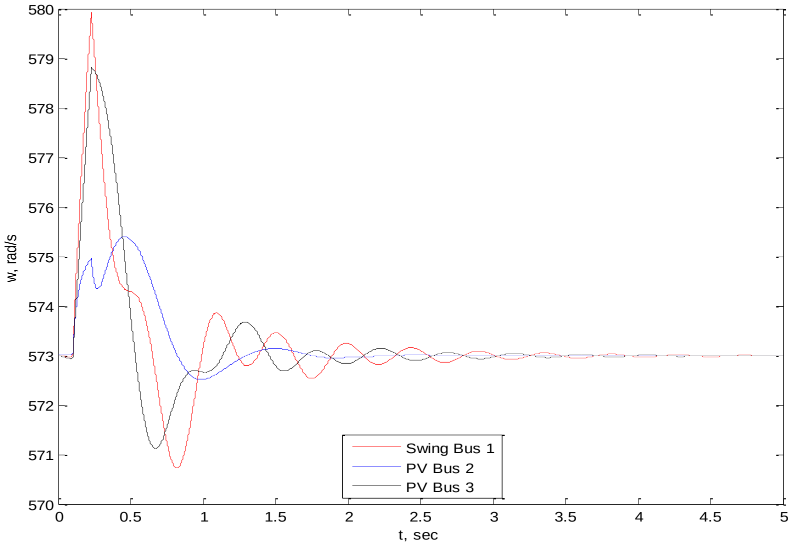

Figure 8. The generators' synchronous speed response when a three phase fault occur

V. 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, such as CCT of the circuit breakers for faults in the system, effect of location of fault within a power system network, effect of operating machines that are poorly damped, effect of load increment on the CCT and effect of fault on the synchronous speed of machines in 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 7-bus test system for an electric utility company using the MATLAB 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.

The results obtained from this study, confirmed and established the findings in previous stability studies regarding these parameters.

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