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Power System Stability Improvement using Thyristor Switched Series Capacitor Facts Device

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***Abstract*— Today power systems play an important role in supplying energy to meet rise in load demand. But this increase in energy is not sufficient to meet the increase in power demand. Alternatively if we installed new power plants than we have to installed new transmission lines in which the cost rises. Due to increase in the power demand continuously and with the deregulation of electricity in the market it is necessary to load the lines up to its maximum thermal limit known as steady state stability limit. It is the maximum flow of power without losing synchronism. This thermal stability limit is limited by transient stability limit. Hence to improve transient stability limit we use facts devices and here series facts device thyristor switched series capacitor is used. It is a discrete control device and the proposed controller is designed. In this paper transient stability of IEEE 9 bus, 3 machine system is designed under severe disturbance under MATLAB Simulink.**

***Index Terms—:* Steady state stability, Transient stability, TSSC FACTS controller, Thyristor Switched Series capacitor (TSSC), MATLAB Simulink**

I. INTRODUCTION

Today power utilities are using variety of new technologies to reduce the risk of power blackouts and minimize the disturbances in the power grid. Many devices have been proposed referred to flexible alternating current devices (FACTS). Of these various facts devices two well known devices belonging to the group of series facts devices are considered here. Thyristor controlled series capacitor which is a continuous device and thyristor switched series capacitor is a discrete device. The basic principle of series compensating facts devices is to alter the reactance of series line and thereby controlling power flow and hence enhance system stability. Disturbances are more severe due to poorly damped systems oscillations, first-swing instabilities and voltage instabilities. This paper mainly focuses on damping power system oscillations and improving voltage profile of the system as instability with respect to voltage profile is studied here. Earlier there was hunting effect in generators and to minimize it we used voltage controlled devices with good inherent voltage capabilities. But it results in lower value of reactance which leads to improved short circuit conditions which tends to instability of the system. Automatic voltage regulators are used to improve power system profile which tends to increase in system reactance and thereby stability is improved. In order to improve system stability and damped oscillations many suitable positions facts device is applied. A controller showing a good performance with one set point is selected for controlling facts devices.

Transient stability is the ability of the system to remain in synchronism even when it is subjected to large disturbances. [1]. So the propose controller can be designed for improving rotor angle as well as for voltage profile. The stability of system can be improved by modern power electronic devices known as facts devices. These devices alter the system operating conditions and absorb active and reactive power and control system reactance and thereby improve stability. In this paper a controller is designed for series facts device thyristor switched series capacitor (TSSC). It is a discrete control device used for operating thyristor at discrete intervals.

This paper comprises of following sections. Section II comprises of reduced system model. Section III comprises of principle of transient stability analysis. Section IV comprises of rotor angle stability. Section V consists of voltage stability. Section VI consists of transient stability improvement strategy. Section VII consists of TSSC facts device and Section VIII consists of controller circuit. Section IX discusses the results and simulation and finally Section X is concluded with conclusion.

II. REDUCED TEST SYSTEM MODEL

For damping the inter area power oscillations, a test system model is shown in fig. 1. The nature of inter area mode of oscillations is to damp the dominant mode of oscillations which is less damped as compared to other modes or poorly damped. With a view to damp these inter area dominant mode of oscillations we consider simple 3-machine test system [4] shown in fig 1. The three machine system is commonly based on 13.8kv/50 Hz system. Series compensation is done here to maintain good voltage profile, power flow transfer capacity and maintain power system stability.

The important goal of TSSC here is to damp dominant mode of oscillation which is of low frequency nearly 1Hz and to improve the rotor angle stability and voltage profile.[2].

To control power flow a TSSC device is placed between bus 1-5, where the system conditions are good.

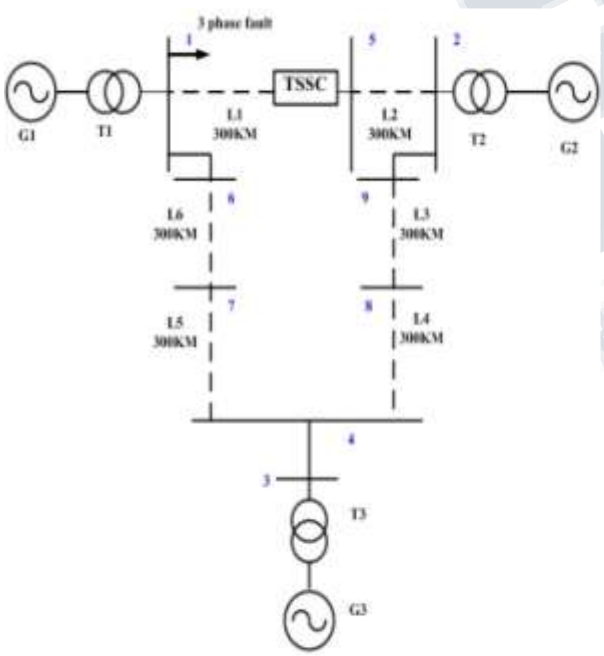

Fig. 1. Single diagram showing fault and TSSC location

III. TRANSIENT STABILITY ANALYSIS

It is the ability of power system to remain its synchronism when subjected to severe faults such as short circuit conditions.[3]. The resulting system response involves large deviations in rotor angles of generator and depends on non linear relationship of power angle. It is mainly caused due to short circuit conditions, sudden load changes and increase in line reactance. As short circuit conditions are more severe therefore transient stability with respect to short circuit i.e. fault conditions is considered.

Transient stability can be improved by series compensation, dynamic braking, clearing fault rapidly and impedance reduction.

Actually first swing stability which is caused due to lack of sufficient synchronizing torque and damping torque is considered for transient stability. Transients caused due to natural phenomenon such as lightning occur occasionally but mainly it is caused due to load switching, breaker switching and short circuit. It causes deviation in voltage and current which when out of equilibrium conditions causes system unstable.

The period of transient is normally limited to 3 to 5 sec and it exists only up to first swing. For power systems with several modes of oscillations and high inertia its period may exist for more than one cycle and for dominant inter area its period is extended up to 10 sec. The nature of occurrence of disturbance is uneven and it changes with the nature of system. So the point of occurrence of most severe conditions is at near the generator bus as the tendency too loose synchronism is more near the generator bus.

IV. ROTOR ANGLE STABILITY

The rotor angle δ which is formed between stator and rotor axis plays an important role in influencing stability. It increases with the increase in load and the maximum power is

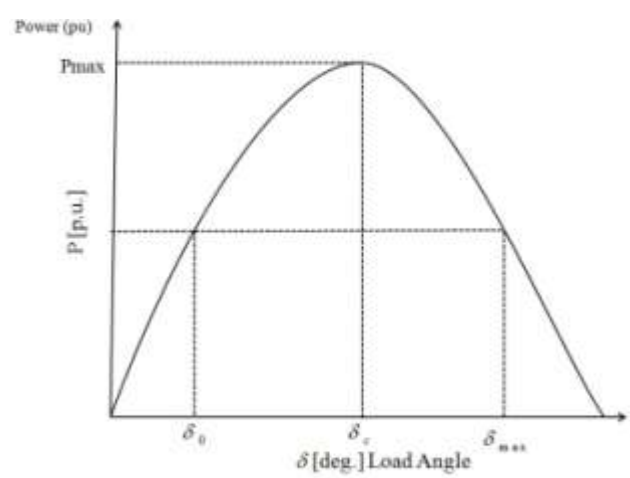

Fig. 2. Power Angle Curve transferred at $\delta = 90^{\circ}$. The steady state equation for power is given as

$$P = \frac{EV}{X_S} \sin \delta \qquad (1)$$

Where line active power P is the input signal, E is sending end voltage, V is the receiving end voltage, X_s is the line reactance and δ is the angle between sending end and receiving end voltage. $\partial p/\partial \delta$ become largest for $\delta = 0^o$ and it decreases as δ approaches to 90^o and becomes zero at $\delta = 90^o$ and turns negative for $\delta > 90^o$. This results that for δ values near to 90^o the compensation will be maximum and for $\delta < 90^\circ$ operating range even small disturbance can produce a correct control signal for damping the oscillations [1].

The relationship between power-angle curve for the relation between transmitted power (P) and load angle (δ) is shown with the help of fig. 2.

Consider a system in which a synchronous generator is feeding power to a load. This transfer of power takes place with the relative difference between sending end and receiving end voltages. The load angle δ is formed between rotor axis and stator magnetic field and it increases with increase in load. But this increase in value of δ takes place from 0° to 90°. During this time the mechanical input of generator increase with increase in load angle. During times, when there is sudden increase or decrease in load or severe faults the rotor will oscillate and goes out of synchronism. Thus results in instability of system. So in order to provide stability during such severe conditions series compensation device i.e. thyristor switched series capacitor is used.

V. VOLTAGE STABILITY

Today's power system with the increase in power demand there is lack of sufficiency of reactive power as already the systems are operating close to their voltage stability limits. This lead to fluctuations in power supply and caused critical disturbances to the power supply network. Due to this system fails to generate adequate reactive power for the balance of power supply and thereby system synchronism is lost. Thus, suitable measures should be taken for improving the voltage stability of system. fig. 3. shows the PV curve where P is the real power flow and V is the receiving end voltage. At no

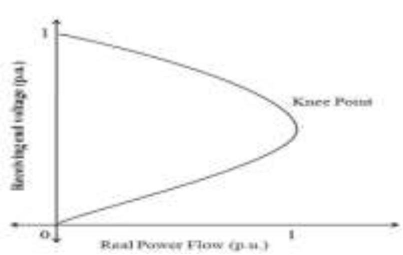

Fig. 3. PV Curve

load the receiving end voltage is 1 p.u. and it drops down with the increase in load demand.

From the fig. 3. the knee point indicates that further increase in power demand result in voltage instability of system. Both series and shunt compensation are used for improving voltage stability limit. Shunt compensators does it by regulating reactive load demand and regulating the terminal voltage and series compensators does it by cancelling a portion of series line reactance and thereby controlling a voltage stiff at the load and improving the voltage profile of the system.

The knee point for two different loads is shown in fig. 4. To the left of the locus the curve decreases with the increase in the receiving end voltage which indicates system with instability. Whereas to the right of locus the reactive power increases with the increase in receiving end voltage and thereby voltage profile and system voltage stability is improved.

The basic criterion for voltage stability is that injection of reactive power should cause corresponding increase in bus voltage and thereby voltage profile is maintained. This is done here by series facts device i.e. thyristor switched series capacitor by injecting negative voltage across impedance which reduces the overall reactance of the line and improves the stability of the system.

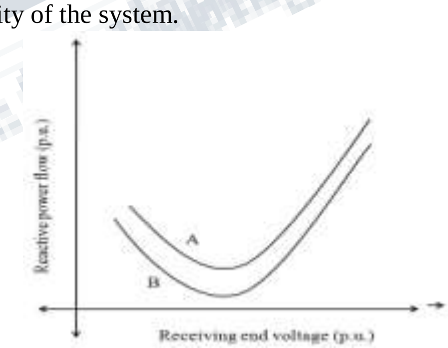

Fig. 4. QV Curve

But, if for any bus in a system, the voltage magnitude decreases after injection of reactive power in the circuit than there is instability in the system.

Thus for a system to operate at stable state, it is necessary to maintain its voltage profile within permissible limits because when a fault occurs on the system it feeds reactive power more and because of that voltage profile of system gets unbalanced and instability takes place. The system is stable with the TSSC series facts device.

VI. TRANSIENT STABILITY IMPROVEMENT STRATEGY

A severe three phase short circuit fault is taken here for severe impact on system for instability and a TSSC device is applied at one of the bus to improve it. fig. 5. shows the improvement in stability for a simple two machine system.

Let the mechanical power be constant throughout. The horizontal line P_m in the figure represents the mechanical power input from the generators. The sinusoidal curves represent the transmitted power from sending end to receiving end with the voltage phase angle between the sending end and receiving end areas.

Assume that severe fault occurs at point A and the power drops to a small value on fault curve at point B. The generators at the sending end are now accelerated with respect to machines at receiving end and the angle separation between them increases. Now as the fault clears at point C by breakers the system will move to post fault curve i.e. C-D-E and it accelerates to the area D-E-H. As further rise in it again increases the electrical power and as mechanical power remains constant, system goes out of synchronism also the deceleration area is smaller than acceleration area A-B-C-D and hence system goes to instability. Now if a series compensation device is placed at point C, for maximizing the compensation than the curve takes path C-D-E-F-G where this area is equal to the area taken by path A-B-C-D and the system becomes stable and oscillation damped out and stability is improved. But if suppose the sufficient compensation is reduced then it will push the power curve

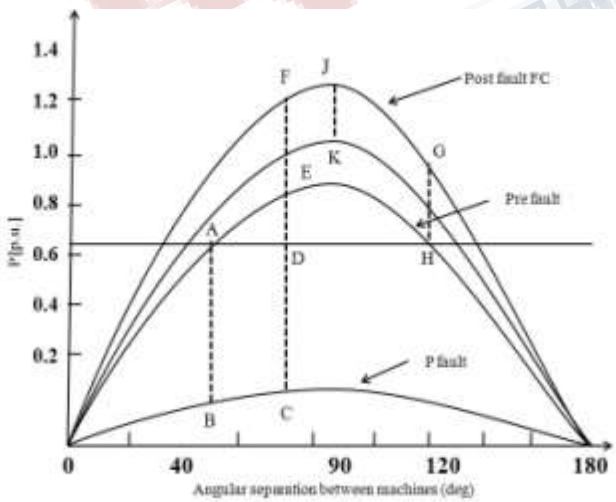

Fig. 5. First swing controller operation after a fault

below the mechanical power flow line and system gets unstable. Similarly if the compensation level is increased than it provides insufficient damping which may again leads the system to instability.[5].

In order to maximize the compensation and to improve stability we have to reduce the compensation level of reactance from X_{tcsc} to $X_{tcscmin}/2$ at point J which will reduce the system deceleration area G-J-F-A-H to G-J-K-A-H which will take place when change in compensation is provided and provides positive damping to the system. The system oscillations damps out and stability is improved.

VII. TSSC FACTS DEVICE

The variable series compensation device is highly effective in both controlling power flow in the line and in improving transient stability. With series compensation the overall effective series transmission impedance from the sending end to the receiving end can be arbitrarily decreased thereby influencing the power flow (1). This capability to control power flow can effectively used to increase the transient stability limit and to provide power oscillation damping. The basic element of a thyristor switched series capacitor [6] consists of capacitor shunted by thyristor bypass valve in fig. 6. The capacitor is inserted into in the line when the thyristor valves are turned off.

A thyristor valve is turned off when the current crosses to zero and capacitor can be inserted into line at zero crossings of line current in fig. 7. But this introduction of thyristor at zero crossing of line current leads to resultant dc offset voltage which impose theoretical limits on thyristor and also caused delay up to one full cycle.

In order to avoid such condition, we should turned on thyristor for bypass only when capacitor voltage is zero. As thyristor switched series capacitor is a discrete controlled device capacitors can be either inserted or bypassed from the circuit. It consists of number of modules of series capacitors connected and it is controlled in a stepwise manner by increase or decrease in the number of capacitors inserted according to the flow of current. Its Matlab Simulink figure is shown in fig. 8.

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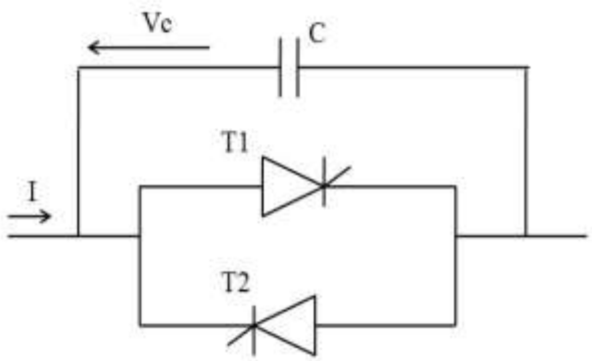

Fig. 6. TSSC facts device

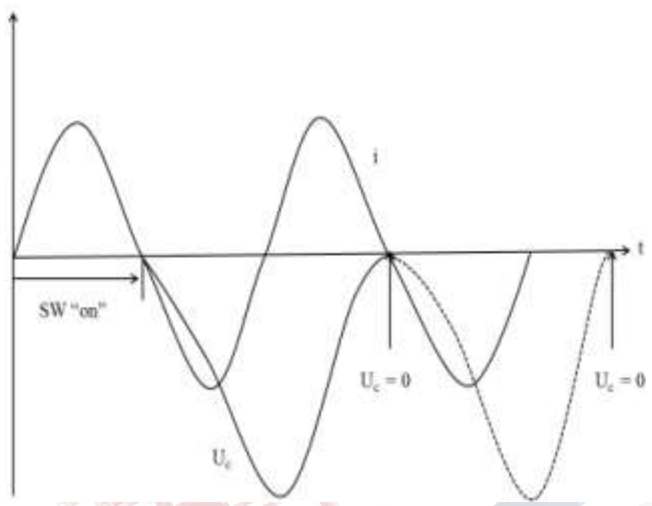

Fig. 7. Capacitor insertion circuit

VIII. TSSC FACTS CONTROLLER

The TSSC controller acting as a power oscillation damping device connected between bus 1 and bus 5 shown in fig. 1. Many suitable positions it is applied but the stability margin gained between bus 1 and bus 5 is more. Voltage across capacitor is used as input signal to generate the output pulses for firing thyristors. The complete controller circuit of Matlab Simulink diagram is shown in fig. 9. The controller circuit here is designed by keeping in view the voltage across capacitor of TSSC facts device.

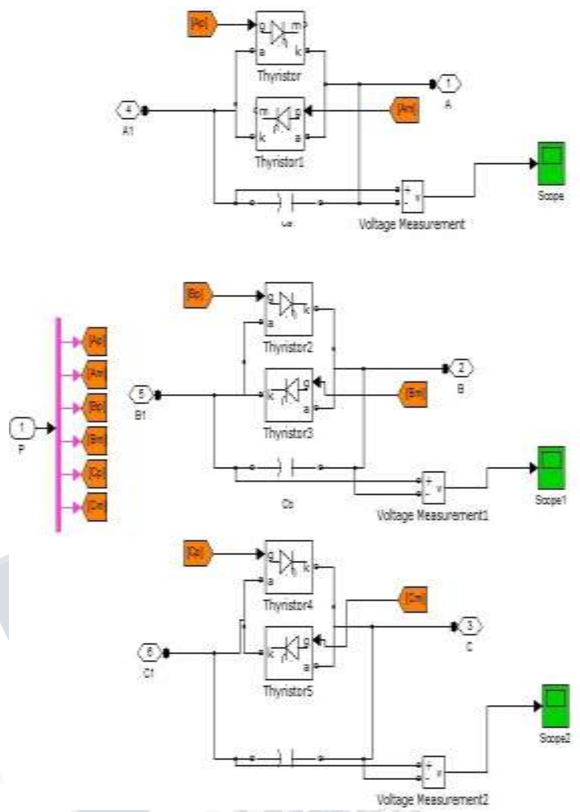

Fig. 8. Simulation diagram of TSSC facts device

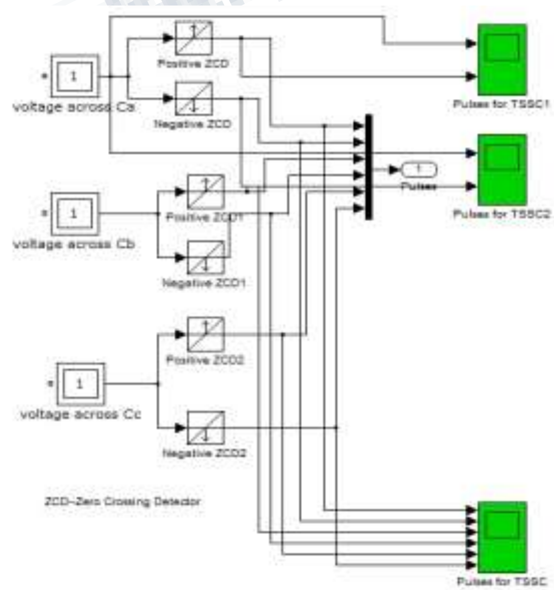

Fig. 9. Controller circuit

In the measurement system it consists of voltage across capacitor of series facts device. This voltage is then compared with the output of zero crossing instants and for every positive and negative crossing instants a thyristor pulses are generated.

The complete waveform with the pulses is shown in fig. 10. As the TSSC is discrete control device it can either insert or bypass capacitor in the circuit with the increase in line current. The controller operates successively for severe faults and used to improve transient stability.

IX. RESULTS AND SIMULATION

Fault is taken near to generator terminals at bus 1 and system is checked for various faults with respect to system instability. The transient time corresponding to system unstable is detected and TSSC facts device is applied between bus 1 and bus 5. As generator 1 is severely affected due to most severe fault i.e. LLLG, swing curves with respect to generator 1 is taken for stability improvement. The rotor angle difference is considered for machine 1 and machine 2.

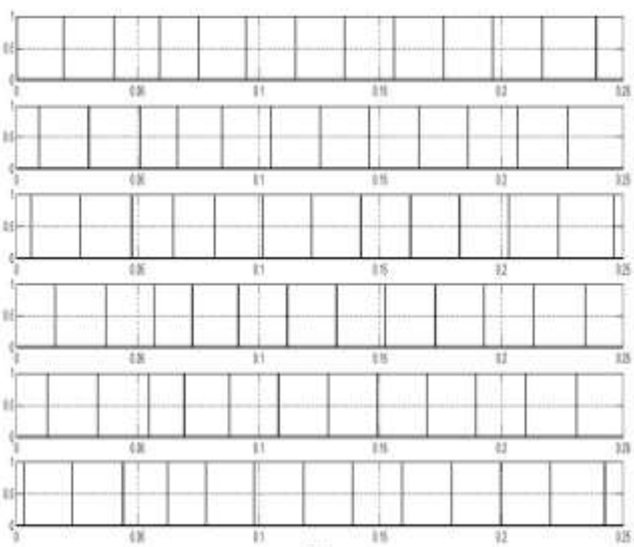

Fig. 10. Output pulses

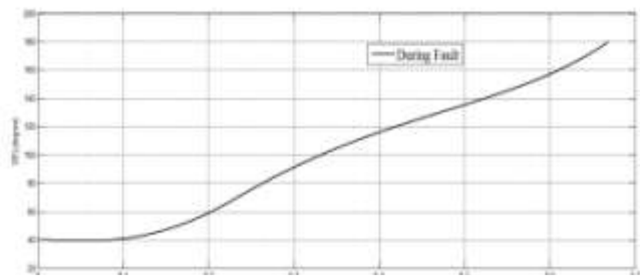

Fig. 11. Output Pulses During Fault

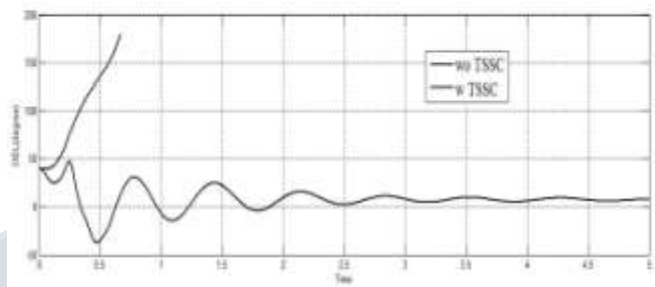

Fig. 12. Output Pulses During Fault

It can be seen from fig. 11. the swing curves for the system without TSSC is unstable in the first swing and after TSSC placed between bus 1 and bus 4 the swing curve is attaining stable state and hence finally oscillations are damped out and systems become stable in fig. 12.

The rotor angle difference (δ) for machine 1 and machine 2 obtains steady state for rotor angle (δ) between 28° - 40°. As the fault occurs making the system unstable so there was loss of power and loss of synchronism for generators. So with the TSSC applied between bus 1 and bus 5 the system get stable by damping oscillations at t = 5 sec with δ = 8°. Fig. 11. and Fig. 12. shows the rotor angle difference variation with and without thyristor switched series capacitor facts device.

Further during the fault the voltage drops down to zero value and if it is unable to built voltage than system loose stability and hence goes out of synchronism. Waveform showing generator voltage variation with and without TSSC facts device is shown in the fig. 13.

From the fig. 13. with thyristor switched series capacitor the voltage profile of the system improves up to 0.85 pu which was earlier drop down to lower value value of the line voltage.

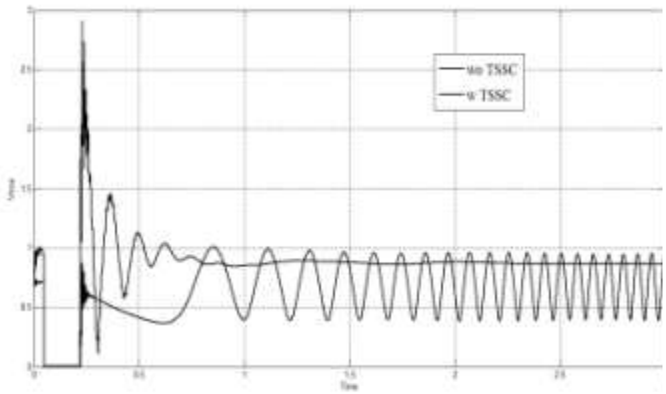

Fig. 13. Generator Voltage Variation

For less severe faults the device may not work satisfactorily. It is clear from the above that the TSSC facts device can improve transient stability for severe faults. For line to ground faults it may or may not work satisfactorily.

X. CONCLUSION

This paper explains the series FACTS controller in improving transient stability. The simulation result gives the clear observation of transient stability. The simulation work is carried for IEEE 9 bus, 3 machine systems with and without thyristor switched series capacitor (TSSC). All the results are compared with and without TSSC and improvement in stability is verified.

The disadvantage for the controller is that it operates successively for higher faults but for smaller faults it may not operate satisfactorily and hence it results in improvement for transient stability for severe faults. Future work can be carried out to damp the sub synchronous oscillations which occur at resonance frequency and make the system operate without losing synchronism. Further comparison of various Facts devices can be done and improvement in stability can be noted.

APPENDIX

The above data is shown for the sample test system [13] shown in fig. 1. The system data are: **Transmission line data:** Voltage level 500kv, 300km, F= 50 Hz, R = 0.016 Ω/km, L = 0.97mH/km, C = 0.0115 µf/km. The table below shows the ratings for generator and transformer.

TABLE I. Machine Ratings

S.NO	*Generator*	*Transformer*
1	1000MVA/13.8KV	1000MVA,13.8/500KV
2	5000MVA/13.8KV	5000MVA,13.8/500KV
3	1000MVA/13.8KV	1000MVA,13.8/500KV

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