Comparison of FACTS Devices for Two Area Power System Stability Enhancement using MATLAB Modelling

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ABSTRACT

Modern Power Transmission networks are becoming increasingly stressed due to growing demand and restrictions on building new lines. Losing stability is one of the major threat of such a stressed system following a disturbance. Flexible ac transmission system (FACTS) devices are found to be very effective in a transmission network for better utilization of its existing facilities without sacrificing the desired stability margin. The static synchronous compensator (STATCOM) and Static Var Compensator (SVC) are the shunt devices of the flexible AC transmission systems (FACTS) family. When system voltage is low, STATCOM generates reactive power and when system voltage is high it absorbs reactive power whereas the Static Var compensator provides the fast acting dynamic compensation in case of severe faults. In this Paper, the performance of SVC is compared with the performance of STATCOM. Proposed controllers are implemented using MATLAB/SIMULINK. Simulation results indicate that the STATCOM controller installed with two machine systems provides better damping characteristics in rotor angle as compared to two machine system installed with SVC. Thus, transient stability enhancement of the two machine system installed with STATCOM is better than that installed with SVC.

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1. INTRODUCTION

Modern power system is a complex network comprising of transmission lines, variety of loads and numerous amount of generators. Today modern power system is facing various challenges due to day by day increasing complexity in their structure and operation. In the recent past years, power system instability got a wide attention due to increased load demand. With the increased loading of long transmission lines, the problem of transient stability after a major fault was becoming a serious issue. With the lack of new generation and over exploitation of existing facilities make these types of problems more severe in modern power systems. Demand for power was rising day by day due to rapid development in industrial sector [2]. Since the last decade, the traditional concepts and practices adopted by power system have changed due to deregulation of electricity market. The changes arises due to lack of adequate funds in setting up the new plants for generation and overall to improve the efficiency of the power system. The deregulated structure is introducing the competition at various levels in trading sectors.

To meet this demand, it becomes essential to enhance the existing generation and transmission facilities. With the increased loading of long transmission lines, the problem of transient stability can become a transmission limiting factor. The design of modern power system should be flexible so that it can adapt itself to variable momentary conditions. While the power flow in some of the transmission lines in their normal limits, other lines get overloaded, which overall deteriorates the system security, stability and voltage profiles. Now it becomes more important to control power flow along transmission lines to meet the need of power transfer [5]. In AC power systems, the electrical generation and load must balance at all times up to some extent i.e. power system must be self-regulating. Stability depends upon both initial operating conditions of the system and severity of disturbance. If the generation is less than load, there is drop in voltage and frequency which leads to generation minus transmission losses and there is chance of system collapse. In case of minor faults, generator excitation controller with only excitation control is sufficient but it is not sufficient to maintain the stability of system under major faults occurring near generator terminals. Thus there is great need to improve electric power utilization, simultaneously maintain the system security and stability.

2. LITERATURE REVIEW

In this chapter some selected research papers related to two area power system stability enhancement using FACTS controllers are reviewed as:-

D. Murali, et al. presents the new challenges to power system stability and in particular transient stability and small signal stability for two area power system [2]. They investigate the improvement of transient stability for two area power system with effective use of different types of FACTS controllers. The performance of UPFC was compared with different types of FACTS devices like Static Var Compensator, Static Synchronous Series Compensator, Thyristor controlled series compensator etc.

Anuradha S. Deshpande, et al. proposed a method of evaluating the first swing stability of a large power system in presence of FACTS devices [3]. They considered FACT device and associated transmission line were represented by its equivalent pi circuit model. The model is then interfaced to the power network to obtain the system reduced admittance matrix which was used to generate the machine swing curves.The proposed method of generating dynamic response and evaluating first swing stability of a power system in the presence of FACTS device is tested on the three machine eleven bus sample test system. The results shows that the first swing of the generator gets reduced which further improves first swing stability.

SthitaprajnaRath, et al. presents a comprehensive review on the research and developments in power system stability enhancement using FACTS damping controllers [4]. They discussed about the several technical issues that may create hindrance in FACTS devices installations.
They conclude that with the use of FACTS controllers, maximum power can be transferred while maintaining dynamic stability and security.

Dr. M. Rajaram, et al. described the real and reactive power flow control through a transmission line by placing a FACT (UPFC) device at sending end of an electrical power transmission system [5]. Matlab/Simulink shows the performance of UPFC. Power flow control performance of UPFC was compared with other FACTS devices like SVC, STATCOM and SSSC.

Arun Kumar, et al. presented a detailed study on power system stability enhancement like frequency stability, rotor angle stability and voltage stability by using different FACTS controllers like SVC, TCSC, SSSC, STATCOM, UPFC and IPFC in an integrated power system networks [6]. They conclude about the essential features of FACTS controllers and their potential to enhance the system stability.

SamehKamel, et al. presents a report on modeling of the standard IEEE 14 bus system by using power system toolbox (PST) package [7]. They described the basic fact about the system which was tested under small and large disturbances to improve the dynamic stability and stability margins. Results show a precise solution of increased stability margins when different FACTS controllers were added. FACTS controllers were modeled and tested to show the effect of these controllers on stability margins under both small and large disturbances.

Salim Haddad, et al. presents a case study on modeling and interface of different FACTS devices in distributed power system by the use of Matlab [8]. Simulation results investigate about the amount of active and reactive power flowing through transmission system. Results also depict the efficiency of FACTS devices in improving the stability of the power system.

M.A. Abido presented a review on the research and developments in the power system stability enhancement using FACTS controllers [9]. They thoroughly discussed about how FACTS devices were installed in the system to overcome the related issues which may arise during installation. Also a brief review of FACTS applications to optimal power flow was presented.

Rahul Somalwar, et al. presented a review of enhancement of transient stability by FACTS devices [10]. They also described about the coordination problem that likely to be occur among different control schemes. They investigate the system under fault conditions by using equal area criterion method.

K. Venkateswarlu, ET al.described the analysis and enhancement of transient stability using shunt controlled FACTS controllers [11]. They briefly described that FACTS devices open up new opportunities for controlling power and enhancing the usable capacity in existing system. Results show the basic simulation of STATCOM for enhancing the transient stability of a two machine system using Matlab. The system was simulated under three phase fault condition and transient stability was predicted before and after the use of FACT device i.e. STATCOM.

Thomas J. Overbye, et al. presented the use of FACTS devices for power system stability enhancement [12]. They thoroughly describe the research on the development of new techniques for analysis and control of power systems using flexible AC transmission systems (FACTS) devices for both voltage and transient stability time frames. Results indicate that the FACTS devices are widely used to increase system stability margins by permitting control intervention during a system disturbance.

Alok Kumar Mohanty, et al. described the power system stability improvement using FACTS devices [13]. They briefly described about the challenges faced by modern power system under fault conditions and explained the need of FACTS devices to overcome these problems. In addition, they listed out the power system constraints and proposed the solutions to meet the power demand in future. They summarized about the semiconductor technology used in FACTS devices.

S.Abazari, et al. proposed the transient stability improvement by using advanced static Var Compensator (SVC) [14]. They propose a new method for calculating the current references for an ASVC. The current references calculated are based on Transient energy function (TEF). Simulation was carried out with the help of C++ and Matlab Simulink. Results show a comparison between optimal control and bang-bang control in an ASVC for improving transient stability in a multi-machine system.

Dr.Tarlochan Kaur, et al. proposed transient stability improvement of long transmission line system by using SVC [15]. They briefly described that shunt FACTS devices-SVC is used in a two area power system for improving the transient stability. Matlab Simulation describes the two area power system with various loads connected at different buses in different cases is being studied. Results indicate that after fault clearing, high transients had appeared in rotor angle difference of two machines when SVC was not connected to system.

Mohammad Mohammadi presents the voltage stability analysis with static Var Compensator (SVC) for various faults in power system with and without power system stabilizer (PSS) [16]. He thoroughly described that when Shunt FACTS devices were placed at midpoint of transmission line, they play a very important role in controlling the reactive power flow, voltage fluctuations and transient stability of the two machine system. His study mainly deals with the location of FACTS devices to improve the transient stability of power system.

D.K Sharma, et al. described a method of voltage stability in power system using STATCOM [17]. They proposed that placing of FACTS devices at key location is an important aspect. They studied the various FACTS devices that can be installed and FACTS devices model is incorporated into Newton-Raphson algorithm to perform load flow analysis. The proposed algorithm is tested on standard IEEE 30 bus power system for optimal allocation of STATCOM.

S.H Hosseini, et al. proposed the transient stability enhancement of AC transmission system using STATCOM [18]. They briefly described that STATCOM can increase transmission capacity, damping low frequency oscillations and improves transient stability. They proposed a control block diagram of STATCOM for transient stability improvement. Matlab was used for simulating the results of two machine system. Results indicate that the STATCOM not only improves the transient stability but also compensated the reactive power in steady state.

Aarti Rai, et al. described the enhancement of voltage stability and reactive power control of distribution system using FACTS devices [19]. They thoroughly described the optimal location of FACTS devices, voltage stability analysis and control of reactive power in system. Matlab software was used for simulation and the performance of the whole system such as voltage stability, transient stability and power swings were analyzed and compared with and without FACTS devices.

Y.L Tan, et al. presents the effects of FACTS controller line compensation on power system stability [20]. They described the effects of line compensation of SMIB power system using FC-TCR type TCSC or SVC for transient stability enhancement. They presented a novel method for analysis of line compensation by SVC. The maximum power transfer for a line depends on degree of compensation. The results indicate the effectiveness of SVC for stability enhancement is increased if the degree of compensation is increased.

Sidharta Panda, et al. described the improvement in power system transient stability with an off-center location of shunt FACTS devices [21]. Their study deals with the placement of Shunt FACTS devices to improve the transient stability of a long transmission line with predefined direction of real power flow. They proved the validity of mid-point location of shunt FACTS devices.

Bindeshwar Singh, presents the application of FACTS controllers in power system for enhances the power system stability [22]. They predicted different kind of stabilities with various FACTS devices. He presents the current status of research and developments in the field of the power system stability such as rotor angle stability, frequency stability, and voltage stability enhancement by using different FACTS controllers in an integrated power system networks.

S.K Srivastava presents an overview on advanced power electronic based FACTS controllers [23]. He studied the better utilization of power system capabilities by installing the FACTS devices. He explained the basic concept of FACTS devices and their utilization to enhance the stability and security of modern power system.

V. Kakkar, et al. explained the recent trends on FACTS and D-FACTS [24]. They briefly explained about the challenges faced by modern power system which includes limited available energy resources, time, capital required and land use restrictions. Results indicate that D-FACTS have more reliability and cost saving approach over FACTS devices.

Karim Sebaa, et al. presents the power system dynamic stability enhancement via coordinated design of PSS and SVC based controllers using hierarchical real coded NSGA-II [25]. Results indicate the solution of tuning and location of minimum number of PSS and FACTS based controllers were proposed.

S.V Ravi Kumar, et al. presents the transient stability using UPFC and SVC [26]. They thoroughly described the damping of power system oscillations after a three phase fault and also analyze the effect of UPFC and SVC on transient stability performance of power system. They developed a general program for transient stability studies using modified portioned approach. The modelling of SVC and UPFC were studied and tested on a 10-generator, 39-bus, New England test generator. Results indicate that the SVC helps in improving the system performance by improving critical clearing time.

Nasimul Islam Maruf, et al. presents a study on thyristor controlled series capacitor as a useful FACT device [27]. They discussed the basic principle and benefits of TCSC during the fault conditions. They conclude that TCSC is a useful FACT device for enhancing the transient stability, steady state stability, dynamic stability and voltage stability of power system under severe conditions.

Vibhor Gupta described the study and effects of UPFC and its control system for power flow control and voltage injection in power system [28]. He studied the operating modes of UPFC. Simulation is carried out in MATLAB and results indicate the use of power flow controller and voltage injection. He concludes about the benefits of using UPFC in the system.

S.JavedSajjadi, described the effects of series and shunt FACTS devices in transient stability enhancement of multi-machine system [29]. They described the injection model of unified power flow controller and series quadrature voltage injection. Results indicate that the shunt compensation was used for power oscillation damping and effects of series and shunt compensation on transient stability was discussed.

N.K Sharma, et al. described the performance of UPFC in several modes operation using different control mechanism based on proportional plus integral control (PI) and Proportional plus integral plus derivative control (PID) [30]. They also developed ANFIS based controller by using ANFIS editor of Matlab. The MATLAB simulation results indicate the capability of UPFC on power flow control and the effectiveness of controllers on the performance of UPFC in the different operating modes.

T.K. Gangopadhyay, et al. discussed the problem of designing the damping controller for low frequency oscillations in power system under dynamic uncertainty [31]. They applied H mixed sensitivity technique to design robust damping controllers for unified power flow controller in uncertain conditions.

3. FACTS CONTROLLERS

FACTS are defined as"a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability.Basically, FACTS controllers can be divided into four categories [1]:

- Series Controller
- Shunt Controller
- Combined series-series Controller
- Combined series-shunt Controller

Table 1. Comparison among FACTS Controllers

Name	Type	Controller Used	Purpose
SVC	Shunt	Thyristor	Voltage Control
SSSC	Series	GTO	Power Flow Control
STATCOM	Shunt	GTO	Voltage Control
UPFC	Shunt and Series	GTO	Voltage and Power Flow Control
TCSC	Series	Thyristor	Power Flow Control
TCPAR	Shunt and Series	Thyristor	Power Flow Control

3.1. Static VAR Compensator (SVC)

SVC is an electrical device for providing the fast reactive power on high voltage transmission networks. An SVC is based on thyristor controlled reactors (TCR), thyristor switched capacitors (TSC), and/or Fixed Capacitors (FC) tuned to Filters as shown in fig1. A TCR consists of a fixed reactor in series with a bi-directional thyristor valve. TCR reactors are as a rule of air core type, glass fibre insulated, epoxy resin impregnated [15].

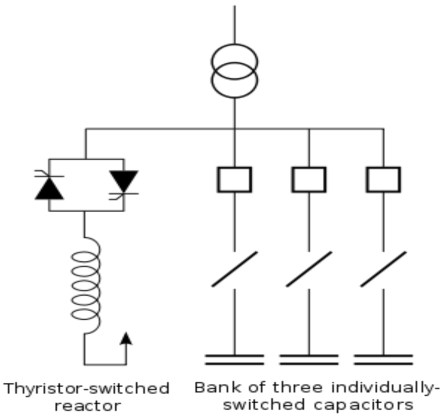

Figure 1. SVC Model

SVCs had a great advantage over simple mechanically-switched compensation schemes is their fast instantaneous response to changes in the system voltage. For this reason they are often operated at close to their zero-point in order to maximize the reactive power correction they can rapidly provide in system whenever required. They are in general cheaper, higher-capacity, faster, efficient and more reliable over dynamic compensation schemes such as synchronous condensers [15].

3.2. Static Synchronous Compensator (STATCOM)

A Static synchronous compensator is a shunt-connected static Var compensator whose capacitive or inductive output current can be controlled independently of the ac system voltage. STATCOM is made up of a coupling transformer, a VSC and a dc energy storage device as shown in fig2. STATCOM is capable of exchanging reactive power with the transmission line because of its small energy storage device i.e. small dc capacitor, if this dc capacitor is replaced with dc storage battery or other dc voltage source, the controller can exchange real and reactive power with the transmission system, extending its region of operation from two to four quadrants.

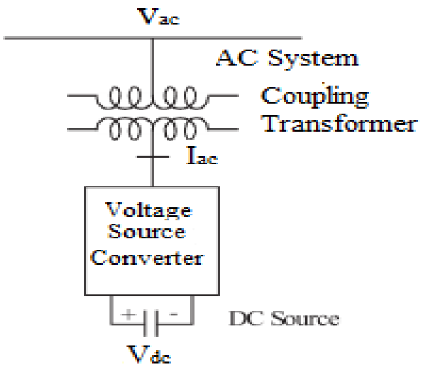

Figure 2. STATCOM Model

4. SIMULATION MODEL AND RESULTS

Consider a two area power system (Area-1 & Area-2) with shunt FACTS devices, connected by a long transmission line as shown in fig-3. Two 1000MW hydraulic generation plants M1 and M2 are connected to a load centre through 500KV, 720KM transmission line. The system was interconnected through 5 buses and RL load. Two machines are equipped with a hydraulic turbine and governor (HTG), excitation system, power system stabilizer and FACT device (SVC or STATCOM).

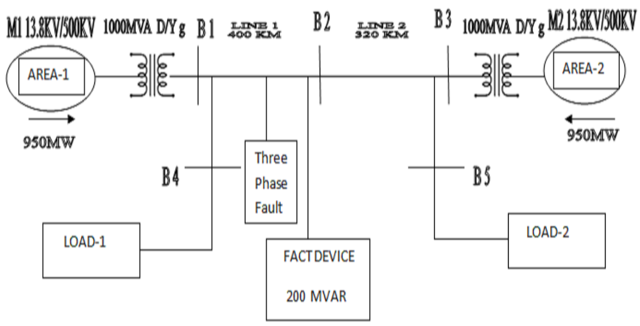

Figure 3. SLD of two area power system

4.1. Two Area System with Three Phase Fault

Two area system as shown in fig.-4 is considered in this study.

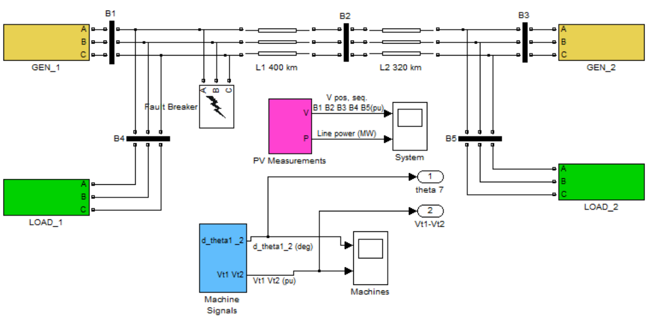

Figure 4. Two Area Systems during Three Phase Fault

It is considered that a 3-phase symmetrical short circuit fault of 0.1seconds occur at bus B1. The system is simulated in MATLAB/Simulink environment and graphs are shown in fig.-5 and fig.-6. From the fig.-5, it is inferred that without the FACT device and Power system stabilizer, the oscillation in generator rotor angle of Area1 and Area2 increases and settling time for the oscillations is found to be high. The difference of the two rotor angle is taken into account and plotted against time.

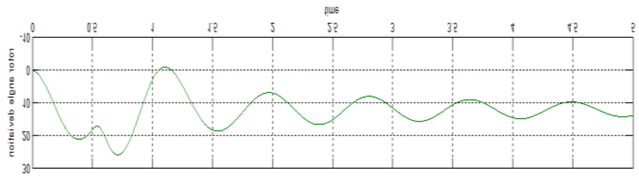

Figure 5. Difference of two rotor angles with time during three phase fault

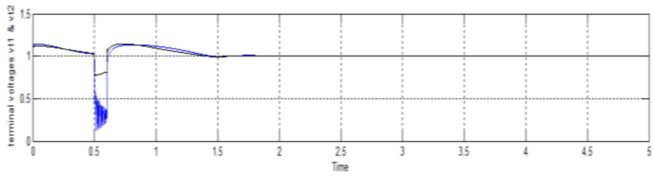

Figure 6. Variation of terminal voltages with time

4.2 Two Area System with FACT device (SVC) and Power System Stabilizer

Two area system as shown in figure 7 is considered in this study.

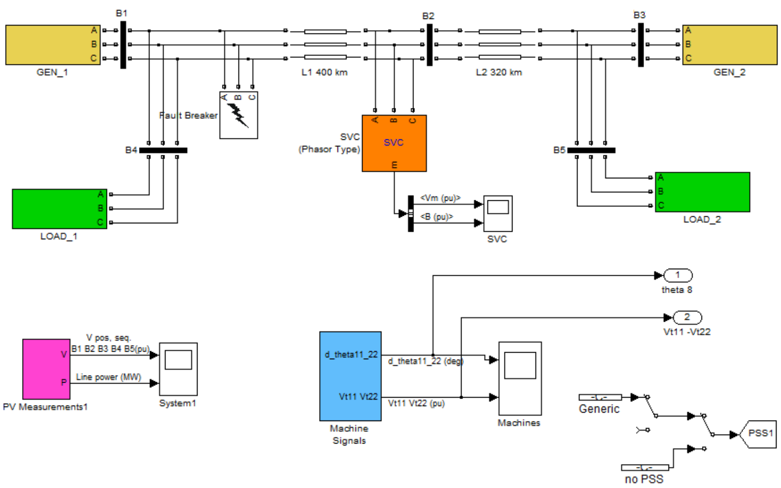

Figure 7. Two Area System installed with SVC and PSS

The system has a SVC installed at B2. It is considered that a 3-phase symmetrical short circuit fault of 0.1seconds occur at bus B1. Put the Generic type PSS in service by setting the command in PSS block equal to 1. Open the SVC block menu and change the SVC mode of operation to voltage regulation. The system is simulated in Matlab/Simulink environment and graphs of SVC are shown in fig-8 and fig-9. From the fig-8, it is inferred that the oscillations in generator rotor angle is decreased and setting time for the oscillations is found to be 4.0 seconds.

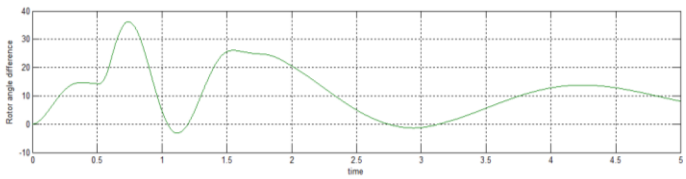

Figure 8. Difference of two rotor angles with time installed with SVC and PSS

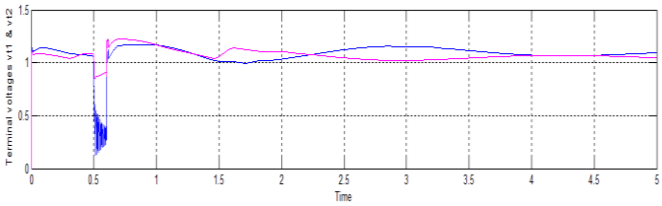

Figure 9. Variation of terminal voltages with time installed with SVC and PSS

4.3 Two Area System with FACT device (STATCOM) and Power System Stabilizer

Two area system as shown in figure 10 is considered in this study.

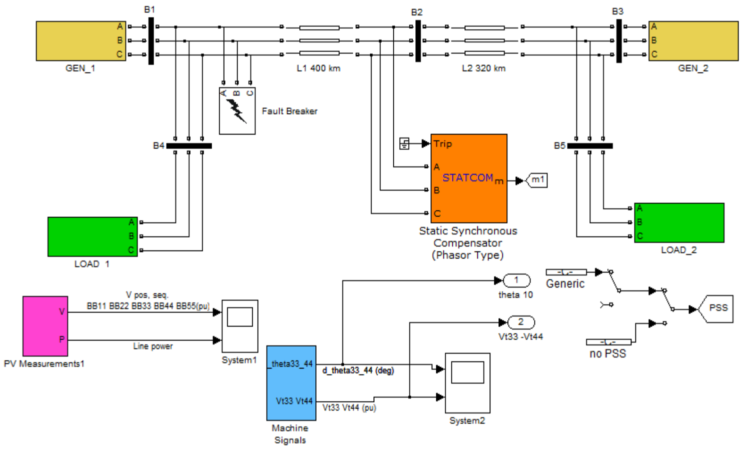

Figure 10. Two Area System installed with STATCOM and PSS

The system has a STATCOM installed at B2. It is considered that a 3-phase symmetrical short circuit fault of 0.1seconds occur at bus B1. Put the Generic type PSS in service by setting the command in PSS block equal to 1. Open the STATCOM block menu and change the STATCOM mode of operation to voltage regulation. The system is simulated in Matlab/Simulink environment and graphs of STATCOM are shown in fig-11 and fig-12. From the fig-11, it is inferred that the oscillations in generator rotor angle is decreased and setting time for the oscillations is found to be 2.8 seconds. Also, terminal voltages profile has been improved after clearance of fault installed with STATCOM. Hence, the transient stability of two machine system installed with STATCOM has been improved considerably and post settling time of the system after facing disturbance is also improved.

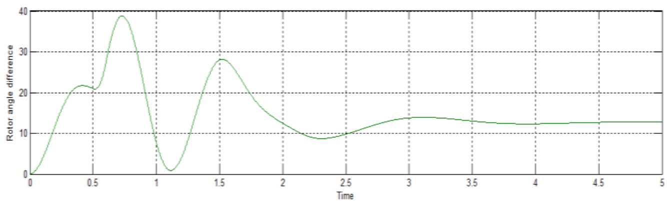

Figure 11. Difference of two rotor angles with time installed with STATCOM and PSS

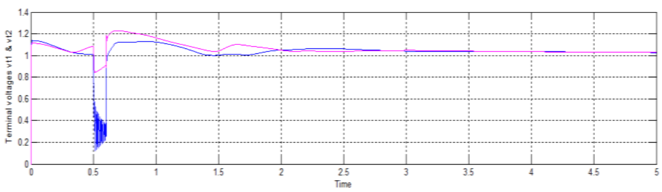

Figure 12. Variation of terminal voltages with time installed with STATCOM and PSS

4.4 Comparison between FACTS Devices

From the simulation results shown in Fig4-Fig12, a comparison is made between the above FACTS devices for stability enhancement of two area power system as shown in Table-2. From the Table-2, it is inferred that STATCOM is the effective FACT device for stability enhancement over SVC as the post settling time obtained from the use of STATCOM is less as compared to that obtained from SVC.

Table 2. Comparison between FACTS Devices for Power System

Two-areaPower System with	PowerSystem Stability Enhancement	Post settling time(inseconds)
SVC	YES	4.0
STATCOM	YES	2.8

5. CONCLUSION

In this paper, various constraints of the modern power system were discussed and on the basis of these constraints, need of FACTS devices were presented. The dynamics of the power system is compared with and without the presence of FACTS devices and Power system stabilizers in the event of major disturbances. The performance of one of the FACT device i.e. STATCOM for transient stability enhancement is compared with the performance of other FACT device i.e. SVC. Controller’s inputs are chosen carefully to provide necessary damping in rotor angle and results are taken through simulation. Proposed FACTS controllers were implemented in MATLAB/SIMULINK. Simulation results indicate that the STATCOM controller installed with two machine systems provides better damping characteristics in rotor angle as compared to two machine system installed with SVC. Also, the post settling time of the two machine system installed with STATCOM is found to be less i.e. near to 2.8sec than the system with SVC. Thus, transient stability enhancement of the two machine system installed with STATCOM is better than that installed with SVC.

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