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Comparison and Performance Analysis of Various FACTS Devices in Power System

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ABSTRACT:

In recent years, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. This paper investigates the enhancement in voltage stability margin as well as the improvement in power transfer capability of transmission line in a power system with the incorporation of Static Synchronous Compensator (STATCOM), Fixed Capacitor Thyristor Controlled Reactor (FC-TCR and) Static Synchronous Series Compensator (SSSC). A simple transmission line system is modelled in MATLAB/SIMULINK environment. The load flow results are first obtained for an uncompensated system, and the voltage and power profiles are studied. The results so obtained are compared with the results obtained after compensating the system using STATCOM, FC-TCR and SSSC to show the voltage stability margin enhancement. The results obtained after simulation demonstrate the performance of the system for each of the FACTS devices in improving the power profile and thereby voltage stability of the same.

Keywords: STATCOM, FC-TCR, SSSC, FACTS, Voltage Stability.

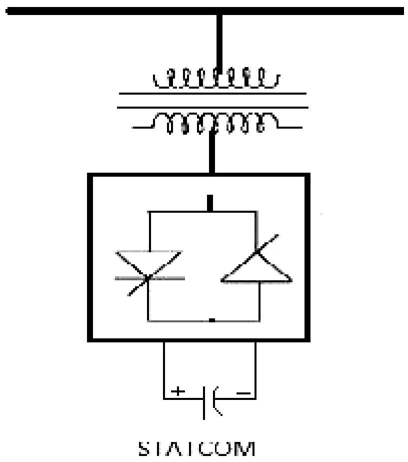
I. INTRODUCTION

Modern power systems are large, interconnected and involves thousands of buses and hundreds of generators. Power system protection devices also form a large part of the system. Environmental as well as economic factors primarily govern the installation of new power system and to transport this power, new transmission line construction are needed to meet the ever increasing load demand. Apart from these factors, new transmission line constructions are expensive and also take considerable amount of time and way of right. Regulatory limitation on the expansion of system network has resulted in reduction in stability margin thereby increasing the risk of voltage collapse [1]. Voltage collapse occurs in power system when system is faulted, heavily loaded and there is a sudden increase in the demand of reactive power. Voltage instability is the prime cause of system voltage collapse. Voltage collapse occurs when the system voltage decays to a level from which it is unable to recover. The consequences of voltage collapse involve partial or full power interruption in the system. One of the main causes of voltage instability in a system is the occurrence of reactive power imbalance in the system. Reactive power imbalance occurs when there is a sudden increase or decrease in reactive power demand in the system The only way to prevent the occurrence of voltage collapse is either to reduce the reactive power load or to provide the system with additional supply of reactive power before the system reaches the point of voltage collapse. This can be done by connecting sources of reactive power, i.e., shunt capacitors and/or Flexible AC Transmission System (FACTS) controllers at appropriate locations in the system. Flexible AC Transmission Systems (FACTS) technology helps utilities in reducing transmission congestion and in utilizing more efficiently the existing transmission system without compromising the reliability and security of the system. Their fast response offers high potential for power system stability enhancement apart from steady state flow control [2]. The benefits of employing FACTS are many: improvement of the dynamic and transient stability, voltage stability and security improvement, less active and reactive power loss, voltage and power profile improvement, power quality improvement, increasing power flow capability through the transmission line, voltage regulation and efficiency of power system operation improvement, steady state power flow improvement, voltage margin improvement, loss minimization, line capacity and loadability of the system improvement [3]. FACTS devices have been defined by the IEEE as “alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability” [4]. The FACTS controllers can be classified as [5]: Shunt controller : - SVC, STATCOM Series controller : - TCSC, SSSC Series-Series controller :- IPFC Shunt-Series controller :- UPFC, TCPST etc.

II. BASIC DESCRIPTION OF FACTS DEVICE

A. Static synchronous compensator (STATCOM)

Fig.1. Static synchronous compensator.



The static synchronous compensator (STATCOM) is another shunt connected GTO based FACTS device.

STATCOM is a static synchronous generator operated as a static VAR compensator which can inject lagging or leading Var into the system. STATCOM have several advantages. It has no rotating parts, very fast in response, requires less space as bulky passive components are eliminated, inherently modular and relocate-able, less maintenance and no problem as loss of synchronism [6]. Simple diagram of STATCOM is shown in Fig. 1. The dc source voltage is converted into ac voltage by the voltage source converter using GTO and ac voltage is inserted into the line through the transformer. In heavy loaded condition if. Output of VSC is more than the line voltage, converter supplies lagging VARs to the transmission line. During low load condition if line voltage is more than then converter absorbs lagging VAR from the system. If output voltage of converter is equal to line voltage, then the STATCOM is in floating condition and this shunt device does not supply or absorb reactive power to the system or from the system. *B. Fixed Capacitor Thyristor Controlled Reactor (FCTCR)* Static VAR compensated FACTS device are the most important device and have been used for a number of years to improve voltage and power flow voltage problems.

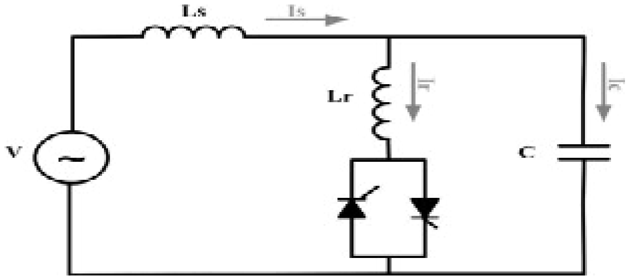


Fig. 2. Fixed capacitor thyristor controlled reactor.

SVC is shunt connected static generator/absorber. Utilities of SVC controller in transmission line are many: a) provides high performance in steady-state and transient voltage stability control, b) dampen power swing, c) reduce system loss d) Control real and reactive power flow. Simple FC-TCR type SVC configuration is shown in figure 2. In FC-TCR a capacitor is placed in parallel with a Thyristor controlled reactor. Is, Ir and Ic are system current, reactor current and capacitor current respectively which flows through the FC-TCR circuit. Fixed capacitor- Thyristor controlled reactor (FC-TCR) can provide continuous lagging and leading VARS to the system [5]. Circulating current through the reactor (Ir) is controlled by controlling the firing angle of back-back thyristor valves connected in series with the reactor. Leading var to the system is supplied by the capacitor. For supplying lagging var to the system, TCR is generally rated larger than the capacitor. *C. Static synchronous series compensator (SSSC)*

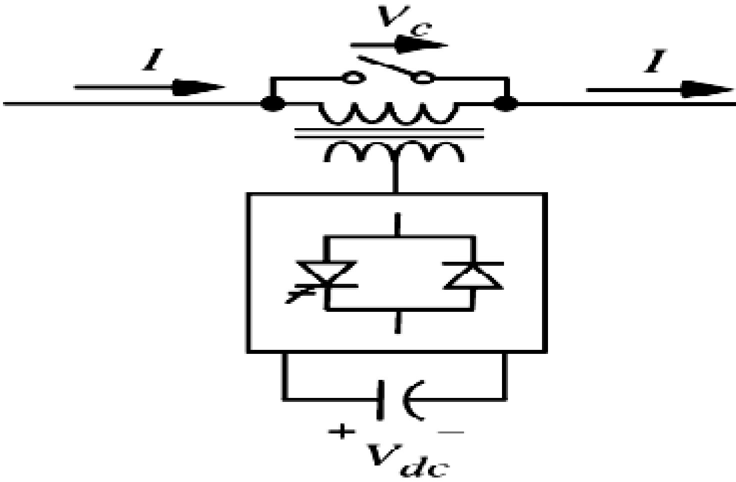


Fig. 3. Static synchronous series compensator.

In present days, SSSC is one of the most important FACTS controller used for series compensationpower. In series compensation the capacitor which is connected in series compensates the inductive reactance of the transmission line. SSSC output voltage (V_c) is in quadrature with the line current (I). The voltage across series capacitor is $-jX_cI$ (where X_c is the capacitive reactance of the series capacitor) and voltage drop across line inductance (XL) is +jXLI cancel each other thus reducing the effect of line inductance. Due to this, power transfer capability is increased [6]. The symbolic representation of SSSC using voltage source converter is shown in Fig. 3.Supply voltage from a dc source is converted into ac voltage using VSC (voltage source converter). Quadrature voltage is injected into the line through a coupling transformer. This injected voltage (V_c) lags the line current (I) by 90ºand series compensation is done. SSSC control flow of real and reactive power through the system.

III. SYSTEM MODEL

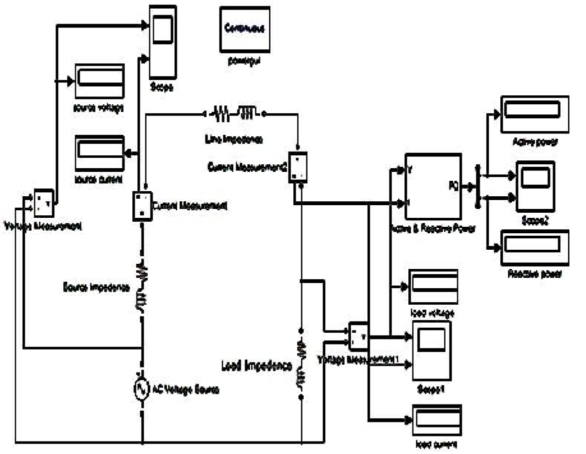


Fig. 4. Basic Transmission Line Model.

The above diagram shows a simplified model of an uncompensated system. The system is modeled in SIMULINK platform. The model is supplied from an 11 kV voltage source. The source impedance (0.01+j0.001) Ω, line impedance (10+j0.028) Ω and the load is kept constant at 30 MW and 60 MVAR for the above transmission line model. The scopes provided displays the signals generated during the simulation. In the above figure, two scopes are provided: one displays the source voltage and current, and the other displays the Load Voltage (VL), Load Current (IL), Real and Reactive Power at the receiving end. The results obtained after simulation are shown below:

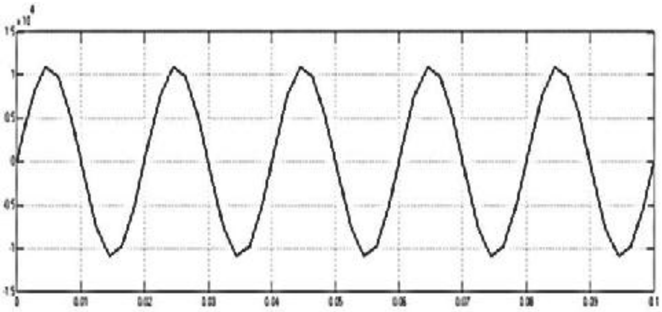


Fig. 5. Source Voltage.

The load voltage is found to be 0.945 kV, which is 15.5% below the required voltage. The real and reactive power profiles are also shown. So, in order to keep the system stable, we have to provide adequate compensation to the system.

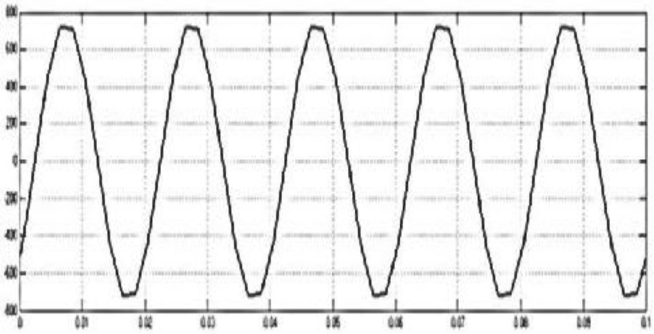


Fig. 6. Source Current.

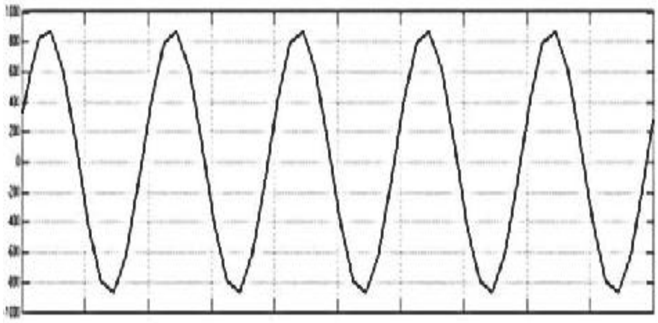


Fig.7. Load Voltage.

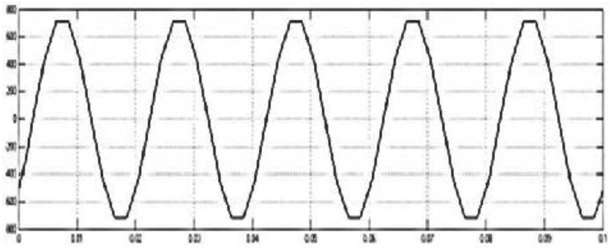


Fig. 8. Load Current.

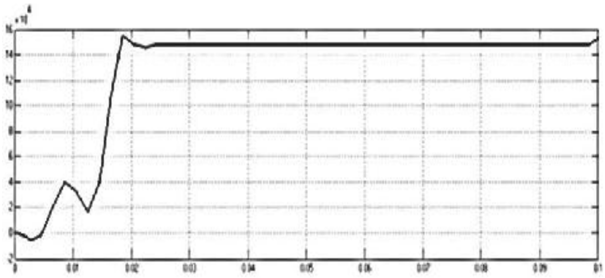


Fig. 9. Real Power.

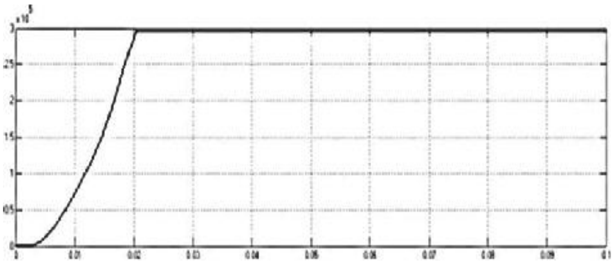


Fig.10. Reactive Power.

It is an established fact, that voltage stability is dependent on the reactive power. So, if we can improve the reactive power to meet the demand, then we can as well improve the voltage profile of the system to prevent it from dipping below the margin. In this paper, compensation using Fixed Capacitor, SVC and STATCOM are studied and compared to obtain the best compensation for the system under study.

IV. COMPENSATION SYSTEM

B. STATCOM Compensated System

The SIMULINK model for a STATCOM compensated system is shown below:

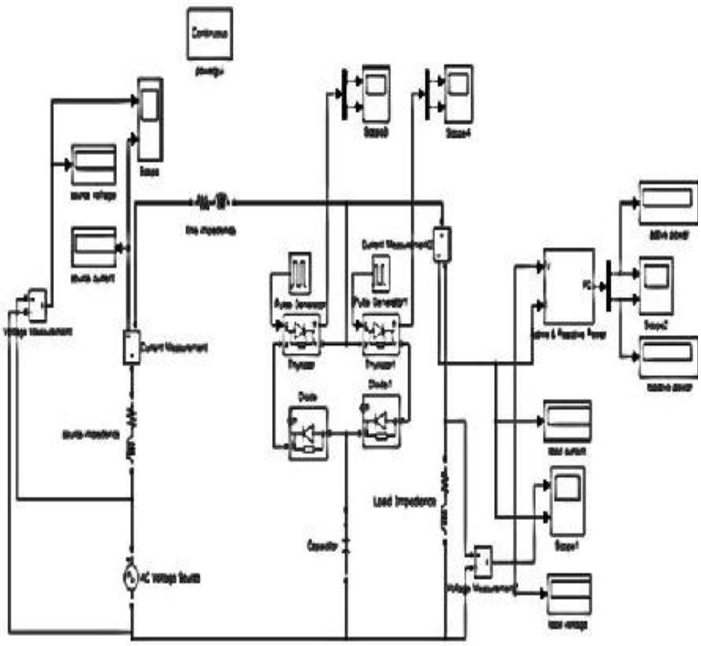


Fig. 11. STATCOM Compensated System.

The above figure shows the configuration of the STATCOM model connected to the system. The plots showing the improvement in the Load Voltage, Load Current and Real and Reactive Power are given below:

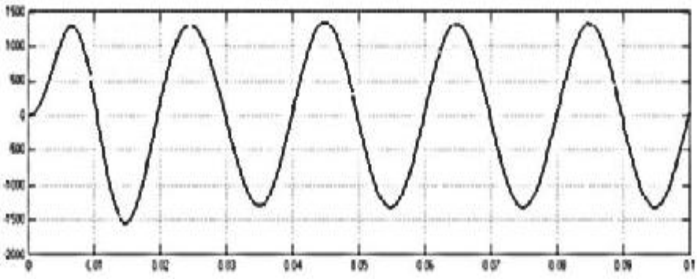


Fig. 12. Load Voltage.

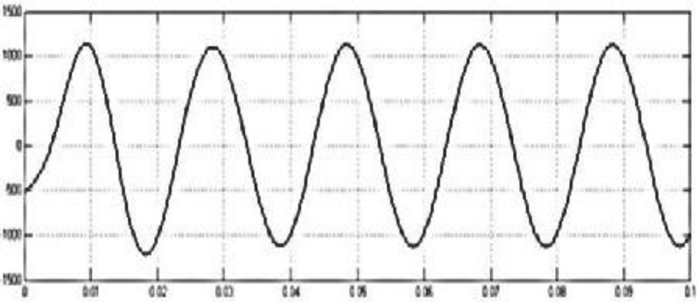


Fig. 13. Load Current.

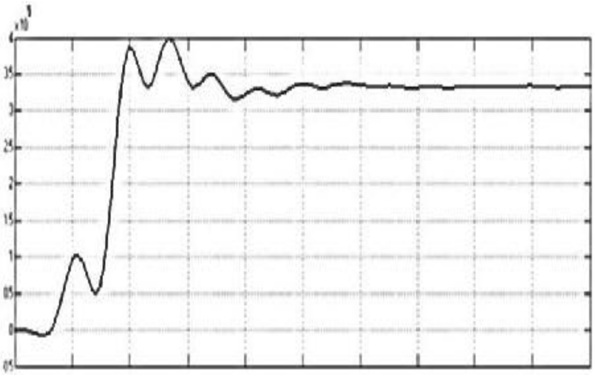


Fig.14. Real Power.

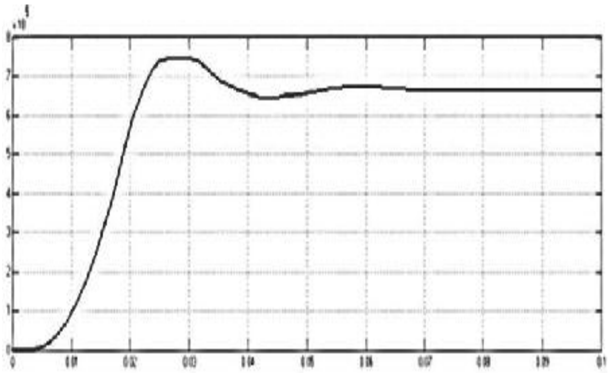


Fig. 15. Reactive Power.

Thus from the above figures, it is seen that there is considerable improvement in the real and reactive power flows as well as the receiving end voltage. For a capacitor value of 1200μF, the Real and Reactive Powers obtained are 0.3342MW and 0.7691MVAR respectively. The receiving end voltage is found to be 1.33kV for the present case. The voltage profile improves further with increased rating upto a certain point. The change in the power flows is obtained for different values of capacitance:

Table 1: Variation of Real and Reactive Power with the Variation of Capacitance.

Capacitance (μF)	Real Power (MW)	Reactive Power (MVar)
50	0.1533	0.3065
100	0.1581	0.3160
200	0.1683	0.3362
250	0.1736	0.3470
300	0.1793	0.3853
350	0.1851	0.3700
400	0.1912	0.3822
500	0.2043	0.4083
600	0.2186	0.4367
800	0.2508	0.5012
1000	0.2891	0.5774
1200	0.3342	0.6665

From the above table, it is seen that, both Real and Reactive power flows are improved impressively upto a capacitor rating of around 1200μF. Increasing the capacitance value further improves the power profile. *B. FC-TCR Compensated System* The SIMULINK model for a FC-TCR compensated system is shown below. The figure shows an SVC, modeled in FC-TCR configuration, connected to the system. The Real and Reactive Powers are obtained for a fixed value of inductance of TCR taken to be 100mH and by varying the capacitance.

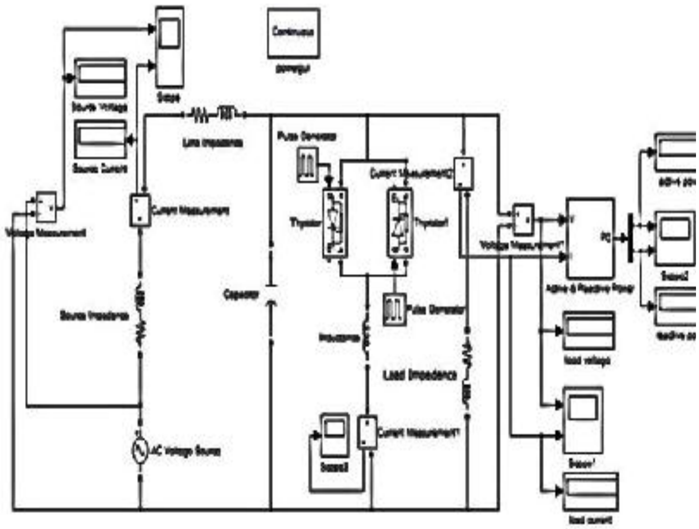


Fig. 16. FC-TCR Compensated System.

Plots for a particular case of the compensated system with the capacitor value 100µF are shown below:

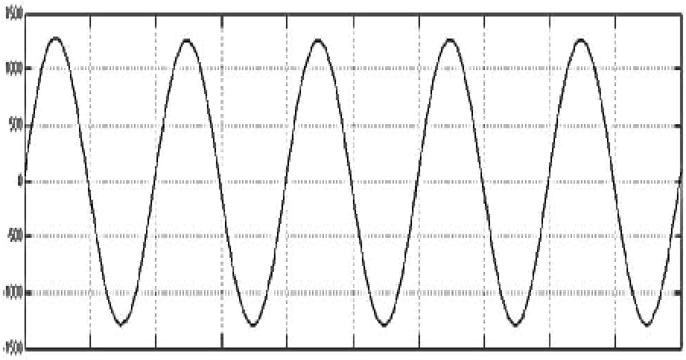


Fig. 17. Load Voltage.

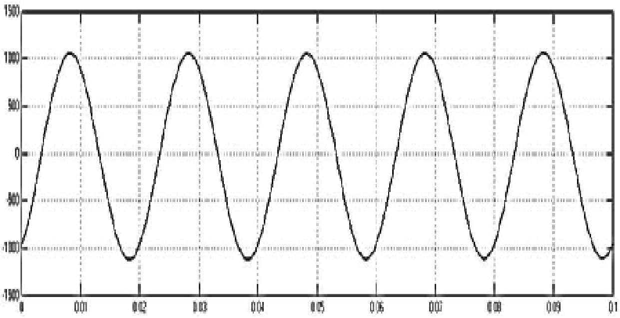


Fig.18. Load Current.

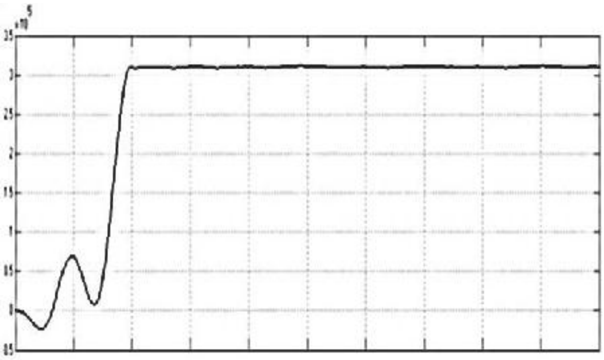


Fig. 19. Real Power.

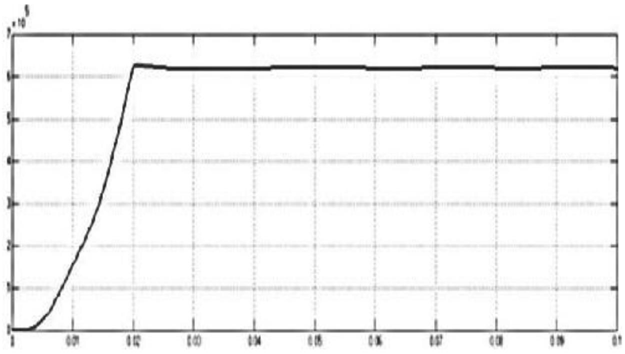


Fig.20. Reactive Power**.**

The change in the Real and Reactive Powers obtained for different capacitor values are tabulated below:

Table 2: Variation of Real and Reactive Power With the Variation of Capacitance.

Capacitance (µF)	Real Power (MW)	Reactive Power (MVar)
50	0.1440	0.2822
100	0.1483	0.2969
200	0.1576	0.3156
250	0.1626	0.3255
300	0.1678	0.3358
350	0.1731	0.3466
400	0.1788	0.3579
500	0.1910	0.3818
600	0.2040	0.4079
800	0.2336	0.4673
1000	0.2687	0.5376
1200	0.3102	0.6205

Thus from the above table we see that both real and reactive powers are compensated to a large extent by incorporating SVC into the system and the power flow improves in direct proportion to the variation of capacitance. Also the receiving end voltage improves considerably with the addition of SVC into the system and helps in keeping the system in stable state. *C. SSSC Compensated System* The SIMULINK model for a SSSC compensated system is shown in figure. The above figure shows the configuration of the SSSC model connected to the system. The plots showing the improvement in the Load Voltage, Load Current and Real and Reactive Power are given below:

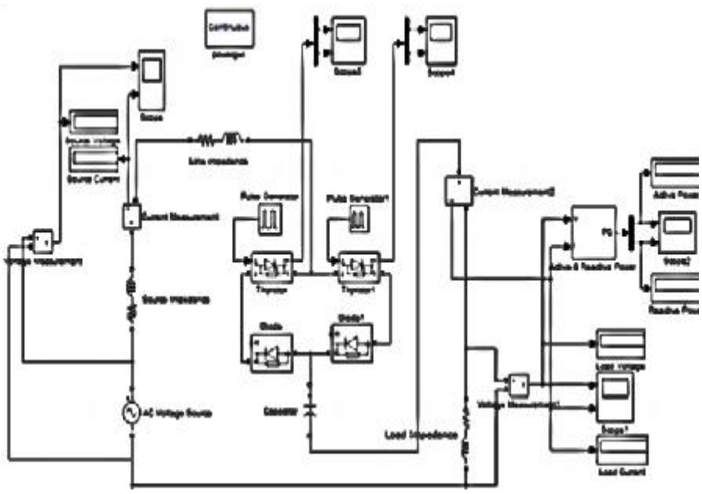


Fig. 21. SSSC Compensated System.

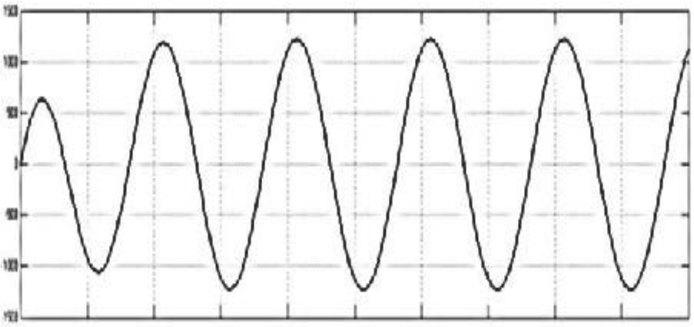


Fig. 22. Load Voltage.

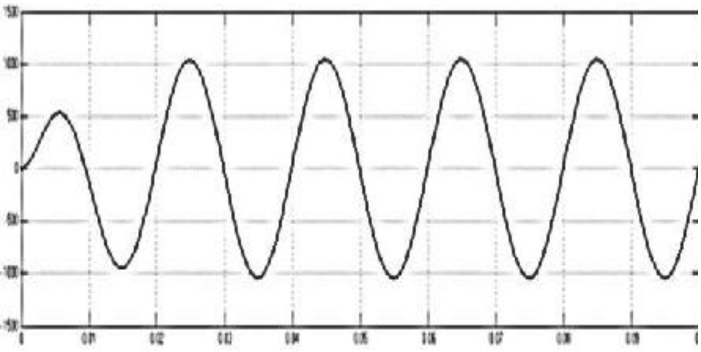


Fig.23. Load Current.

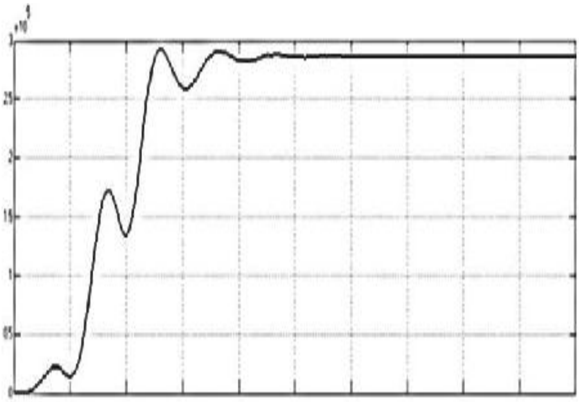


Fig. 24. Real Power.

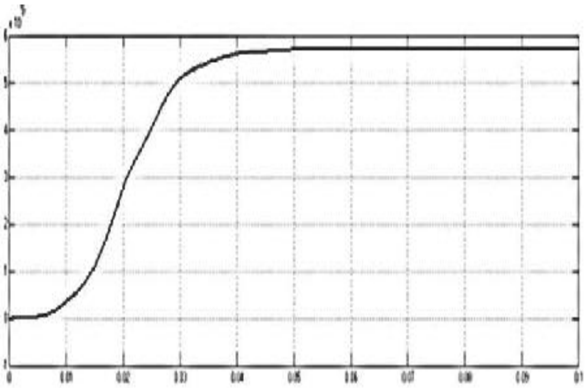
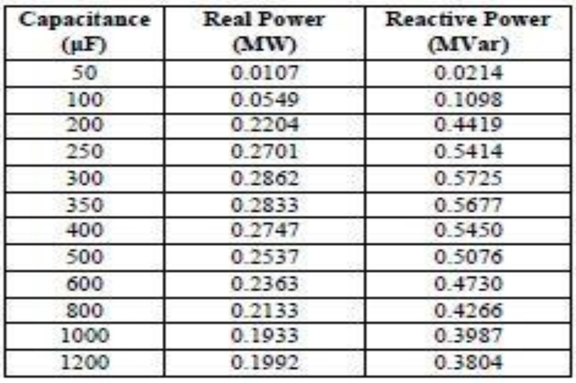


Fig. 25. Reactive Power.

Thus from the above figures, it is seen that there is considerable improvement in the real and reactive power flows as well as the receiving end voltage. For a capacitor value of 300μF, the Real and Reactive Powers obtained are 0.286MW and 0.5725MVar respectively. The change in the power flows is obtained for different values of capacitance

Table 3: Variation of Real and Reactive Power with the Variation of Capacitance.

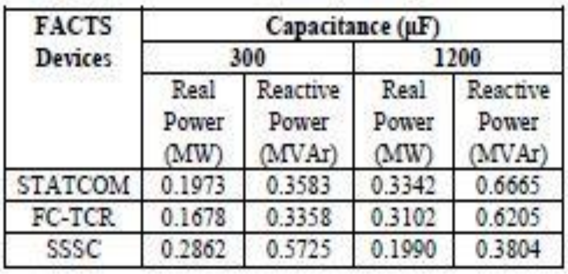


Capacitance (μF)	Real Power (MW)	Reactive Power (MVar)
50	0.0107	0.0214
100	0.0549	0.1098
200	0.2204	0.4419
250	0.2701	0.5414
300	0.2862	0.5725
350	0.2833	0.5677
400	0.2747	0.5450
500	0.2537	0.5076
600	0.2363	0.4730
800	0.2133	0.4266
1000	0.1933	0.3987
1200	0.1992	0.3804

From the above table, it is seen that, both Real and Reactive power flows are improved impressively upto a capacitor rating of around 300μF. Increasing the capacitance value further deteriorates the power profile.

IV. RESULTS AND CONCLUSION

Table 4: Comparison of power flow between above FACTS Devices.



FACTS Devices	Capacitance (μF)			
	300		1200	
	Real Power (MW)	Reactive Power (MVAr)	Real Power (MW)	Reactive Power (MVAr)
STATCOM	0.1973	0.3583	0.3342	0.6665
FC-TCR	0.1678	0.3358	0.3102	0.6205
SSSC	0.2862	0.5725	0.1990	0.3804

It is seen from the above simulation results that both the Power Flow and Voltage profiles are improved with all the compensating devices, but maximum real and reactive power compensation is obtained with the introduction of STATCOM in the system. STATCOM offers better performance in regulating the Voltage Stability of the system. But care has to be taken in determining the rating of the compensating devices in order to make the system stable as well as cost effective. In this paper, the variations in power and voltage profiles with controlled parameter variations have been presented. The results obtained clearly shows that in case of fixed Capacitor

Compensation, a capacitor value of 300μF will be appropriate, whereas, in case of FC-TCR, a fixed inductor value of 100mH and capacitor of 1200μF yields good results. For the STATCOM, a capacitor rating of 1200μF gives best results. This paper presents an elaborate comparison between STATCOM, FC-TCR and SSSC. It will help in determining the appropriate capacitor and inductor values (as the case may be) for achieving optimum performance by the compensating devices.

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