Improvement of Transient Stability of IEEE 14 Bus System by using Series FACTS Controllers

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Abstract—
In this paper Transient stability analysis is done for an IEEE 14 bus system with a three phase fault created at a bus. The simulation is done on PSAT in MATLAB.. It has been found from time domain simulation that series FACTS Controllers i.e. TCSC, SSSC has enhance the transient performance of the system by damping out the power oscillations under large disturbance conditions with less settling time. In this paper three cases are considered i) steady state system ii) faulty system iii) transient stability enhanced system with TCSC and SSSC. The study demonstrates that series FACTS controllers can enhance the transient stability of the power system.

Index Terms: IEEE-14 Bus System, PSAT (Power System Analysis toolbox, SSSC, TCSC, Transient stability, FACTS Controller

1 INTRODUCTION

In interconnected power system there are numerous numbers of generators, transformers, buses, transmission lines and loads. There are undesirable oscillations and transients are produced due to nonlinear characteristics of power system components, small and large signal perturbations. In long transmission lines series compensation, shunt compensation, series and shunt compensation schemes are used in order to enhance the transient stability of the system as well as enhance power transfer capability [3]. PSS, AVR are used to damp out electromechanical oscillations and improve the transient stability of the system. Stability of the power system depends upon the initial operating condition of the system and the severity of the disturbance [14]. Different types of FACTS controllers are used to enhance the power transfer capability and to improve the transient stability of the interconnected system. Series compensation is an effective and economic solution to the problem of enhancing power transfer and improving transient system stability.[2] Some of the advantages of the utilization of FACTS devices in transmission systems are increasing in maximum transmissible power in transmission lines, improving in the stability of transmission systems These advantages are not achievable with traditional mechanical switches based approaches because of lack of continuous control and the necessity of large stability margin with them. The contents of this paper are as follows: First the Series FACTS Controllers, Second the single line diagram of IEEE-14 bus standard system, third the transient stability enhancement of multimachine system using Series FACTS Controllers during prefault, fault and post fault condition. The power flow analysis is done using Newton-Raphson method. By varying the inverter firing angle α the reactive power variation can be instantly achieved and hence improving the transient stability.

2 STRUCTURE AND BEHAVIOR OF SERIES FACTS CONTROLLERS OPERATION OF SSSC

The Static Synchronous Series Compensator (SSSC) is a series connected FACTS controller based on VSC and can be called as an advanced type of Controlled series compensation. SSSC have symmetric capability in both capacitive and inductive operating modes and there is also possibility of connecting an energy source on the DC side to exchange real power with the AC network. The Schematic Diagram and equivalent circuit of SSSC as shown in figure.

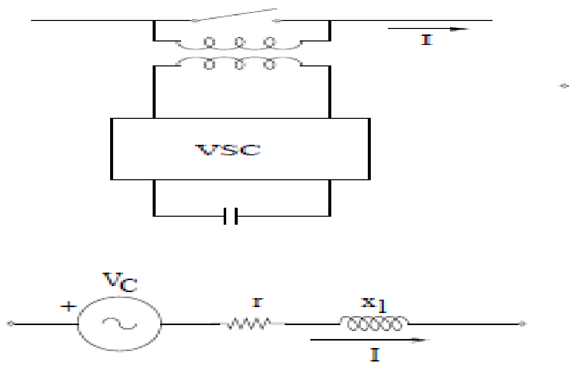


Figure 1: Schematic and equivalent of SSSC

The magnitude of V_C can be controlled to regulate power flow. Assuming the injected voltage is sinusoidal. The winding resistance and leakage reactance of the connecting transformer appear is series with the voltage source V_C. If there is no energy source on DC side neglecting the losses in the DC capacitor and losses in the converter, the power balance in steady state leads to $Re[V_C I^*] = 0$ ………………… (1)

Equation (1) shows that V_C is in quadrature with I. If V_C lags I by 90°, the operating mode is capacitive and the current in the line is increased with resultant increase in power flow. If V_C leads I by 90° the operating mode is inductive, and the line current is decreased [9]. Considering the single line containing a SSSC the derivation of network equations by taking neglecting, zero sequence components, we can express the network equations (using two phase variables α and β) in the complex form as follows $L\frac{d\hat{i}}{dt} + R\hat{i} = \hat{v}_s - \hat{v}_c - \hat{v}_R$

Where $\hat{i} = (i\beta + ji\alpha)$

$\hat{v}_c = v_s\beta + jv_s\alpha$

$\hat{v}_s = v_s\beta + jv_s\alpha$

$\hat{v}_R = v_s\beta + jv_s\alpha$

Transforming from α, β to D-Q components which are related as $\begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} ID \\ IQ \end{bmatrix}$$

2.1 Operation of TCSC

A single line diagram of a TCSC is shown in Figure 2 which shows two modules connected in series. There can be one or more modules depending on the requirement. To reduce the costs, TCSC may be used in conjunction with fixed series capacitors. It can be used in three operating modes:

a) Bypassed mode
b) Inserted with thermistor valve blocked
c) Inserted with vernier control

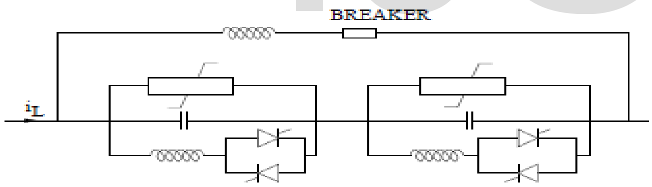


Figure 2: Single line diagram of TCSC

2.2 Single Line Diagram of IEEE 14 Bus System

A single line diagram of IEEE14 bus system is shown in Fig. 3 having loads assumes to be having constant impedance and all generators are operate with constant mechanical input power and with constant excitation. It consists of five synchronous machines with IEEE type-1 exciters, three of which are synchronous compensators used only for reactive power support with generator1 taken as reference generator. IEEE 14 bus data, line data, SSSC Data, TCSC data given in Appendix.

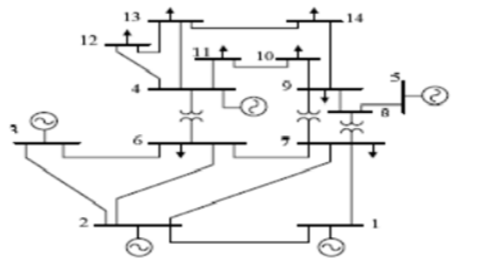


Figure 3: Single Line Diagram of IEEE 14 Bus test system

Power system analysis tool box (PSAT) software is used for the simulation of the result. The main features of PSAT are power flow, continuation power flow, optimal power flow, small signal stability analysis, time domain simulation, phasor measurement unit placement, complete graphical user interface, CAD for network design, user define models, command line usage etc.

3 PSAT MODEL IEEE 14 BUS SYSTEM PREFAULT

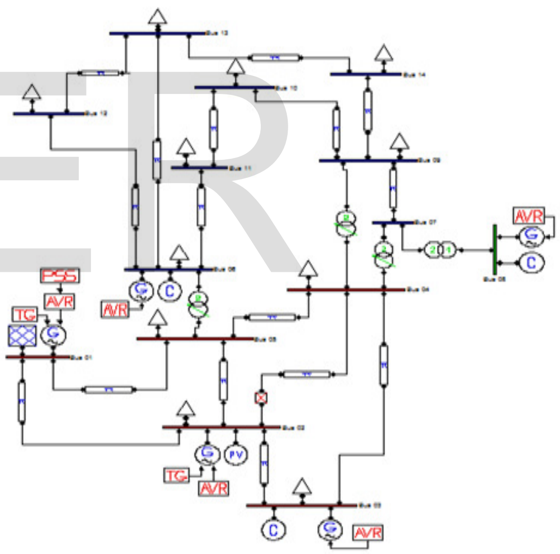


Figure 4: PSAT model of IEEE 14 Bus system

This is the steady state condition that is the prefault condition. Transient stability is more in this condition. The IEEE 14 bus system built using PSAT library. Once defined in the simulink model then load the network in PSAT and solve for power flow. The power flow analysis is carried out for the IEEE 14 bus system using PSAT Software. Load flow study is the steady state condition of the power system network. The NR method for power flow computation using PSAT software as follows: Newton-Raphson Method for Power Flow Computation

C:\Users\dell\Desktop\psat\tests\d_014_pss_l14lokesh(mdl)"
Writing file "fm_call" ...
PF solver: Newton-Raphson method

Single slack bus model
Iteration = 1   Maximum Convergence Error = 0.40086
Iteration = 2   Maximum Convergence Error = 0.015935
Iteration = 3   Maximum Convergence Error = 0.00024325
Iteration = 4   Maximum Convergence Error = 5.7396e-008
Initialization of Synchronous Machines completed.
Initialization of Automatic Voltage Regulators completed.
Initialization of Turbine Governors completed.
Initialization of Power System Stabilizers completed.
Power Flow completed in 0.05 s.
From the above iteration it is clear that the maximum convergence error is 5.7396e-008. Rotor angle-time graph, are plotted for IEEE 14 bus system using PSAT software.

4 PSAT MODEL IEEE 14 BUS FOR FAULT CONDITION

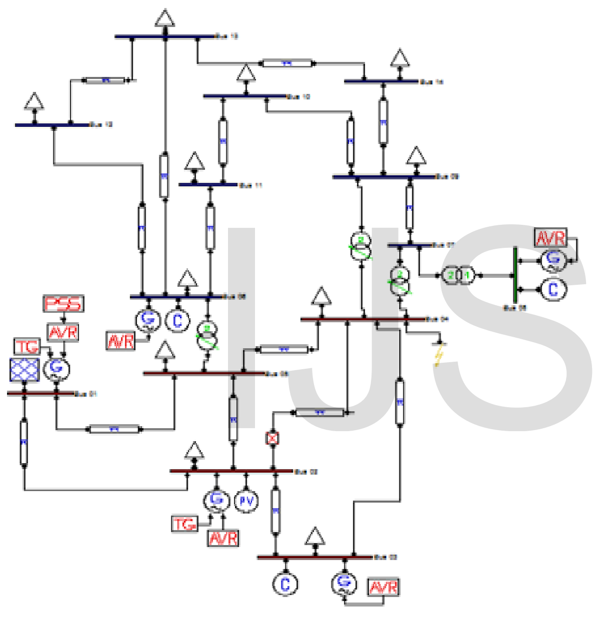


Figure 5: IEEE 14 bus systems during fault condition

Power system has been affected by high electromechanical oscillations whenever there is a disturbance occurs due to loss of a large load, due to fault, sudden loss of generation etc. which may lead to loss of synchronism of generators. Short circuit is a severe type of disturbance. Whenever there is a fault occurs the electrical powers from the nearby generators are reduced severely, whereas the powers from remote generators are extremely affected. However, either the system may be stable even with sustained fault or it may be stable only if the fault is cleared with sufficient rapidity. The stability of the system not only depends on the occurrence and type of fault but also depends on the clearing time, location of fault, and the method used for clearing it.

To create a transient instability a three phase fault occurs at bus no. 4. The introduced fault is a transient fault. The introduced fault time is 0.15s and fault clearing time is 0.25s
"C:\Users\dell\Desktop\psat\tests\d_014_pss_l14lokeshfaultbus4(mdl)"
Writing file "fm_call"
PF solver: Newton-Raphson method
Single slack bus model
Iteration = 1   Maximum Convergence Error = 0.40086
Iteration = 2   Maximum Convergence Error = 0.015935
Iteration = 3   Maximum Convergence Error = 0.00024325
Iteration = 4   Maximum Convergence Error = 5.7396e-008
Initialization of Synchronous Machines completed.
Initialization of Automatic Voltage Regulators completed.
Initialization of Turbine Governors completed.
Initialization of Power System Stabilizers completed.
Power Flow completed in 0.16 s
Voltage-time, rotor angle-time, Power time graph are plotted for IEEE 14 bus system under faulty condition using PSAT software.

5 PSAT MODEL OF IEEE 14 BUS WITH SSSC

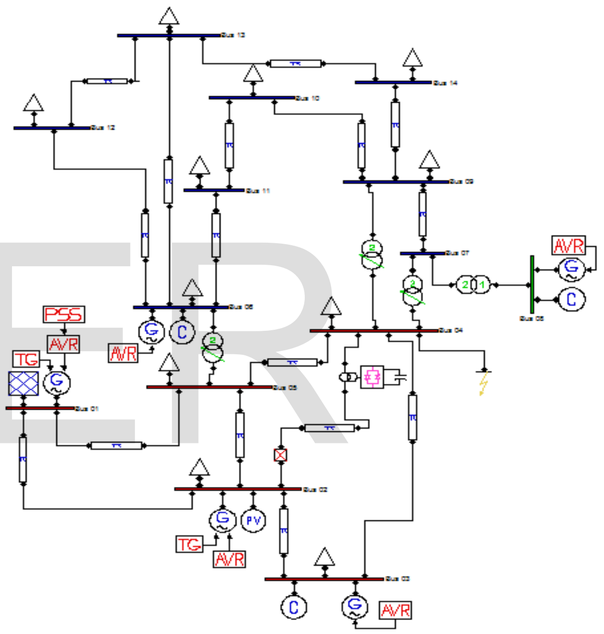


Figure 6: IEEE 14 bus system using SSSC during fault

To create a transient instability a three phase fault occurs at bus no. 4. The introduced fault is a transient fault. The introduced fault time is 0.15s and fault clearing time is 0.25s.
Series FACTS controller i.e. SSSC is added in the circuit at the faulty bus. Rating and other data of SSSC has been given in the appendix. SSSC it is a series FACTS controller device which improves the transient stability of the multimachine system. The stability of the system depends upon the type of fault and the methods used for clearing the fault. It also depends upon the occurrence of the fault and crictical clearing time.
Newton-Raphson Method for Power Flow Computation
Data file
"C:\Users\dell\Desktop\psat\tests\d_014_pss_l14lokeshsssc(mdl)"
Writing file "fm_call"

PF solver: Newton-Raphson method
Single slack bus model
Iteration = 1   Maximum Convergence Error = 0.39906
Iteration = 2   Maximum Convergence Error = 0.020786
Iteration = 3   Maximum Convergence Error = 0.00044594
Iteration = 4   Maximum Convergence Error = 2.074e-007
Initialization of Synchronous Machines completed.
Initialization of Automatic Voltage Regulators completed.
Initialization of Turbine Governors completed.
Initialization of Power System Stabilizers completed.
Initialization of SSSC completed.
Power Flow completed in 0.17 s

Voltage-time curve, rotor angle-time, power-time graph are plotted for IEEE 14 bus system under faulty condition using PSAT software.

6 PSAT MODEL OF IEEE 14 BUS WITH TCSC

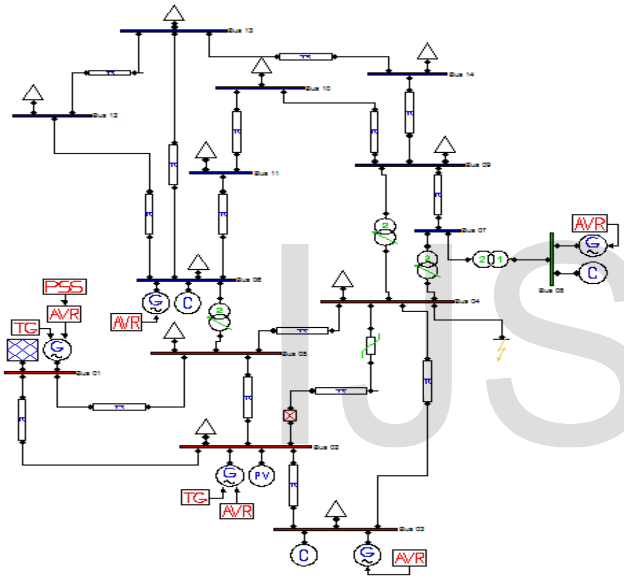


Figure: 5 IEEE 14 bus systems using TCSC in fault Condition

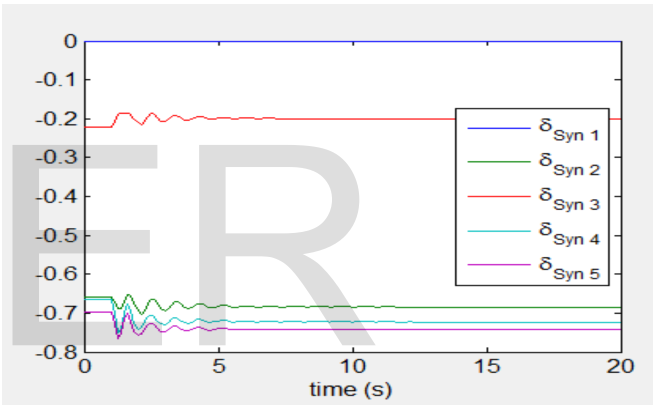
Newton-Raphson Method for Power Flow Computation
Data file
"C:\Users\dell\Desktop\psat\tests\d_014_pss_l14lokeshtcsc(mdl)"
Writing file "fm_call"
PF solver: Newton-Raphson method
Single slack bus model
Iteration = 1   Maximum Convergency Error = 0.38397
Iteration = 2   Maximum Convergency Error = 0.011379
Iteration = 3   Maximum Convergency Error = 0.00013128
Iteration = 4   Maximum Convergency Error = 2.2143e-008
Initialization of Synchronous Machines completed.
Initialization of Automatic Voltage Regulators completed.
Initialization of Turbine Gorvernors completed.
Initialization of Power System Stabilizers completed.
Initialization of TCSC completed.
Power Flow completed in 0.05 s

Voltage-time curve, rotor angle-time, power-time graph are plotted for IEEE 14 bus system under faulty condition with TCSC using PSAT software.

7 SIMULATION RESULTS

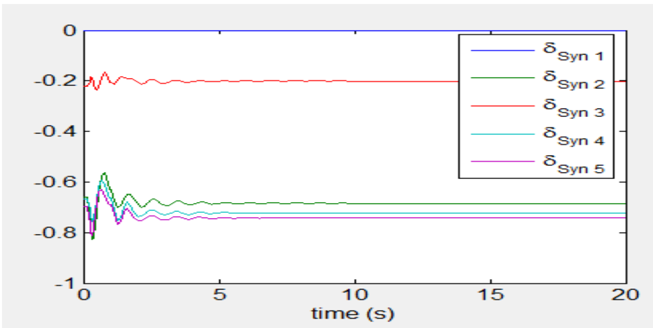
The output of generators during prefault, fault and post fault conditions is plotted using PSAT software. Using PSAT software we obtained the voltage time graph, synchronous generator active power graph with time. From simulation results we can see that before prefault system is stable and after fault system becomes unstable. During the fault the transmitted electrical power decreases significantly while the mechanical input power to the generator remains constant, as a result the generator continuously accelerate and the rotor angle when the fault is cleared at 0.25s the speed is continuously increasing and the system is not able to gain stability due to the lack of damping. Simulation results show that transient stability of the power system has been increased by using FACTS controllers.

PREFAULT CONDITION



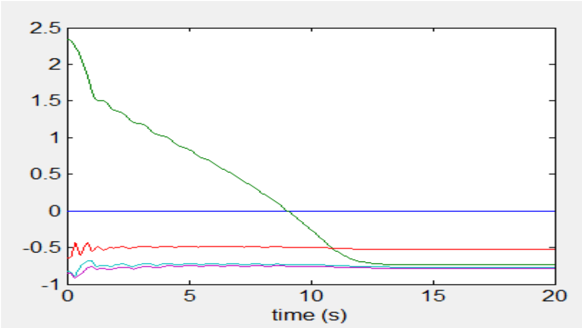
ROTOR ANGLE CURVE PREFAULT CONDITION

FAULT CONDITION



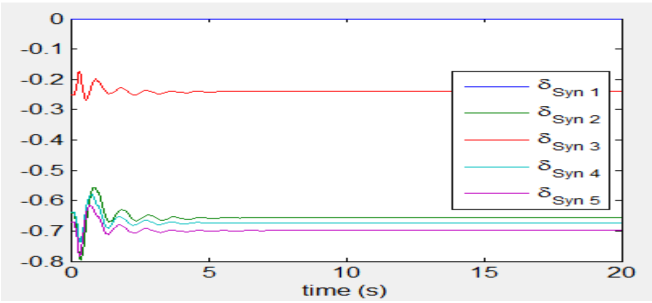
ROTOR ANGLE CURVE FAULT CONDITION

POST FAULT CONDITION WITH SSSC



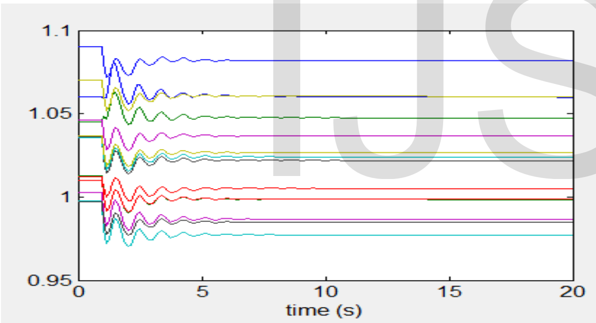
ROTOR ANGLE CURVE WITH SSSC

POST FAULT CONDITION WITH TCSC



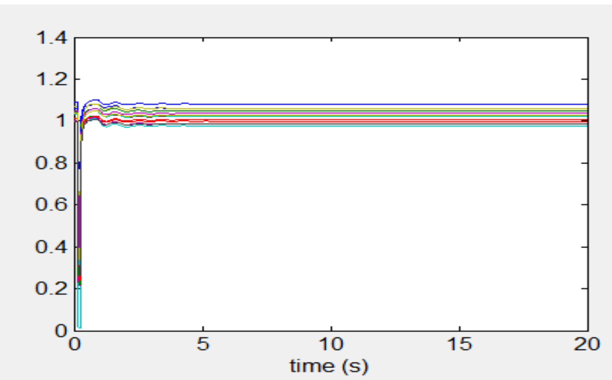
ROTOR ANGLE CURVE WITH TCSC

PRE FAULT CONDITION



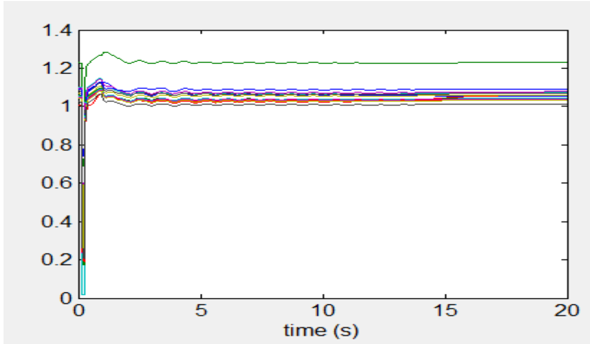
VOLTAGE-TIME CURVE PREFAULT

FAULT CONDITION



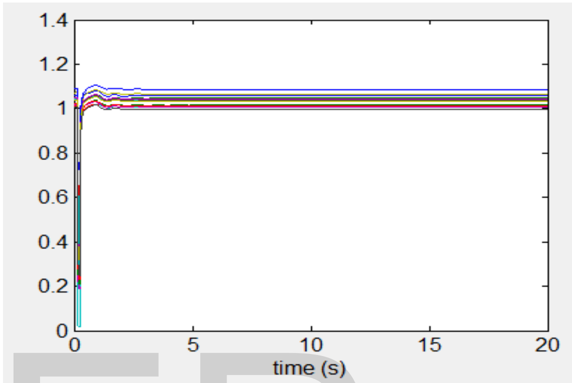
VOLTAGE-TIME CURVE WITH FAULT

POST FAULT CONDITION WITH SSSC



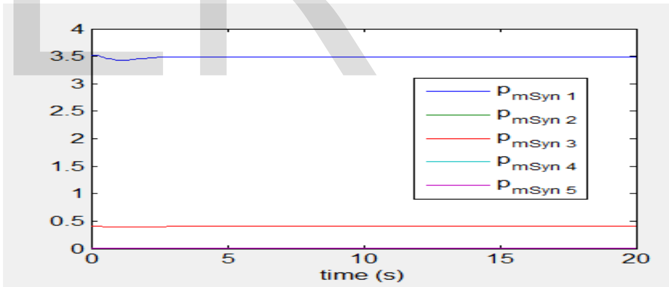
VOLTAGE-TIME CURVE WITH SSSC

POST FAULT CONDITION WITH TCSC



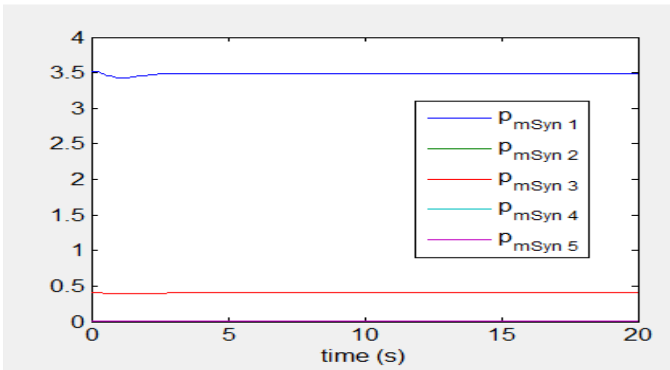
VOLTAGE- TIME CURVE WITH TCSC

PRE FAULT CONDITION



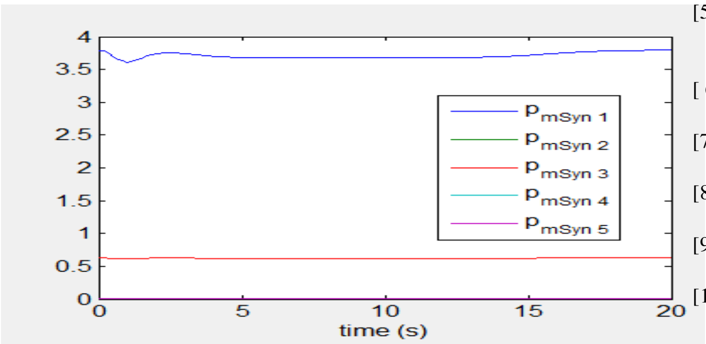
GENERATOR POWER-TIME CURVE PREFAULT

FAULT CONDITION



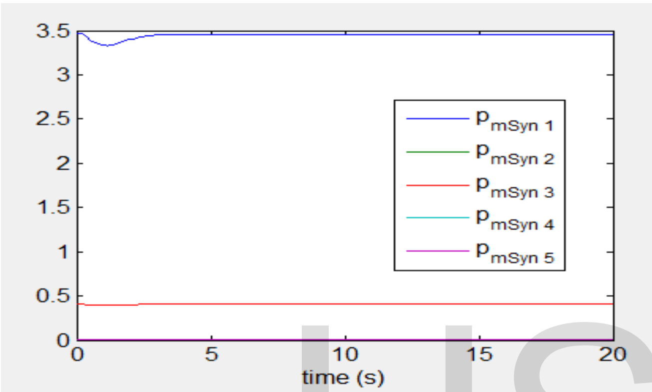
GENERATOR POWER-TIME CURVE WITH FAULT

POST FAULT CONDITION WITH SSSC



GENERATOR POWER-TIME CURVE WITH SSSC

POST FAULT CONDITION WITH TCSC



GENERATOR POWER-TIME CURVE WITH TCSC

8 CONCLUSIONS

In this paper the transient stability enhancement of multimachine system is analyzed. A three phase fault occurs at 0.15 sec and has been cleared at 0.25 sec. The simulation results using PSAT software shows clearly the impact of TCSC and SSSC have enhanced the transient stability of multimachine system. The stability has determined by plotting the rotor angle time by introducing the Series FACTS controller's i.e. TCSC and SSSC in the faulty system. Thus it is concluded that series FACTS controllers helps in enhancing the transient stability of multimachine system.

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APPENDIX

IEEE 14 BUS LINE DATA

LINE No.	FROM BUS	TO BUS	R(p.u.)	X(p.u.)	B/2(p.u.)	Transformer Tap
1	1	2	0.0194	0.0592	0.0264	1
2	1	5	0.0540	0.2230	0.0219	1
3	2	3	0.0469	0.1979	0.0187	1
4	2	4	0.0581	0.1763	0.0246	1
5	2	5	0.0569	0.1738	0.0017	1
6	3	4	0.0670	0.1710	0.0173	1
7	4	5	0.0133	0.0421	0.0064	1
8	4	7	0.0000	0.2090	0.0000	0.978
9	4	9	0.0000	0.5562	0.0000	0.969
10	5	6	0.0000	0.2520	0.0000	0.932
11	6	11	0.0949	0.1989	0.0000	1
12	6	12	0.1229	0.2558	0.0000	1
13	6	13	0.0662	0.1303	0.0000	1
14	7	8	0.0000	0.1763	0.0000	1
15	7	9	0.0000	0.1101	0.0000	1
16	9	10	0.0318	0.0845	0.0000	1
17	9	14	0.1271	0.2703	0.0000	1
18	10	11	0.0821	0.1921	0.0000	1
19	12	13	0.2210	0.1998	0.0000	1
20	13	14	0.1710	0.3480	0.0000	1

IEEE 14 BUS DATA : GENERATION AND LOAD

BUS No.	Bus code	Magnitude (p.u.)	Angle in degree	Generation		Load	
				MW	MVAR	MW	MVAR
1	1	1.06	0	232.4	-16.9	0	0
2	2	1.045	0	40	42.4	21.7	12.7
3	2	1.01	0	0	23.4	94.2	19
4	0	1	0	0	0	47.8	3.9
5	0	1	0	0	0	7.6	1.6
6	2	1.07	0	0	0	11.2	7.5
7	0	1	0	0	0	0	0
8	2	1.09	0	0	0	0	0
9	0	1	0	0	0	29.5	16.6
10	0	1	0	0	0	9	5.8
11	0	1	0	0	0	3.5	1.8
12	0	1	0	0	0	6.1	1.6
13	0	1	0	0	0	13.5	5.8
14	0	1	0	0	0	14.9	5

GENERATOR DATA					
	GEN 1	GEN 2	GEN 3	GEN 4	GEN 5
MVA	615	60	60	25	25
KV	69	69	69	18	13.8
HZ	60	60	60	60	60
Ra (p.u.)	0.00	0.0031	0.0031	0.0014	0.0014
X_L (p.u.)	0.2396	0.00	0.00	0.134	0.134
X_d (p.u.)	0.8979	1.05	1.05	1.25	1.25
X_d' (p.u.)	0.2998	0.1850	0.1850	0.232	0.232
X_d'' (p.u.)	0.23	0.13	0.13	0.12	0.12
T'_{d0} (s)	7.4	6.1	6.1	4.75	4.75
T''_{d0} (s)	0.03	0.04	0.04	0.06	0.06
X_q (p.u.)	0.646	0.98	0.98	1.22	1.22
X_q' (p.u.)	0.646	0.36	0.36	0.715	0.715
X_q'' (p.u.)	0.4	0.13	0.13	0.12	0.12
T'_{q0} (s)	0.80	0.3	0.3	1.5	1.5
T''_{q0} (s)	0.033	0.099	0.099	0.21	0.21

SERIES FACTS CONTROLLER DATA		
	TCSC	**SSSC**
MVA	100	100
KV	69	69
HZ	60	60
Operating Mode	Constant power	Constant power
% Series Compensation	38%	40%
Regulator Time Constant	0.7	0.3
K_p	4	10
K_i	1	5