TRANSIENT STABILITY ANALYSIS ON A MULTI-MACHINE SYSTEM IN PSAT

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Abstract

Modern power system are subject to large disturbances such as three phase short circuit faults. When a fault occurs on a system the generators rotor angle becomes unstable and thus it losses synchronism with the system and it becomes unstable. Thus transient stability analysis can be performed on a system in order to understand the generators performance when subjected to a short circuit fault. When the system is subjected to a fault the generator experiences transient oscillations in rotor speed and angle which can be effectively suppressed with the incorporation of Automatic Voltage Regulator (AVR) and Power System Stabilizer (PSS). The simulations have been performed using the MATLAB/PSAT software.

Keywords—*Transient stability, Three phase fault Faults, AVR, PSS.*

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1. INTRODUCTION

Power system stability has been a very important problem for secure power system operation since 1920s [1-2]. Many major blackouts caused by power system instability have stressed the importance of this phenomenon [3]. Power system stability is defined as the property of a power system that enables it to remain in a state of equilibrium after being subjected to a disturbance [4-5].

Power system stability is mainly categorized as angle stability and voltage stability. Angle stability is the ability of the power system to maintain synchronism and torque balance of synchronous machines. It is further classified as small-signal stability and transient stability. Voltage stability is defined as the ability of the power system to maintain steady state acceptance voltage and reactive power balance. It is further divided as large disturbance voltage stability and small disturbance voltage stability [6].

Transient stability analysis in power system is concerned with the power systems ability to remain synchronously stable following a server disturbance [6-7]. This paper explains the transient stability analysis problems. Here two area system is used as a test system and transient stability analysis has been performed by simulating a three phase fault on the bus. The simulations have been performed using MATLAB/PSAT toolbox [8]. When a three phase fault is simulated on the test system, the system becomes unstable. Thus AVR and PSS are connected to the synchronous generator for decreasing the inter area oscillations making the system stable [9].

The paper is organized in six chapters. Chapter 2 explains the transient stability in detail, chapter 3 discusses the AVR and PSS used for simulation, chapter 4 contains the test system, chapter 5 contains the simulation results and chapter 6 contains the conclusion.

2. TRANSIENT STABILITY

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, loss of generation, or loss of a large load. The system when subjected to such disturbances can affect the generator rotor angles, power flows, bus voltages and other system variables.

Fig 1 shows a single machine infinite bus system, where the generator is represented by the classical model and the speed governor effects are neglected. Fig 2 represents the equivalent circuit of single machine infinite bus system.
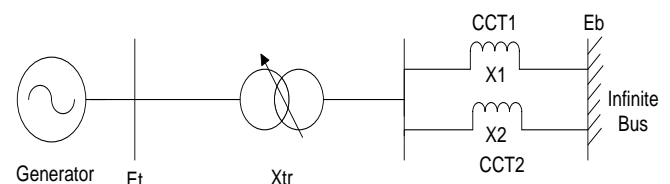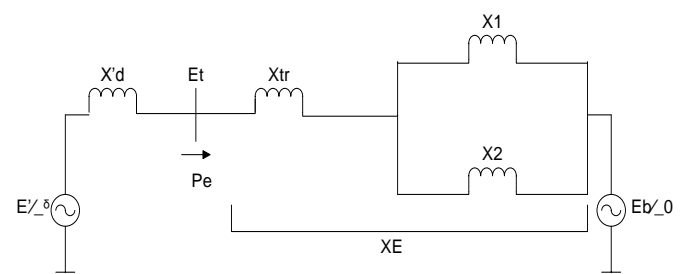

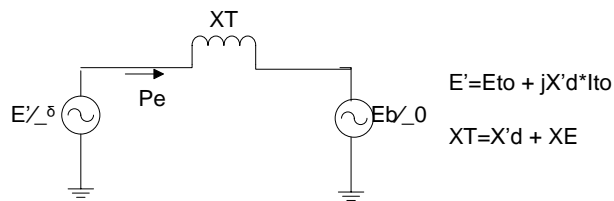**Fig 1:** Single-machine infinite bus system

Fig 2: Equivalent circuit

Fig 3: Reduced equivalent circuit

The voltage behind the transient reactance (X'_d) is denoted by E'. The rotor angle δ represents the angle by which E' leads E_b. When the system is subjected to a disturbance, the magnitude of E' remains constant at its pre-disturbance value and δ changes as the generator rotor speed deviates from synchronous speed ω_0.

Fig 3 is the reduced equivalent circuit of the single machine infinite bus system.

The generators electrical power output is

$$P_e = \frac{E'E_b}{X_T} \sin \delta = P_{max} \sin \delta \qquad (1)$$

Where $P_{max} = \frac{E'E_b}{X_T}$ $\qquad (2)$

Since the stator resistance is neglected, P_e represents the air-gap power as well as the terminal power.
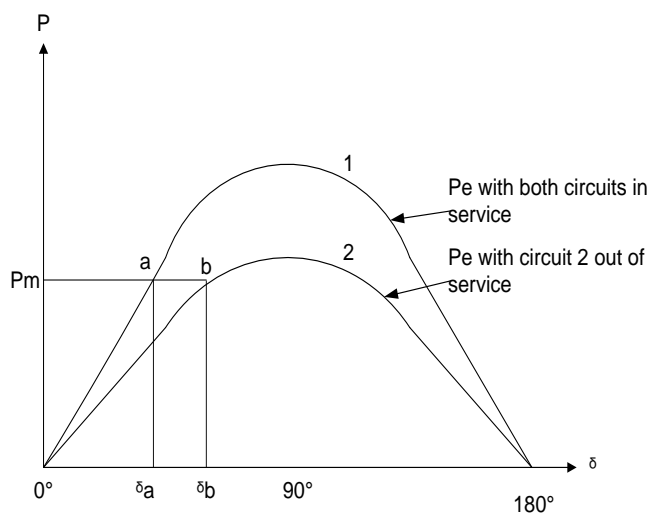
Fig 4: Power-angle relationship

Fig 4 represents the power-angle relationship. There are two curves in fig 4; curve 1 and curve 2. Curve 1 represents the power-angle relationship when both circuits are in service. In this situation when the mechanical input power is P_m, the steady state electrical power output P_e is equal to P_m and the operating condition is represented by point a on the curve and δ_a is the corresponding rotor angle.

Curve 2 represents the power-angle relationship when circuit 2 is out of service. When one of the circuits is out of service, the effective reactance X_T is higher. Hence, the maximum power transfer is low. In this situation, the mechanical input power is P_m, but now the rotor angle is δ_b corresponding to the operating point b on curve 2. Here the rotor angle is higher in order to transmit the same steady state power.

The equation of motion or swing equation ca be written as

$$\frac{2H}{\omega_0} \frac{d^2\delta}{dt^2} = P_m - P_{max} \sin \delta \qquad (3)$$

Where
P_m =mechanical power input, in pu
P_{max} =max electrical power output, in pu
H=inertia constant, in MW.sec/MVA
δ =rotor angle, in electrical radians
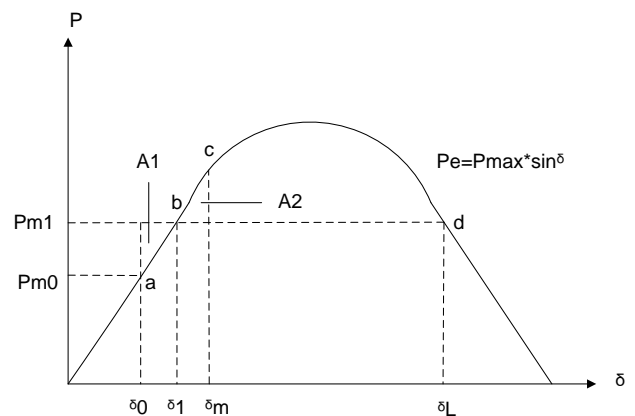t=time, in sec

2.1 Equal-Area Criterion
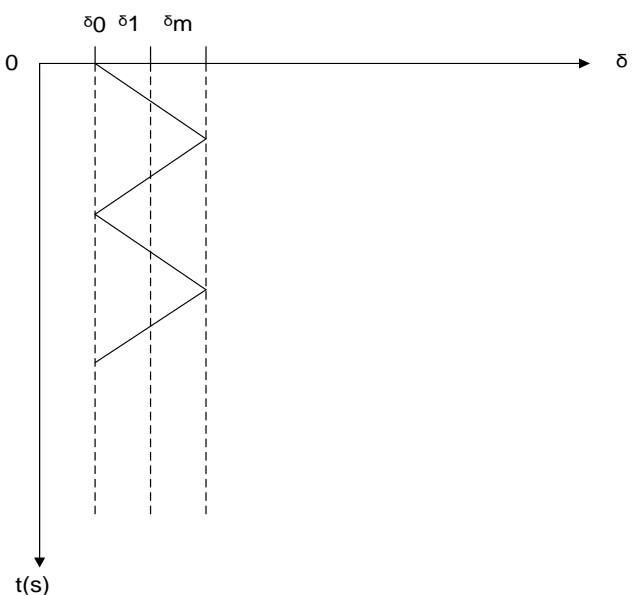

Fig 5: Power angle variation

Fig 6: Rotor angle time response

For the system shown in fig 6 it is necessary to solve the swing equation to determine whether the rotor angle remains stable or not. One of the limitations of the swing equation method is that it is not applicable to multi-machine system with detailed representation of synchronous machines.

The relation between the rotor angle and the accelerating power is

$$\frac{d^2\delta}{dt^2} = \frac{\omega_0}{2H}(P_m - P_e) \qquad (4)$$

Eq(4) cannot be solved directly as P_e is a non-linear function of δ. So, both sides are multiplied by $2\frac{d\delta}{dt}$, then

$$2\frac{dt}{d\delta}\frac{d^2\delta}{dt^2} = \frac{\omega_0(P_m - P_e)}{H}\frac{dt}{d\delta}$$

Or

$$\frac{dt}{d\delta}\left[\frac{d\delta}{dt}\right]^2 = \frac{\omega_0(P_m - P_e)}{H}\frac{dt}{d\delta} \qquad (5)$$

Integrating gives

$$\left[\frac{d\delta}{dt}\right]^2 = \int \frac{\omega_0(P_m - P_e)}{H}d\delta \qquad (6)$$

Initially the speed deviation $\frac{d\delta}{dt}$ is zero. It will change as a result of the disturbance. As shown in fig 5, for a stable operation δ deviates in a bounded region. It also needs to become zero sometime after the disturbance.

So, a criterion of stability can be defined by the following equation

$$\int_{\delta_0}^{\delta_m} \frac{\omega_0}{H}(P_m - P_e)d\delta = 0 \qquad (7)$$

Where
δ_0 = initial rotor angle
δ_m = maximum rotor angle.
Thus, it can be concluded that when area A_1 is equal to area A_2, the system is stable.

The energy gained during acceleration when δ changes from $\delta_0 to \delta_1$ is

$$E_1 = \int_{\delta_0}^{\delta_1} (P_m - P_e)d\delta = area A_1 \qquad (8)$$

The energy lost during deceleration when δ changes from δ_1 to δ_m is

$$E_2 = \int_{\delta_1}^{\delta_m} (P_e - P_m)d\delta = area A_2 \qquad (9)$$

Thus the equal area criterion can be used to determine the maximum swing of δ and the stability of the system without solving the swing equation.
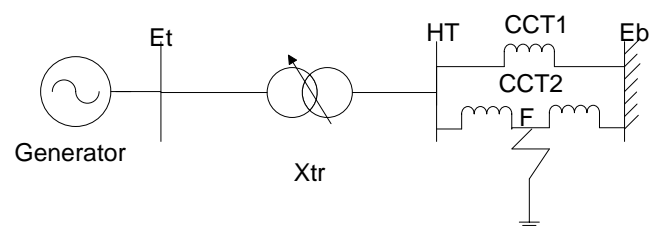
2.2 Response to a Short-Circuit Fault
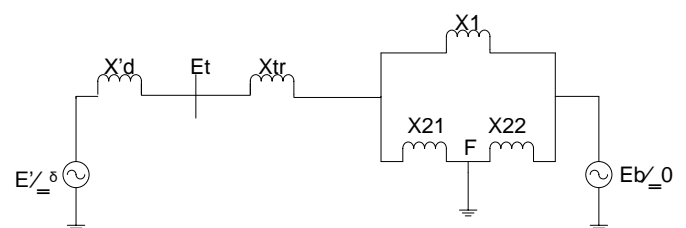

Fig 7: Single-line diagram

Fig 8: Equivalent circuit

Figure 7 represents a single machine infinite bus system, a three phase fault is analyzed at point F. Figure 8 represents the equivalent circuit of the single machine infinite bus system. If the fault location F is near the sending end (HT) no power is transmitted to the infinite bus. But if the fault location F is located some distance away from the sending end, some active power is transmitted to the infinite bus while the fault is still on.

Figure 9 and 10 show power-angle plots for three conditions: (1) pre-fault (2) a three phase fault on circuit 2 at some distance from the sending end and (3) post-fault. Figure 9 represents a stable case while figure 9 represents the unstable case.
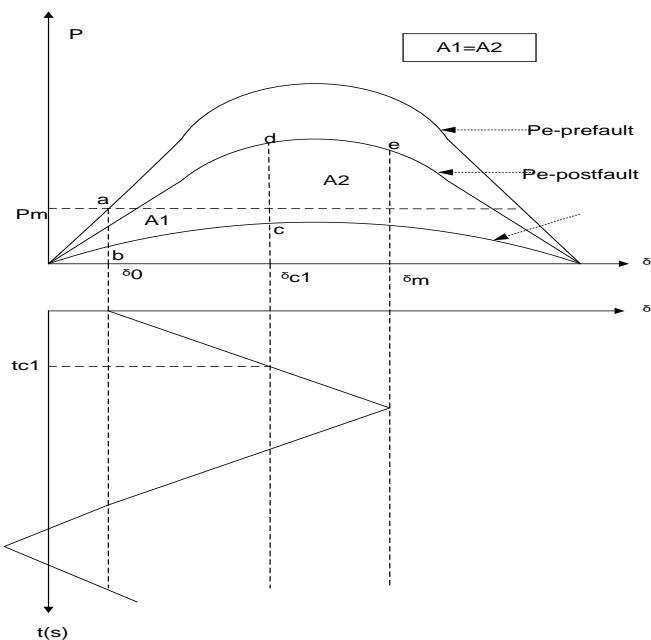
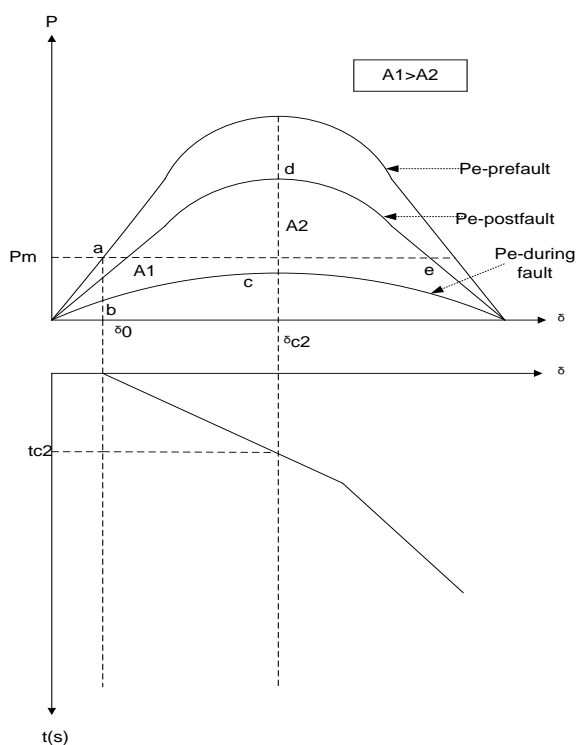**Fig 9:** Response to a fault cleared in t_{c1} seconds-stable case

Fig 10: Response to a fault cleared in t_{c2} seconds-unstable case

3. AUTOMATIC VOLTAGE REGULATOR AND POWER SYSTEM STABILIZER

3.1 Automatic Voltage Regulator

PSAT has three different types of AVRs. AVR type I is a standard Italian regulator, AVR type II is the standard IEEE model 1 and AVR type III is the simplest model which can be used for rough stability evaluations [8].

The model used in this paper is AVR type III and shown in fig 12. It is described by the following equations:

$$\dot{v}_m = (V - v_m)/T_r \tag{10}$$

$$\dot{v}_r = (\mu_0(1 - \frac{T_1}{T_2})(v_{ref} - v_m) - v_r)/T_2 \tag{11}$$

$$\dot{v}_f = ((v_r + \mu_0\frac{T_1}{T_2}(v_{ref} - v_m) + v_{f0})\frac{V}{V_0} - v_f)/T_\varepsilon \tag{12}$$

Where
v_m =Indexes of state variable
T_r =Measurement time constant
v_r =Regulator voltage
μ_0 =Regulator gain
T_1 =Regulator zero
T_2 =Regulator pole
v_{ref} =Reference voltage
v_f =Field voltage
v_{f0} =Field voltage offset
v_0 =Bus voltage offset
T_ε =Fixed small time constant
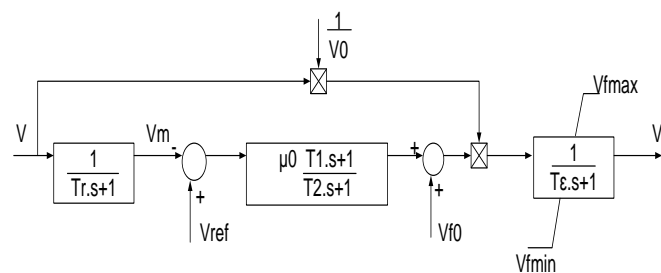
Fig 12: AVR type III

3.2 Power System Stabilizer

PSS are used for damping power system oscillations. PSAT provides five models of PSS [8]. The model used in this paper is type II which is shown in fig 13. It described by the following equation:

$$\dot{v}_1 = -(K_w v_{sI} + v_1)/T_w \tag{13}$$

$$\dot{v}_2 = ((1 - \frac{T_1}{T_2})(K_w v_{SI} + v_1) - v_2)/T_2 \tag{14}$$

$$\dot{v}_3 = ((1 - \frac{T_3}{T_4})(v_2 + (\frac{T1}{T2}(K_w v_{SI} + v_1))) - v_3)/T_4 \tag{15}$$

$$\dot{v}_S = (v_3 + \frac{T_3}{T_4}(v_2 + \frac{T1}{T2}(K_w v_{SI} + v_1)) - v_S)/T_\varepsilon \tag{16}$$

Where

v_1 =Indexes of the state variable v_1

v_2 = Indexes of the state variable v_2

v_3 = Indexes of the state variable v_3

v_s = Indexes of the state variable v_s

K_w =Stabilizer gain

T_w =Wash-out time constant

T_1 =First stabilizer time constant

T_2 =Second stabilizer time constant

T_3 =Third stabilizer time constant

T_4 =Fourth stabilizer time constant
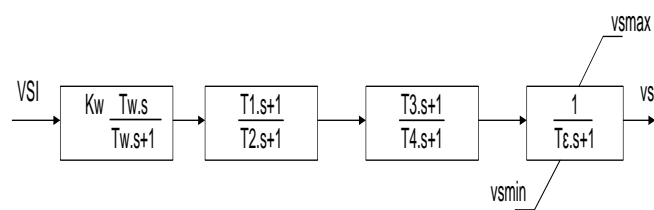
T_ε =Small time constant

Fig 13: PSS type II

4. TEST SYSTEM

The test system used here is two area system. The system consists of four generators, four step-up transformers, two loads and two shunt capacitors. The data for the system has been taken from [6]. The system is shown in figure 11.
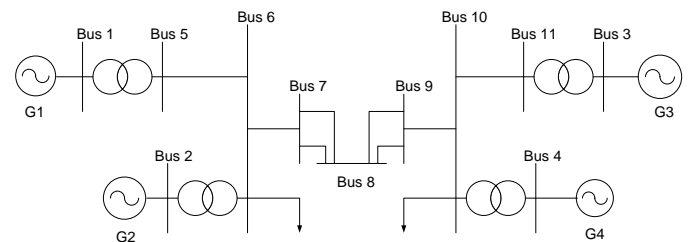
Fig 11: Two Area System

Here two cases are simulated:

Case (1) all synchronous generators are considered without the effect of AVR and PSS and

Case (2) all Synchronous generators are considered with the effect of AVR and PSS.

5. SIMULATION RESULTS

The simulation has been performed in MATLAB/PSAT toolbox. As discussed earlier the test system used is two area system. A three phase fault is simulated on the system. The fault is simulated at 5s and the fault clearing time is 5.25s.

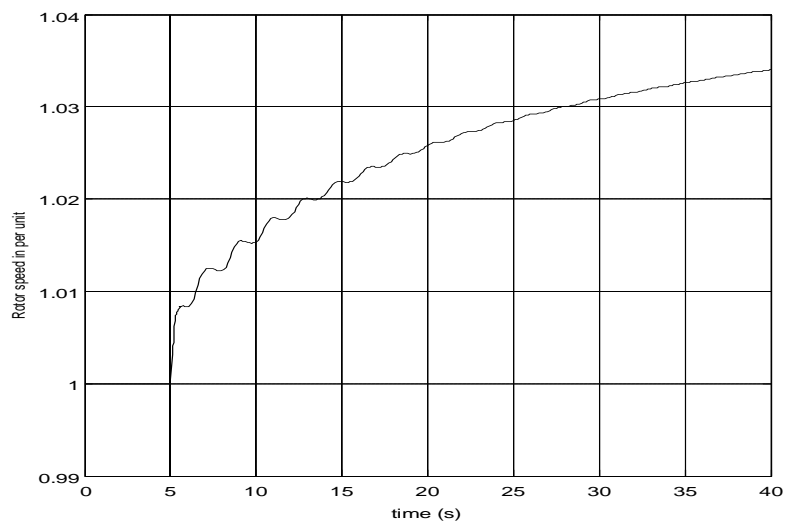Case (1) all synchronous generators are considered without the effect of AVR and PSS
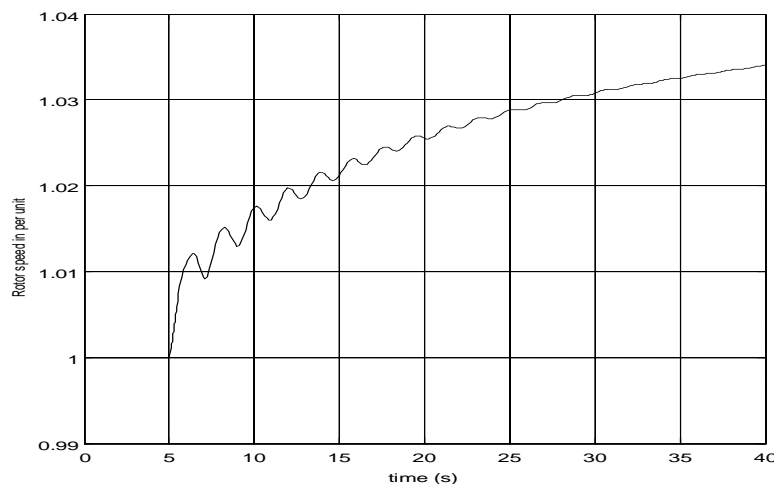
Generator 1:
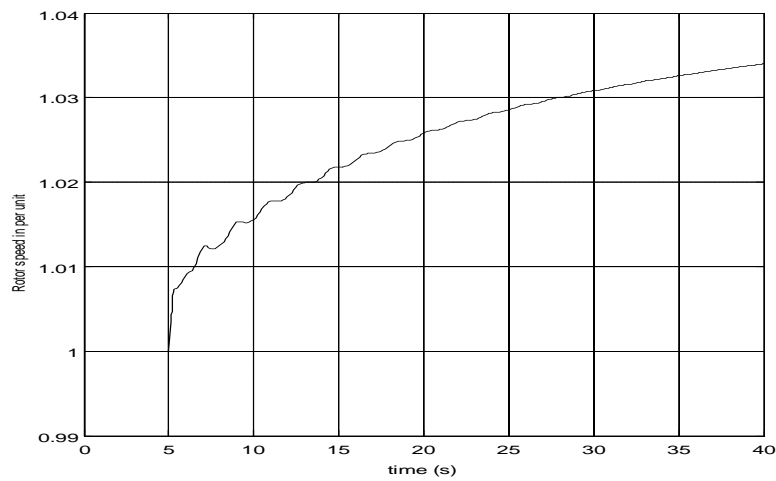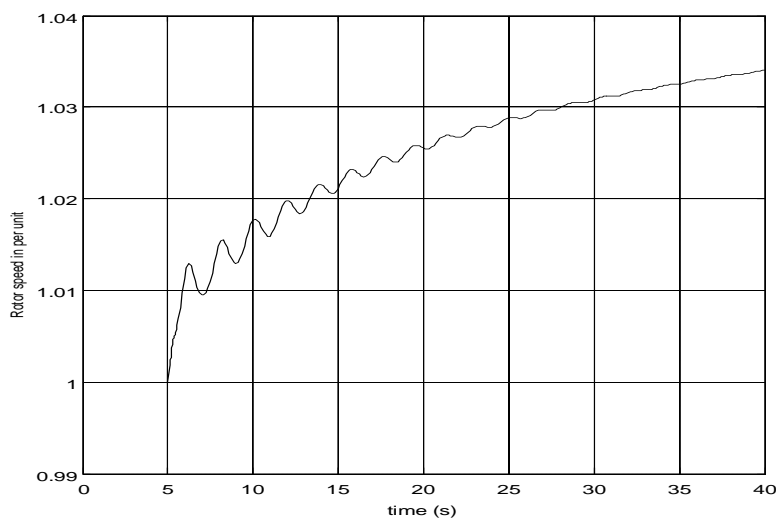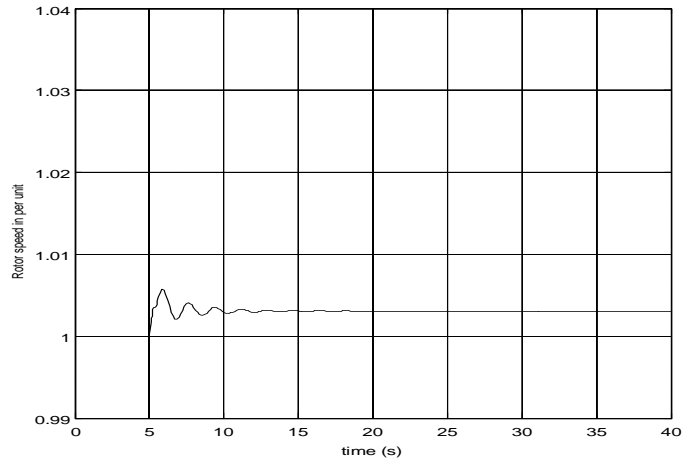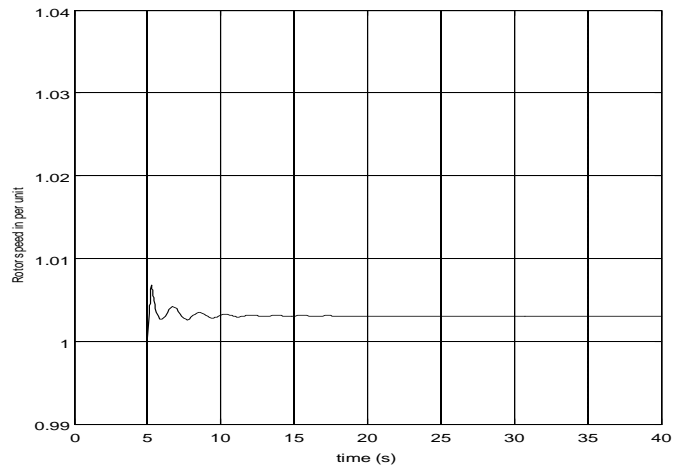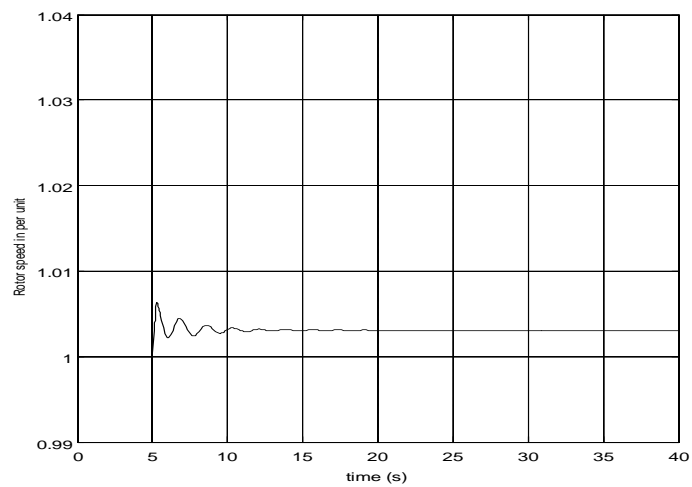
Generator 2:

Generator 3:

Generator 4:

Fig 14: Rotor speed for case (1)

Case (2) all Synchronous generators are considered with the effect of AVR and PSS

Generator 1:
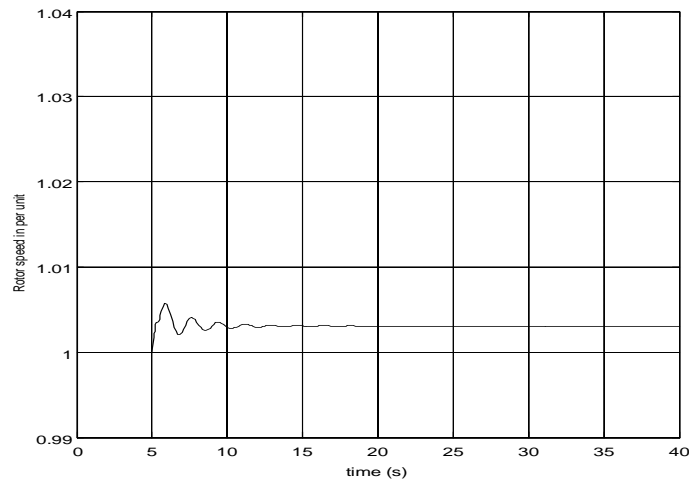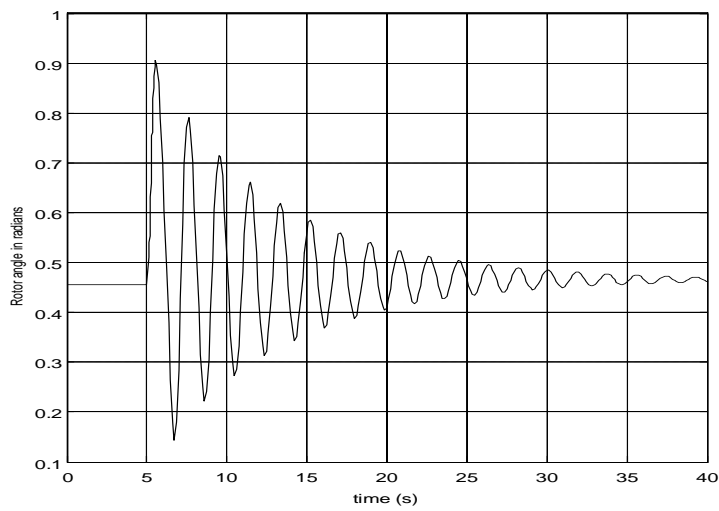

Generator 2:
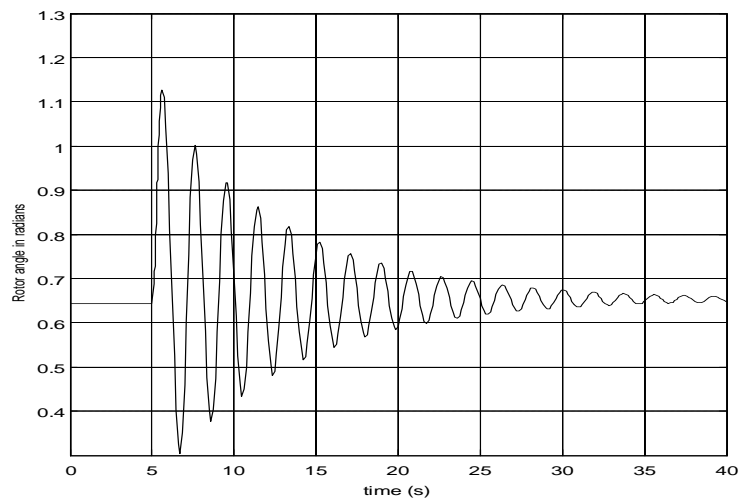

Generator 3:

Generator 4:

Fig 15: Rotor speed for case (2)

Case (1) all synchronous generators are considered without the effect of AVR and PSS and
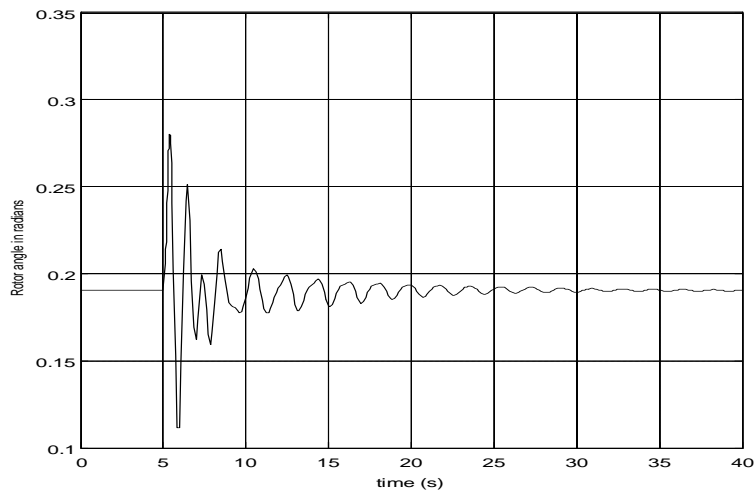
Generator 2:
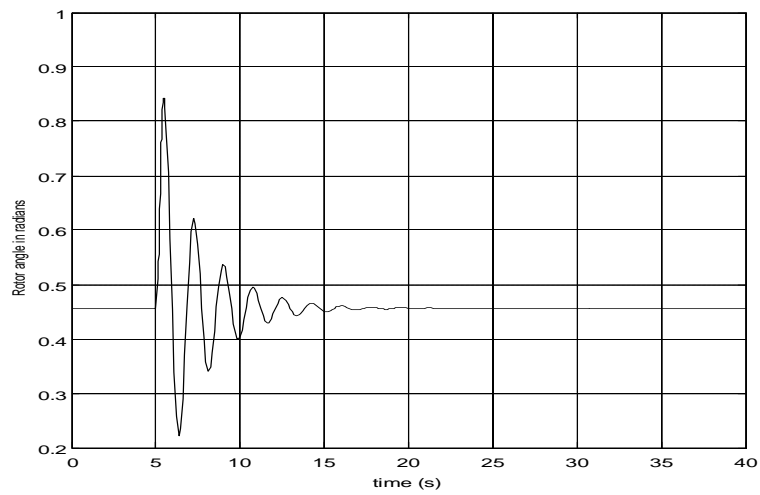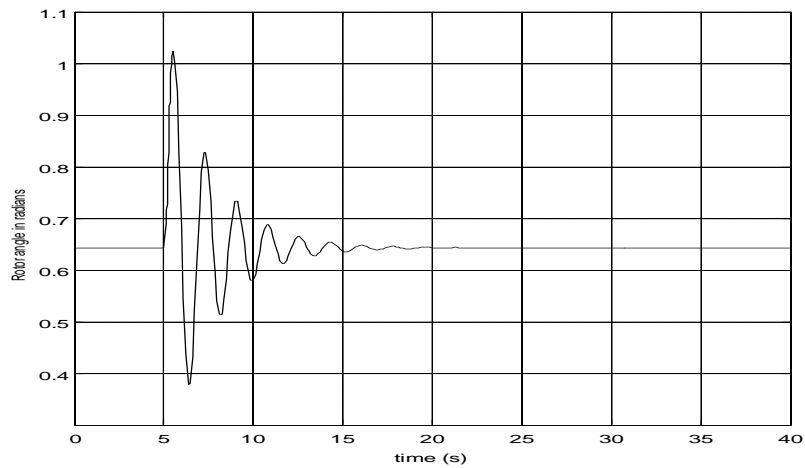

Generator 3:

Generator 4:

Fig 16: Rotor angle for case (1)

Case (2) all Synchronous generators are considered with the effect of AVR and PSS.
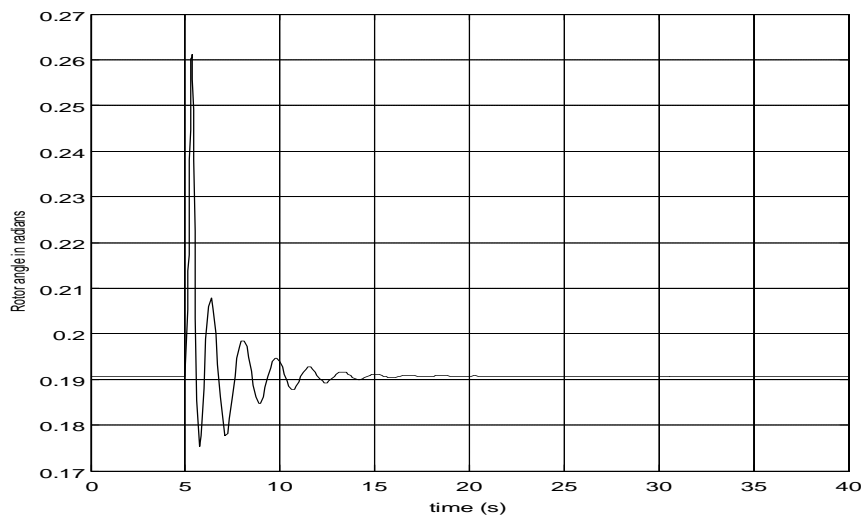
Generator 2:

Generator 3:

Generator 4:

Fig 17: Rotor angle for case (2)

As seen in figure 14 and 16, the rotor speed and angle have large oscillations which makes the system unstable. Thus in order to reduce these inter-area oscillations AVR and PSS are connected to the synchronous generator which reduce the oscillations of the rotor speed and angle and make the system stable. The results of the case (2) rotor speed and angle can be seen in figure 15 and 17.

6. CONCLUSION

Transient stability analysis is performed on a two area system by simulating a three phase fault on a bus in MATLAB/PSAT. From the results it can be concluded that the system becomes unstable when subjected to a three phase fault but when AVR and PSS are connected to the synchronous generator the inter-area oscillations can be damped effectively.

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