
Exemplary Design and Correlation of FACTS Devices in Power Systems

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Abstract

The Power electronic based FACTS devices can be added to power transmission and distribution systems, at strategic locations to improve system performance and hence both the system voltage fluctuations and transient stability. Exemplary Design, correlation and simulation of Fixed Capacitor Thyristor Controlled Reactor (FC-TCR), Static synchronous compensator (STATCOM), Thyristor controlled Series Capacitor (TCSC) Thyristor controlled Series Reactor(TCSR), Static synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) for power system stability enhancement and improvement of power transfer capability have been presented in this paper. First, power flow results are obtained and then power (real and reactive power) profiles have been studied for an uncompensated system and then compared with the results obtained after compensating the system using the above-mentioned FACTS devices. The simulation results demonstrate the performance of the system for each of the FACTS devices in improving the power profile and thereby voltage stability of the same. All simulations have been carried out in MATLAB/SIMULINK environment.

Keywords: FACTS, real and reactive power, FC-TCR, STATCOM, Voltage stability, SSSC, TCSC, TCSR, UPFC.

1. Introduction

The need for more efficient electricity systems management has given rise to innovative technologies in power generations and transmissions. The combined cycle power station is a good example of a new development in power generation and flexible AC transmission systems, FACTS as they are generally known, are new devices that improve transmission systems. Worldwide transmission systems are undergoing continuous changes and restructuring. In addition, the economical utilization of transmission systems assets is of vital importance to enable utilities in industrialized countries to remain competitive and to survive. Static VAR compensated FACTS devices are the most important devices and have been used for a number of years to improve voltage and power flow through the transmission line by resolving dynamic voltage problems. 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.

2. Basic description of FACTS devices

2.1 Fixed Capacitor Thyristor Controlled Reactor (FC-TCR)

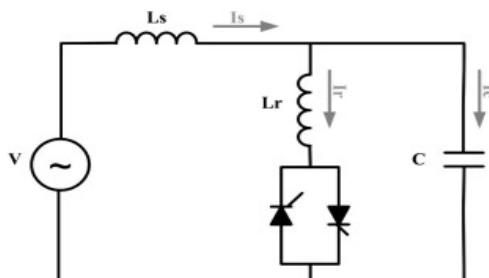


Fig1: Fixed Capacitor Thyristor Controlled Reactor

Simple FC-TCR type SVC configuration is shown in Fig 1. In FC-TCR, a capacitor is placed in parallel with a thyristor controlled reactor. I_s , I_R and I_C 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. Circulating current through the reactor (I_R) 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 vars to the system, TCR is generally rated larger than the capacitor.

2.2. Static synchronous compensator (STATCOM)

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

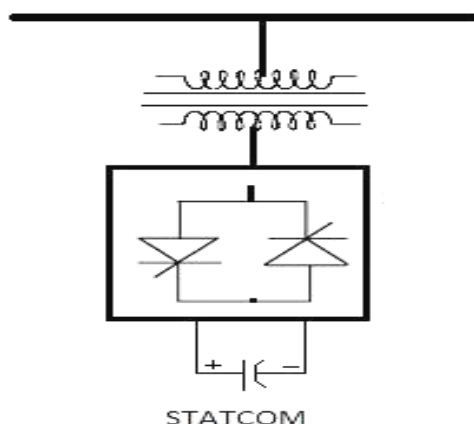


Fig 2: Static synchronous compensator

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 relocatable, less maintenance and no problem as loss of synchronism. Simple diagram of STATCOM is shown in figure [2]. 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 o/p 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.

2.3 Thyristor - Controlled Series Capacitor (TCSC):

TCSC is one of the important FACTS controllers. A capacitive reactance compensator which consists of a series capacitor bank shunted by a Thyristor-controlled

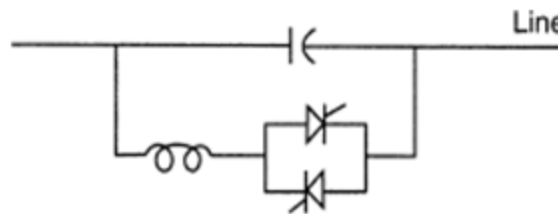


Fig 3: Thyristor Controlled Series Capacitor

reactor in order to provide a smoothly variable series capacitive reactance is called a Thyristor-Controlled Series Capacitor. The TCSC shown in above fig. is based on thyristors without the gate-turn off capability. A variable reactor such as a Thyristor-Controlled Reactor (TCR) is connected across a series capacitor. When the TCR firing angle is 180 degrees, the reactor becomes non-conducting and the series capacitor has its normal impedance. As firing angle changes to below 180 degrees, the capacitive impedance increases and when it reaches 90 degrees, the reactor fully conducts and the total impedance becomes inductive as the reactor impedance is designed to be much lower than series capacitor impedance at which TCSC helps in limiting fault current. For better performance, TCSC can be made of a single, large unit, or may consist of several equal or different-sized smaller capacitors.

2.4 Thyristor - Controlled Series Reactor (TCSR):

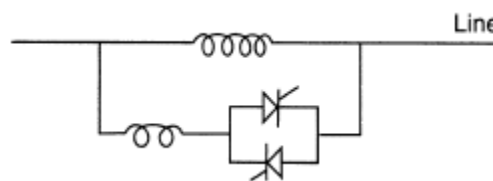


Fig 4: Thyristor Controlled Series Reactor

An inductive reactance compensator which consists of a series reactor shunted by a thyristor-controlled reactor in order to provide a smoothly variable series inductive reactance. The above fig. shows the TCSR. A variable reactor such as TCR is connected across a series inductor. When the firing angle of TCR is 180 degrees, it stops conducting and the uncontrolled reactor acts as a fault current limiter. As the angle of TCR decreases below 180 degrees, the net inductance decreases until firing angle reaches 90 degrees. At 90 degrees the net inductance is the parallel combination of the two reactors. Like TCSC, TCSR may be a single large unit or several smaller series units.

2.5 Unified power flow controller (UPFC)

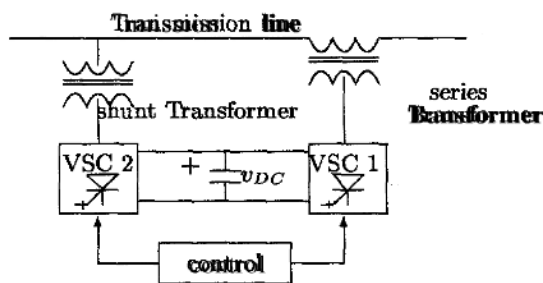


Fig 5: Unified Power Flow Controller

A Unified Power Flow Controller is an electrical device for providing fast-acting reactive power compensation on high voltage electricity transmission networks. It uses a pair of three-phase controllable bridges to produce current that is injected into a transmission line using a series transformer. The controller can control active and reactive power flows in a transmission line. The UPFC uses solid state devices, which provide functional flexibility, generally not attainable by conventional thyristor controlled systems. The UPFC is a combination of a static synchronous compensator and a static synchronous series compensator coupled via a common DC voltage link. The UPFC allows a secondary but important function such as stability control to suppress power system oscillations improving the transient stability of power system.

2.6 Static Synchronous Series Compensator (SSSC)

The static synchronous series compensator is placed in the group of series connected FACTS devices. The SSSC consists of a voltage source inverter connected in series through a coupling transformer to the transmission line. A source of energy is required for providing and maintaining the DC voltage across the DC capacitor and compensation of SSSC losses. The model of SSSC which consists of a series connected voltage source in series with an impedance. This impedance represents the impedance of coupling transformer.

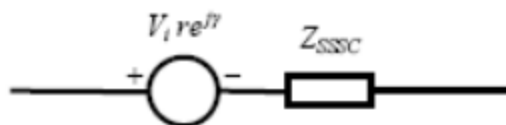


Fig 6: Equivalent circuit of SSSC

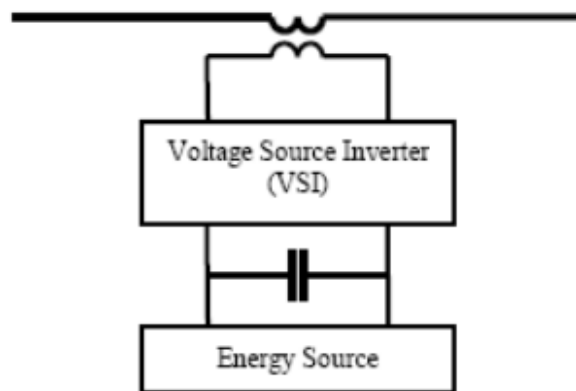


Fig 7: Static Synchronous Series Compensator

3. Simulation & Design of Various FACTS Devices

3.1 Simulation Design of Basic Transmission line

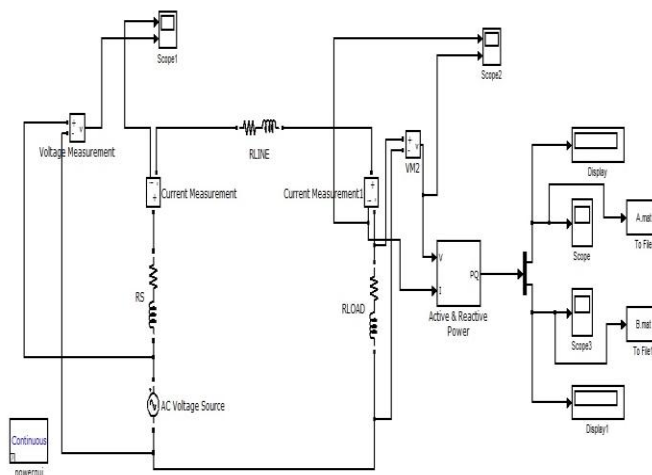


Fig 8: Simulation Design of Transmission Line

Design parameters:

$$V_S = 11 \text{KV}, f = 50 \text{Hz}$$

$$Z_S = 0.01 + j0.001$$

$$Z_{LINE} = 5 + j0.001$$

$$Z_{LOAD} = 1 + j0.02$$

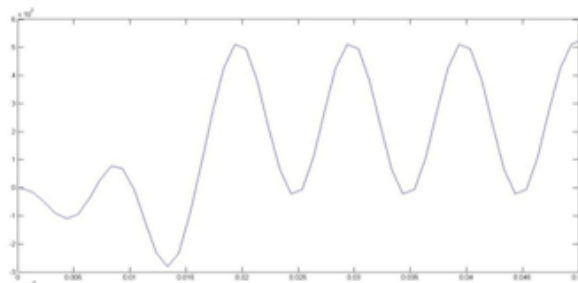


Fig 9: Real Power without Compensation:

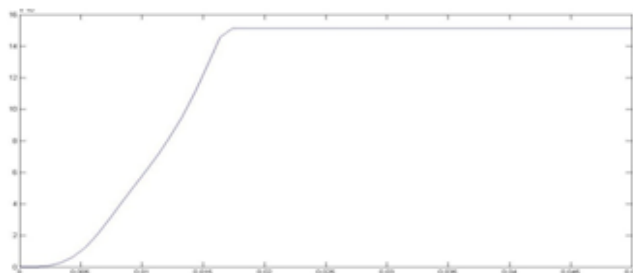


Fig 10: Reactive Power without Compensation

3.2 Simulation Design of FC-TCR

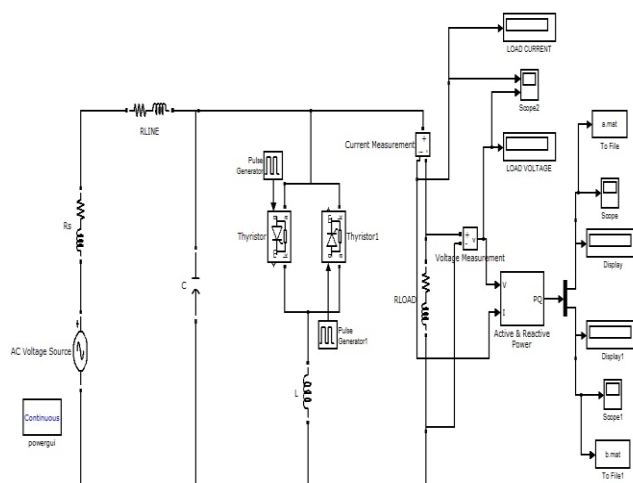


Fig 11: Simulation Design of FC-TCR

Design Parameters:

$V_S=11\text{KV}$, $F=50\text{HZ}$, $C=250\mu\text{F}$, $L=250\text{mH}$

$Z_S=0.01+j0.001$; $Z_{LINE}=0.01+j0.001$; $Z_{LOAD}=1+j0.1$

Firing Angle = 90°

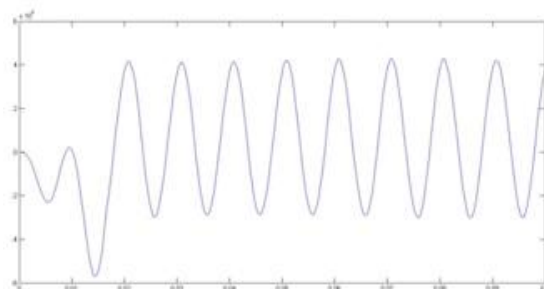


Fig 12: Real Power with FC-TCR Compensation

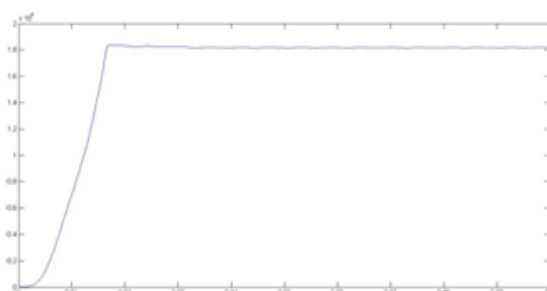


Fig 13: Reactive Power with FC-TCR Compensation

The following Table shows the simulation results of Transmission line with FC-TCR compensation for different values of Reactance with the fixed value of capacitor. As the value of Capacitance increases, the flow of Real and Reactive powers also increases.

Table 1 : Simulation of FC-TCR with Different Values of Reactance

S. No	Reactance (mH)	Real Power (MW)	Reactive Power (MVAR)
1	50	0.3327	1.702
2	100	0.3449	1.771
3	150	0.3488	1.796
4	200	0.3508	1.808
5	250	0.352	1.816
6	300	0.353	1.821
7	350	0.3533	1.825
8	400	0.3541	1.827
9	450	0.3544	1.83
10	500	0.3546	1.831

3.3 Simulation Design of STATCOM:

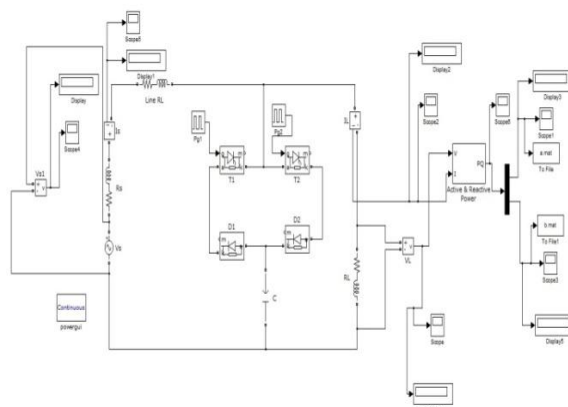


Fig 14: Simulation Design of STATCOM

Design Parameters:

$V_S=11\text{KV}$, $f=50\text{Hz}$, $C=50\mu\text{F}$

$Z=0.01+j0.001$; $Z_{LINE}=0.01+j0.001$; $Z_{LOAD}=1+j0.1$

Firing Angle $=90^\circ$

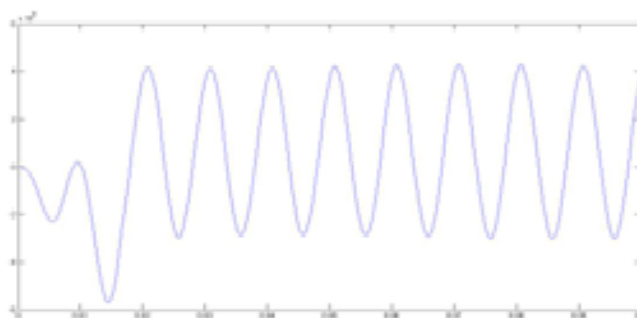


Fig 15: Real Power with STATCOM Compensation

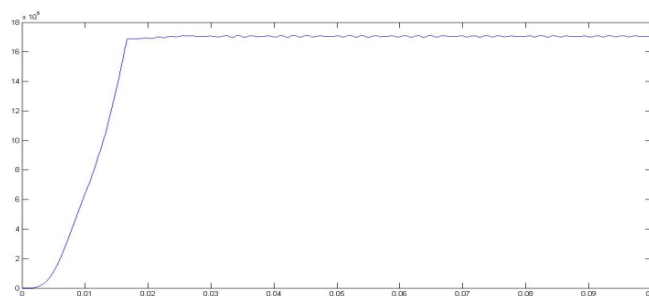


Fig 16: Reactive Power with STATCOM Compensation

The following Table shows the simulation results of Transmission line with STATCOM compensation for different values of capacitance. As the value of Capacitance increases, the flow of Real and Reactive powers also increases

Table 2: Simulation of STATCOM with Different Values of Capacitance

S. No	Capacitance (μF)	Real Power(MW)	Reactive Power(MVAR)
1	50	0.329	1.705
3	150	0.345	1.773
4	200	0.348	1.811
5	250	0.365	1.837
7	350	0.376	1.940
9	450	0.421	1.971
10	500	0.375	2.127

3.4 Simulation Design of TCSC:

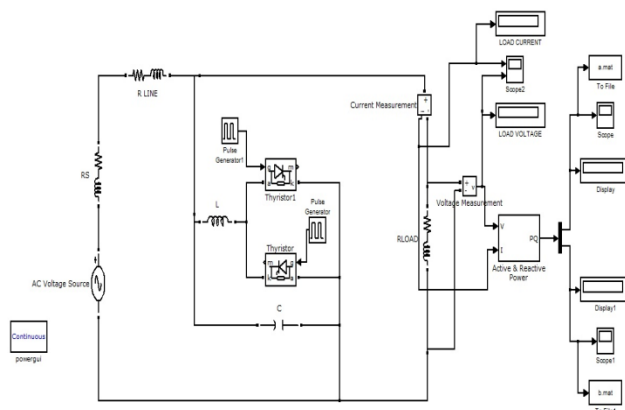


Fig 17: Simulation Design of TCSC

Design Parameters

$$V_S = 11 \text{KV}, f = 50 \text{Hz}$$

$$Z_S = 0.01 + j0.001; Z_{LINE} = 0.01 + j0.001; Z_{LOAD} = 1 + j0.1$$

$$\text{Firing Angle} = 90^\circ, L = 250 \text{mH}, C = 250 \mu\text{F}$$

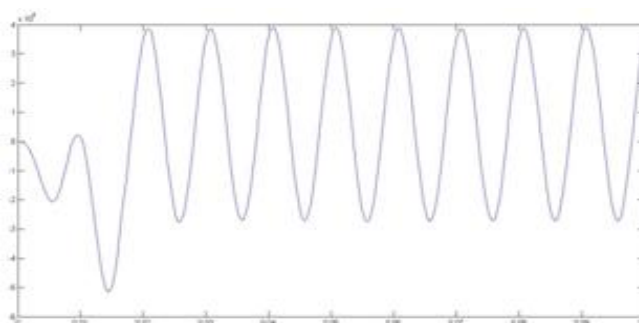


Fig 18: Real Power with TCSC Compensation

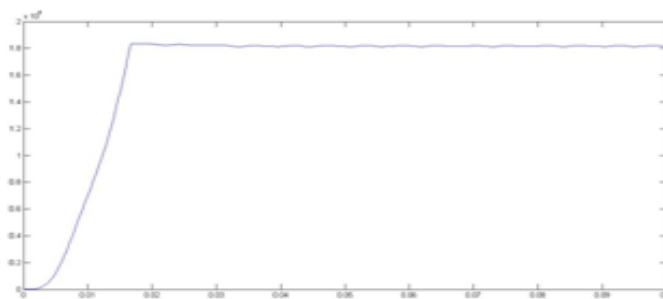


Fig 19: Reactive Power with TCSC Compensation

The following Table shows the simulation results of Transmission line with TCSC compensation for different values of Capacitor. As the value of Capacitance increases, the flow of Real and Reactive powers also increases.

Table 3: Simulation of TCSC with Different Values of Capacitance

S. No	Capacitance (μF)	Real Power (MW)	Reactive Power (MVAR)
1	50	0.325	1.608
2	100	0.331	1.711
3	150	0.338	1.745
4	200	0.344	1.781
5	250	0.352	1.816
6	300	0.360	1.853
7	350	0.366	1.892
8	400	0.374	1.932
9	450	0.381	1.973
10	500	0.388	2.016

3.5 Simulation Design of TCSR:

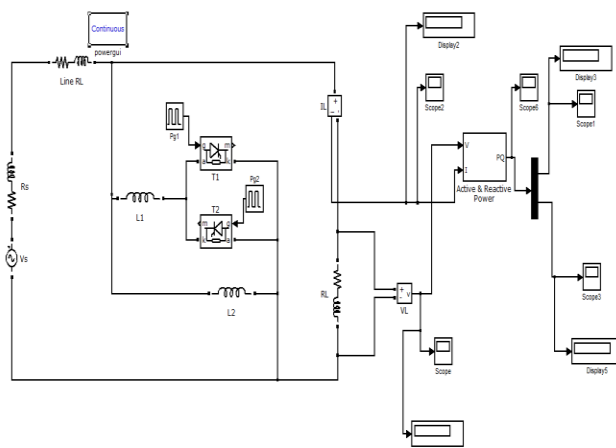


Fig 20: Simulation Design of TCSR

Design Parameters

$$V_S=11\text{KV}, f=50\text{HZ},$$

$$L_1=250\mu\text{F}, L_2=250\text{UF}$$

$$Z_S=0.01+j0.001$$

$$Z_{LINE}=0.01+j0.001$$

$$Z_{LOAD}=1+j0.1$$

$$\text{Firing Angle}=90^\circ$$

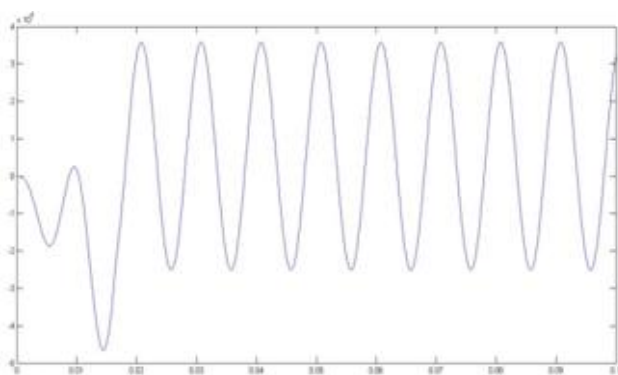


Fig 21: Real Power with TCSC Compensation

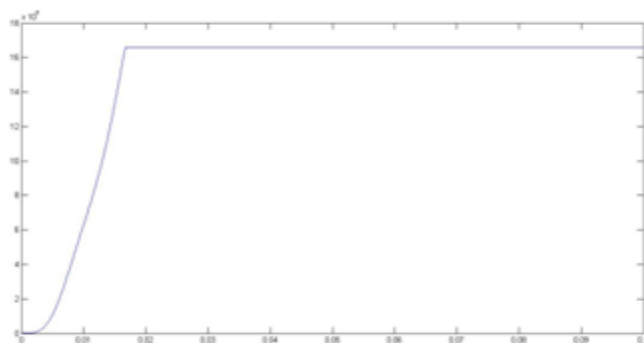


Fig 22: Reactive Power with TCSC Compensation

The following Table shows the simulation results of Transmission line with TCSR compensation for different values of Reactance. As the value of Capacitance increases, the flow of Real and Reactive powers also increases.

Table 4: Simulation of TCSR with Different Values of Capacitance

S.No	Reactance (mH)	Real Power (MW)	Reactive Power (MVAR)
1	50	0.296	1.525
2	100	0.307	1.582
3	150	0.311	1.604
4	200	0.313	1.615
5	250	0.314	1.621
6	300	0.315	1.625
7	350	0.315	1.628
8	400	0.316	1.630
9	450	0.316	1.632
10	500	0.317	1.634

3.6. Simulation Design of SSSC

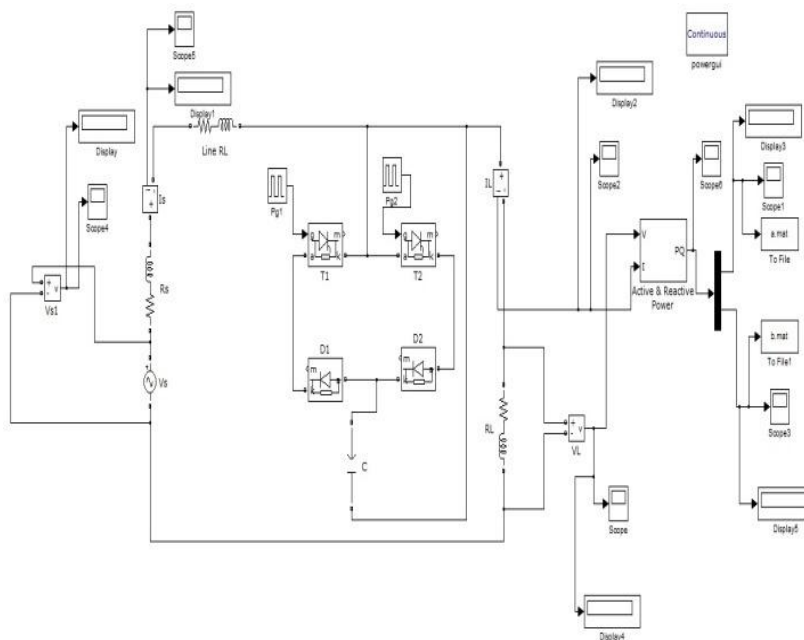


Fig: 23 Simulation Design of SSSC

Design Parameters:

$V_S=11\text{KV}$, $f=50\text{Hz}$, $C=250\mu\text{F}$

$Z_S=0.01+j0.001$; $Z_{LINE}= 0.01+j0.001$; $Z_{LOAD}=1+j0.1$

Firing Angle $=90^\circ$

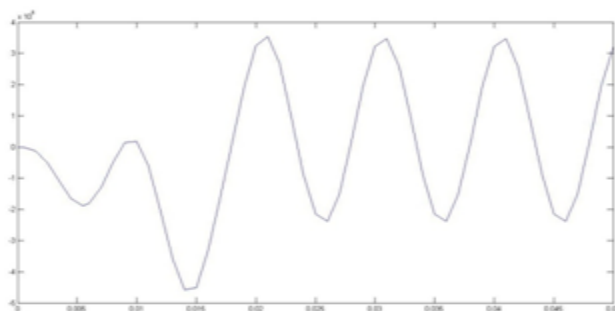


Fig 24: Real Power with SSSC Compensation

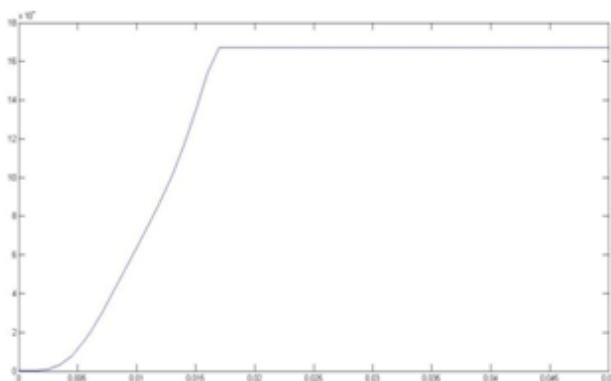


Fig 25: Reactive Power with TCSC Compensation

3.7 Simulation Design of UPFC:

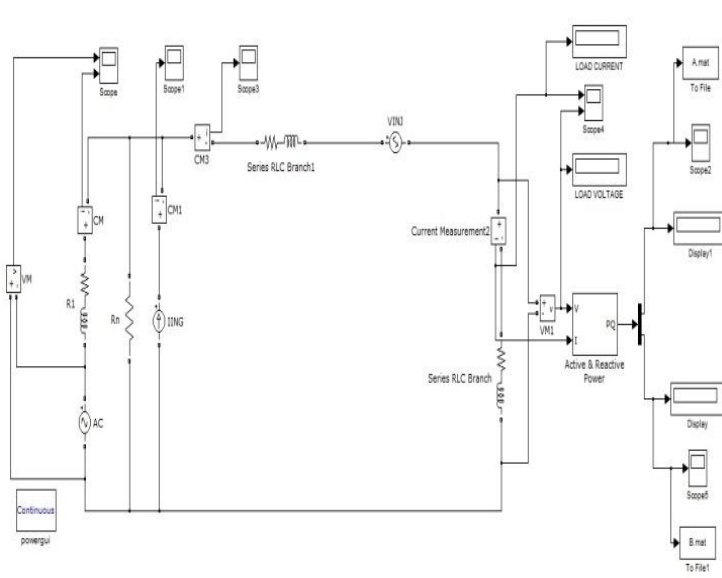


Fig: 26 Simulation Design of SSSC

Design parameters

$$V_S = 11 \text{KV}, f = 50 \text{Hz}$$

$$Z_S = 0.01 + j0.001; Z_{LINE} = 0.01 + j0.001; Z_{LOAD} = 1 + j0.1$$

$$\text{Firing Angle} = 90^\circ$$

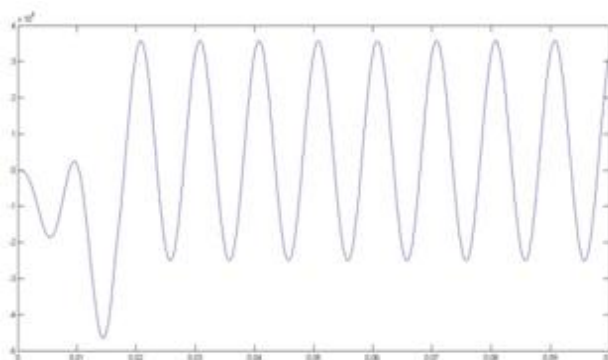


Fig 27: Real Power with SSSC Compensation

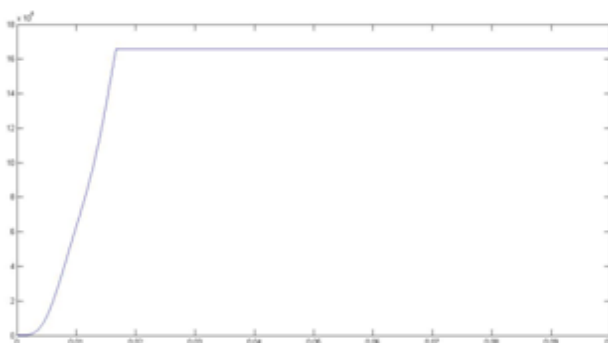


Fig 28: Reactive Power with SSSC Compensation

The following Table shows the simulation results of Transmission line with UPFC compensation for different values of injected current. As the value of current increases, the flow of Real and Reactive powers also increases.

Table 5: Simulation of UPFC with Different Values of Injected Currents

S.No	Injected Current(A)	Real Power(MW)	Reactive Power(MVAR)
1	50	0.3201	1.657
2	100	0.3205	1.675
3	150	0.3210	1.675
4	200	0.3214	1.675
5	250	0.3218	1.675

4. Conclusion

MATLAB/SIMULINK environment is used for this comparative study to model and simulate FC-TCR type SVC, STATCOM, TCSC, TCSR, SSSC, and UPFC connected to a simple transmission line. This paper presents performance analysis of all the above FACTS devices and an elaborate comparison between their performances. Power flow and voltage profile are seen to improve with all the compensating devices. This paper describes the control strategy for Real and Reactive powers of the transmission line using different FACTS devices. Results show that in case of FC-TCR and STATCOM compensation, reactive power flow improves proportionally with increasing capacitance and is maximum at maximum value of capacitance (250 μ F here). In case of TCSC a fixed inductance of 250mH and capacitor value of 250 μ F gives best result. For SSSC compensation and UPFC a capacitor rating of 250 μ F yields best result. Hence, it can be concluded that UPFC provides most desirable performance when connected to the system as compared to other FACTS devices.

5. References

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6. Biographies



Mr. B. Ashok Kumar completed B.Tech in S.V.H College of Engineering, Machilipatnam in 2004 and completed M.E with the specialization power electronics & industrial drives in Satyabhama University, Chennai in 2009. At present he is pursuing Ph.D from VIT University, Chennai in the area “Smart grid metering”. He is having 8 years of excellent teaching experience. He attended and published various papers in national & international level.



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