Comparison between Symmetrical and Unsymmetrical Fault on Multimachine Power System

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***Abstract*— Power system stability is the ability of a system to regain its stable condition after occurring of some form of disturbances. These disturbances create many problems due to the complexity in modern power systems resulting from number synchronous machines are connected. With recent technologies, Flexible AC Transmission System (FACTS) devices is used in the system for better utilization. This paper presents the modelling and simulation of Thyristor controlled series compensator (TCSC) used in multi-machine power system for symmetrical and un-symmetrical fault and compare their performances. It has been observed that settling time of oscillations and first peak of line power, rotor angle deviation and bus voltages after the occurrence of fault are decreased in case of L-G fault and when TCSC controller is used. After rigorous comparison, it has been found that symmetrical fault is severe than the un-symmetrical fault and proposed TCSC controller has marvelous performance in rapid mitigation of power system oscillations thereby improving the stability of the system..**

***Keywords*— FACTS devices, TCSC controller, Power System Stabilizer (PSS), L-G fault, 3-phase fault.**

I. Introduction

With increased in demand and utilization of electrical energy, power utilities throughout the world are placing great prominence on raising the stability limits of the system and power system stability is taken as an important problem for severe system operation [1 - 3]. Basically, power system stability is the capability of a power system to retain synchronism after the occurrence of disturbances [4 5]. The occurrence of instability in power system is due to the large number of interconnections, types and variations of loads etc. [6]. One effective solution for stability problem is fitting PSS. The PSS is taken as the first order controller for mitigation of power oscillation which is used to be in excitation control [7]. But in power system, use of PSS alone is not sufficient for mitigation of inter-area oscillations [8, 9].

With advance technology, power electronics introduces the use of FACTS devices for enhancement of power system stability because FACTS controller operate very fast [10]. They can sustain the bus voltages at desired level and enhance the stability of power system network [11]. They also control active and reactive power simultaneously [12 13].

FACTS devices are classified as series or shunt connected. This paper presents the modelling of TCSC for damping of power system oscillation which is a series connected FACTS device and it allows fast and continuous changes in transmission line impedance [14, 15, 16]. It has many advantages like it can reduce the net losses of system, provide voltage support, mitigate sub-synchronous resonance (SSR), damped out the power system oscillations and finally increase the power system stability.

The PSS is effective in damping the power system oscillation. But there are some cases where PS Stabilizers are unsuitable for damping the inter area oscillations [17]. So, this paper proposes the simultaneously use of PSS and TCSC controller in multi machine power system.

In this paper II section describes the modelling of power system under study with TCSC is presented in section II, which is two machine power system. Section III shows the modelling of PSS and TCSC controller. Results are given and discussed in section IV and conclusion are presented in section V.

II. Power System under Study

Test system used in this work as presented in figure 1. The system consists of two hydraulic generating units. The first unit is of 1000 MVA, 13800V, 50 Hz and second unit is of 5000MVA, 13800V, 50 Hz. These generating units are connected with the load of 5000 MW and have a transmission line of 800 kms in between. The load is located near machine 2. The generators having hydraulic turbine and governor, excitation system.

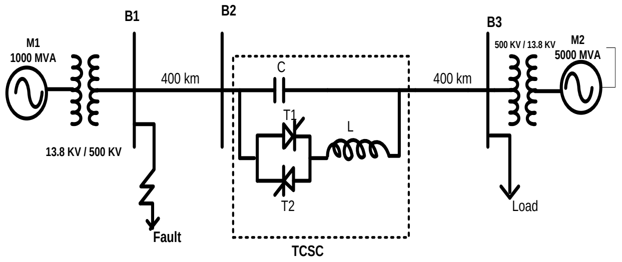

Fig. 1: System under study

The excitation system includes a DC exciter and voltage regulator. The TCSC is placed at the midpoint of the transmission line whose capacitance and reactance are 21.97 µF and 43mH respectively. Symmetrical and un-symmetrical faults are introduced into the system at time 1 seconds and clears at 1.1 seconds.

III. Modelling of PSS and TCSC Controller

A. *Power System Stabilizer (PSS):*

Power system stabilizers can stabilize the voltage output of the system by providing additional external signals to the exciter of the generator. Normally, two types of PSS are present i.e. generic and multiband power system stabilizer. In this work, only generic PSS has been used. The main purpose of generic PSS is to stabilize the generated oscillations in the rotor of machine. These oscillations are referred as power swings. Figure 2 shows the block diagram of generic PSS. It takes the speed deviation dω of machine or accelerated powered P_a as input and generates a signal V_{stab} as output which is feedback to the synchronous machine.

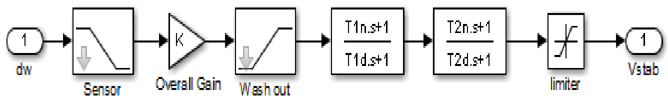

Fig. 2: Generic Power System Stabilizer

B. *Thyristor Controlled Series Capacitor:*

The basic TCSC scheme was introduced by Vithayathil in 1986 as a method of fast adjustment of network impedance. The overall impedance from one end to another end can be decreased by using series compensation thereby increasing the power flow [18]. This ability to control power flow can be used to provide the damping of power system oscillations. It is in series with a capacitor C which is paralleled by a thyristor-controlled reactor (TCR) and L_s as shown in figure 3.

The TCSC can be controlled according to the variation of firing angle α, and according to the firing angle, X_{TCSC} will change in the manner which is shown by the following relation below:

$$X_{TCSC} = \frac{V_{CF}}{\pi} = X_c - \frac{X_c^2(2\beta+\sin 2\beta)}{(X_c - X_L)\pi} + \frac{4X_c^2}{X_c - X_L}\frac{\cos^2\beta}{k^2-1}\frac{(k.\tan k\beta - \tan\beta)}{\pi}$$

Where,

X_c = Nominal reactance of the fixed capacitor C
X_L = Inductive reactance of L which is shunted with C
β = conduction angle, β = π – α
α = firing angle
k = Compensation ratio

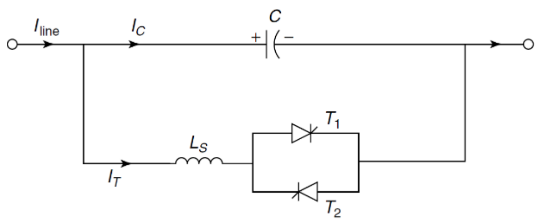

Fig. 3: A basic TCSC module

A TCSC is modeled as a variable capacitive reactance within the operating region defined by limits imposed by α. Thus,

$X_{TCSC\ min} \le X_{TCSC} \le X_{TCSC\ max}$
with $X_{TCSC\ min} = X_{TCSC}(\alpha_{max}) = X_c$
and $X_{TCSC\ max} = X_{TCSC}(\alpha_{min})$

IV. Results and Discussion

The multi machine power system which is shown in figure 1 are tested for LG fault and three-phase fault. The system performance with and without compensation is also analyzed. Figure 4 to 16 show the performance of the system, when faults occur at 1 seconds and clears at 1.1 second. The system has been examined for different cases i.e. firstly for uncompensated system and then the system using PSS only and finally the system using TCSC controller also.

A. *Without compensation*

Figure 4 shows the line power w.r.t time when the system hasn't any compensation. It is clearly seen from the graph that the system is unstable without compensation.

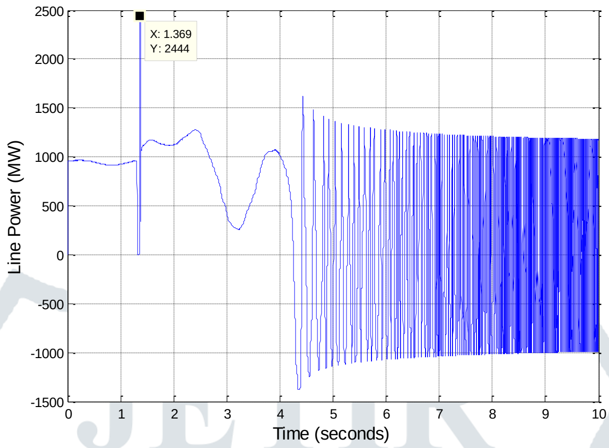

Fig. 4: Line Power Vs time

B. *With PSS only*

Figure 5 to 7 shows the line power, positive sequence voltages of buses and rotor angle deviation when L-G fault is applied to the power system. Figure 8 to 10 shows the graphs of all the above parameters when 3-phase fault is applied on the transmission line. It is observed from these results, that the oscillations are damped out and system become stable. The exact settling time of the oscillations are shown in Table I and II.

Case 1: L-G fault

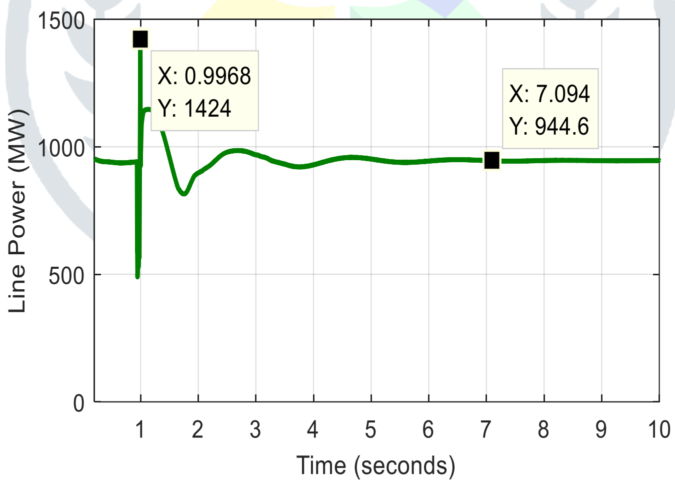

Fig. 5: Line Power Vs time

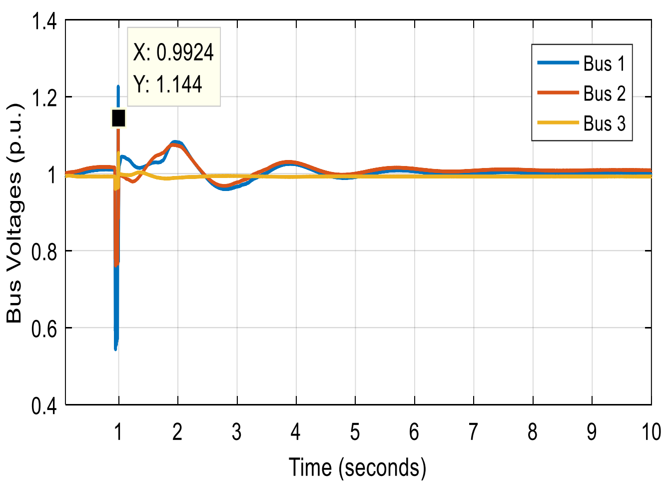

Fig. 6: Positive Sequence voltages of buses Vs time

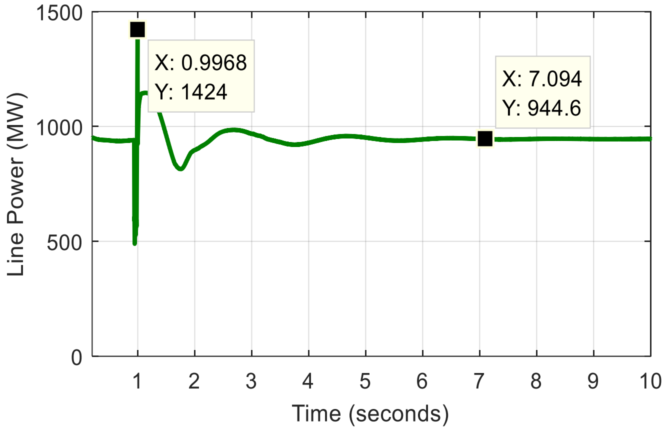

Fig.7: Rotor Angle deviation Vs time

Case 2:For 3 Phase Fault

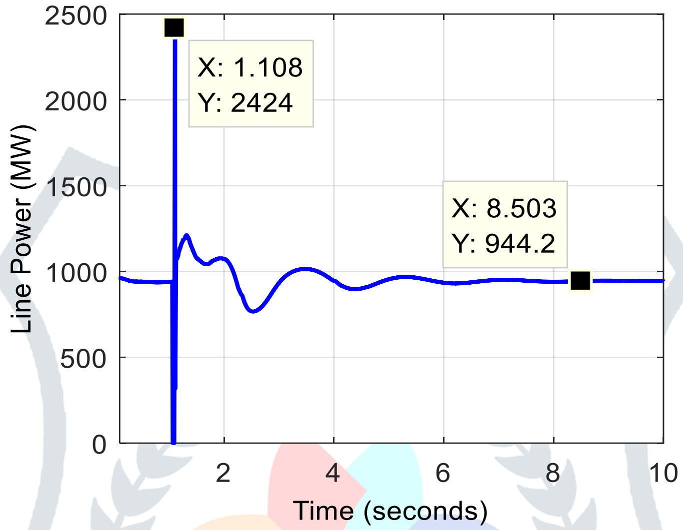

Fig. 8: Line Power Vs time

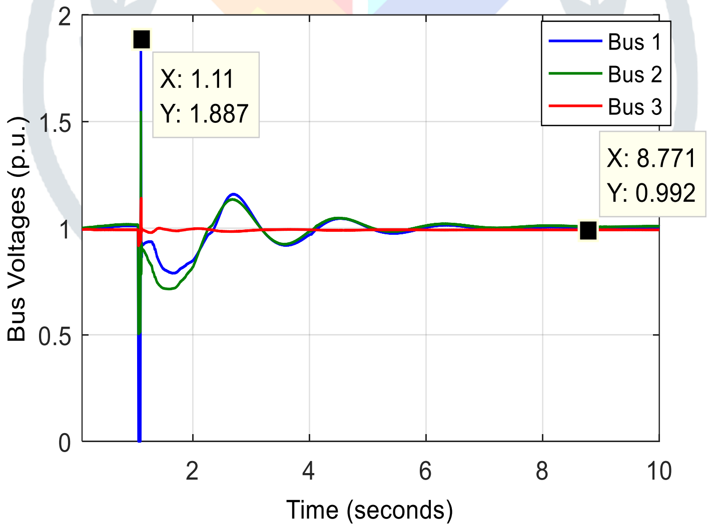

Fig. 9: Positive Sequence voltages of buses Vs time

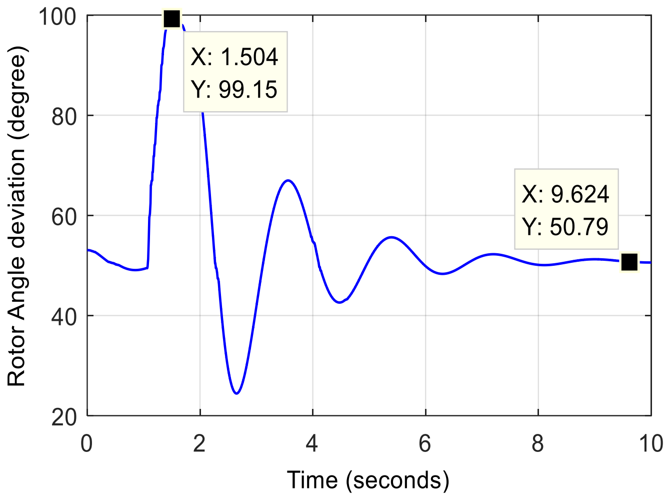

Fig.10: Rotor Angle deviation Vs time

C. With PSS and TCSC controller

The performance of the system using combined control of PSS and TCSC controller are seen from figure 11 to 16. It is evident from these results that oscillations are damped out earlier as compared to the system using PSS alone.

Figure 11 to 13 shows the line power, positive sequence voltages of buses and rotor angle deviation when L-G fault is applied to the power system with TCSC. Figure 14 to 16 shows the graphs of all the above parameters when 3-phase fault is applied on the transmission line. It is observed from these results, that the oscillations are damped out earlier than the system with PSS only. The exact settling time of the oscillations are shown in Table I and II.

Case 1: LG Fault

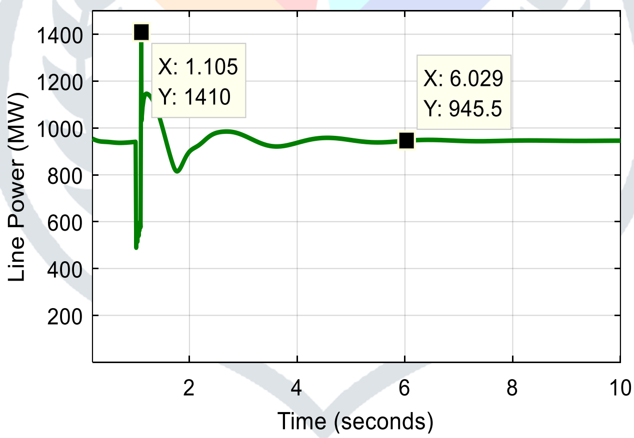

Fig.11: Line Power Vs time

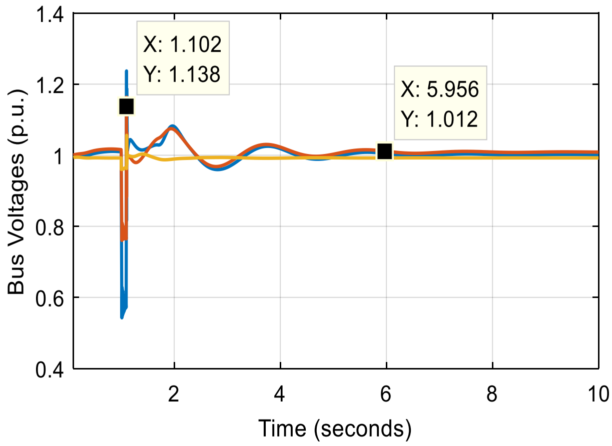

Fig.12: Positive sequence of buses Vs time

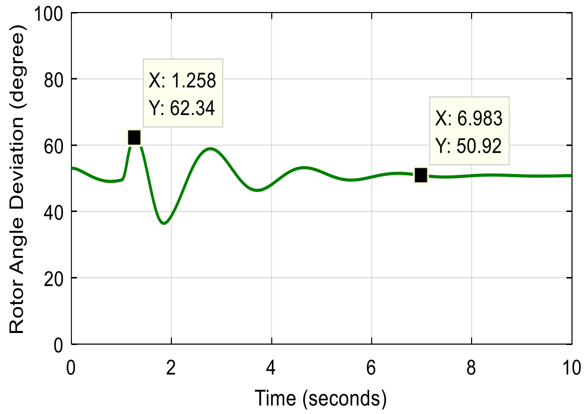

Fig.13: Rotor Angle deviation Vs time

Case 2: 3-Phase Fault

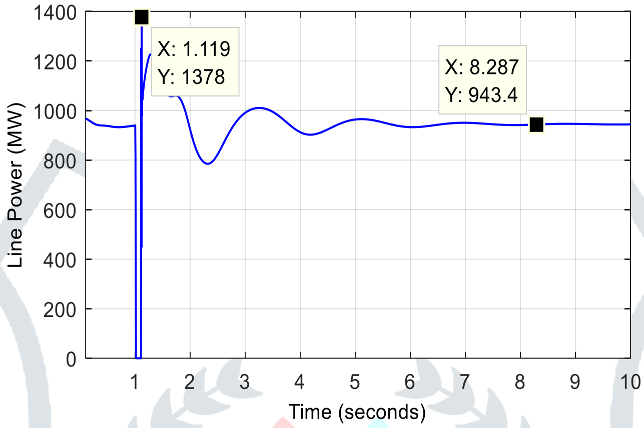

Fig. 14: Line Power Vs time

The settling time of the oscillations are reduced when TCSC is used with PSS which is clearly shown in table I and II. From all the results it is also seen that settling time of the oscillations are less when fault is unsymmetrical. The maximum peak of line power, positive sequence voltages and rotor angle deviation after the occurrence of both the fault was decreased when the system uses TCSC controller. It has also observed that the over shoot peak of the parameters at the time of fault occurrence is higher in case of 3-phase fault. So, it can be said that 3-phase fault is severe than the L-G fault. The exact variation of the peak of different parameter of the system after the occurrence of fault is shown in Table III and IV.

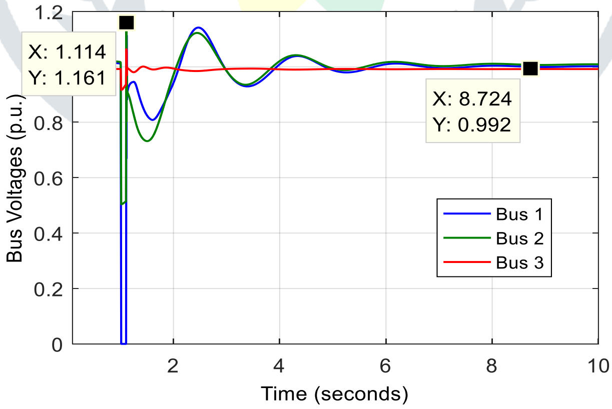

Fig. 15: Positive Sequence voltages of buses Vs time

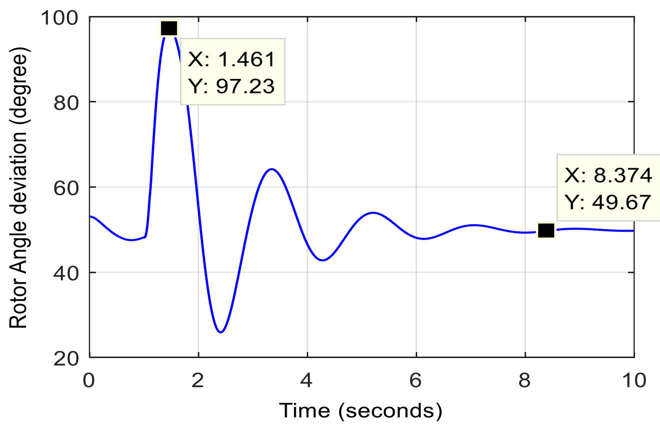

Fig.16: Rotor Angle deviation Vs time

TABLE I: SETTLING TIME OF THE OSCILLATIONS AFTER CLEARANCE OF FAULT (FOR LG FAULT)

	With PSS only (sec)	With PSS and TCSC controller (sec)
Line Power	6.094	5.029
Bus voltage	5.452	4.956
Rotor Angle deviation	7.237	5.983

TABLE II: SETTLING TIME OF THE OSCILLATIONS AFTER CLEARANCE OF FAULT (FOR 3-PHASE FAULT)

	With PSS only (sec)	With PSS and TCSC controller (sec)
Line Power	7.503	7.287
Bus voltage	7.771	7.724
Rotor Angle deviation	8.624	7.374

Table I and II shows the settling time of the oscillations occurred in the line power, bus voltages, and the rotor angle deviation of the system after the clearance of L-G and three-phase fault. It has been seen that the oscillations of line power are damped out approx. one second faster when TCSC controller is used. So, it has been said that proposed TCSC controller has better performance in fast damping of power system oscillations.

Table III and IV shows the maximum peak of line power, rotor angle deviation and bus voltage of the system after the occurrence of L-G and three-phase fault. From this table, it has been observed that the system performance has been improved with coordinated PSS and TCSC controller thereby enhancing the stability of given system.

TABLE III: MAXIMUM PEAK OF OSCILLATIONS AFTER THE OCCURRENCE OF FAULT (FOR L-G FAULT)

	With PSS only	With PSS and TCSC controller
Line Power (MW)	1424	1410
Rotor Angle deviation (deg)	62.45	62.34
Bus voltage (p.u.)	1.144	1.102

TABLE IV: MAXIMUM PEAK OF OSCILLATIONS AFTER THE OCCURRENCE OF FAULT (FOR 3-PHASE FAULT)

	With PSS only	With PSS and TCSC controller
Line Power (MW)	2424	1378
Rotor Angle deviation (deg)	99.15	97.23
Bus voltage (p.u.)	1.89	1.16

TABLE V: COMPARISON BETWEEN L-G AND 3-PHASE FAULT

a. Based on Settling Time of Oscillations

	For L-G Fault (seconds)	For 3-Phase Fault (seconds)
Line Power	5.029	7.287
Rotor Angle deviation	4.956	7.724
Bus voltage	5.983	7.34

b. Based on Maximum Peak overshoot

	For L-G Fault	For 3-Phase Fault
Line Power (MW)	1424	2424
Rotor Angle deviation (deg)	62.45	99.15
Bus voltage (p.u.)	1.144	1.89

Table V (a) and (b) shows the comparison between the symmetrical and unsymmetrical fault based on settling time power oscillations after clearance of fault and maximum overshoot at the time of fault occurrence. It can be seen from table V (a), that the in case of L-G fault, settlement of oscillations is about 2.2 second faster than that of 3-phase fault. From Table V (b), it can observe that the maximum peak of line power at the time of 3- phase fault occurrence is about 1000MW higher than the L-G fault case. Similarly, the maximum peak of Bus voltages and rotor angle deviation is higher in case of 3-phase fault. So, from all comparison it has been observed that the three-phase fault is more severe than the L-G fault and in both types of fault, system performance is enhanced with coordinated PSS and TCSC controller.

II. Conclusions

In this present work, the combined effect of PSS and TCSC controller are investigated. The proposed controller is tested on a multi machine power system for L-G and three-phase faults. It has been concluded from the all results that the settling time and maximum peak of the power system oscillations are reduced in case of L-G fault and when TCSC controller is used in the system. So, two things are concluded from all the comparisons are (i) System with TCSC has better performance and (ii) Symmetrical fault is much severe than the unsymmetrical fault. Hence this proposed design enhances the power system stability which is very effective under different fault conditions.

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