Enhancement of Voltage and power Flow by Series FACTS devices Using TCSC and SSSC

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Abstract: **In the recent year due to lack of new generation and an increase in the load causes the inadequate reactive power and thus it leads to voltage drops. The active power and reactive power can be controlled by using the FACTS devices for the enhancement of the stability of the power system. The Series FACTS devices are connected in series to the transmission line for the voltage profile improvement and as well as reducing the transmission line losses. The TCSC series facts device which controls the effective line reactance by connecting a variable reactance in series with a line, in the capacitive mode it injects the voltage in series to the transmission line thus is contributes better voltage profile. The SSSC is used for voltage stability improvement and it controls the active and reactive power. In this paper, the facts devices Thyristor Controlled Series Capacitor (TCSC) and Static Synchronous Series Compensator (SSSC) are taken and the performance of TCSC and SSSC are compared for the better voltage profile improvement, active power flow improvement, reduction of losses are analyzed by taking IEEE 14 Bus test system and developed on MATLAB/SIMULINK platform.**

***Index Terms*: TCSC, SSSC**

I. INTRODUCTION

In Integrated network maintaining the voltage levels and reducing the power losses are more crucial. Voltage stability is the ability of the power system to maintain steady voltages at all buses in the system after being subjected to disturbances i.e.; even after fault occurrence, overloading condition etc. If the voltage is not under the control it may lead to the cascading condition and further, it may be sustained to blackouts. FACTS device are incorporated in the integrated network for controlling the power flows in the transmission lines. FACTS device are cost-effective rather than constructing the new transmission line and usage of synchronous condensers for power flow and voltage improvement. The series FACTS device partially cancels the line reactance and thus, the voltage drop across the reactance decrease, voltage improves. In many practical applications, the series FACTS device is capacitive-type rather than inductive. The series FACTS devices are taken in this paper for active power flow improvement and maintenance of voltage levels. The TCSC (Thyristor Controlled Series Capacitor) and SSSC (Static Synchronous Series Compensator) are the series type of FACTS device and the advantages are power flow control, enhancement of voltage stability, reactive power compensation, reduction of power losses, mitigation of power oscillation and sub synchronous resonance. The SSSC device with 24 pulse VSC injects the voltage in series to the transmission line. These Series FACTS are incorporated in the IEEE14 Bus standard test system and the data is taken from [2]. The results are compared in section IV and final conclusion.

II. TCSC FACTS DEVICE:

The TCSC (Thyristor Controlled Series Compensator) is the parallel combination of TCR and a capacitor. The TCR (Thyristor Controlled Reactor) consists of a bidirectional thyristor value is in series with an inductor. The TCSC is a simple parallel LC circuit, but the TCSC is controlled by thyristors thus the waveforms are not pure sinusoidal as parallel LC combination circuit [1]. The capacitor is to supply the reactive power and to reduce the series reactance of the transmission line. The overall equivalent reactance of TCSC is varied by firing angle. The reactance of the transmission line is smoothly adjusted by TCSC. The firing angles are given in table2 in the appendix.

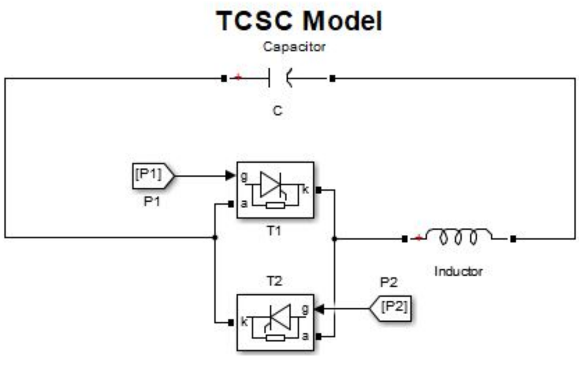

Figure 2: Basic Structure of TCSC model

2.1Different Modes of TCSC

The angle between the zero crossing to the instant of the thyristor is fired is called the delay angle. The delay angle of the thyristors is varied in order to control the modes of the TCSC device. TCSC can be operated either in inductive mode or in a capacitive mode based on the application.

a) ***By passed Thyristors****:* In this mode, all current flows through the TCR and TCSC acts as a small reactor

b) ***Blocked Mode:*** Thyristors are blocked; no triggering the TCSC acts as a fixed capacitor the equivalent reactance is capacitive.

c) ***Capacitive mode****:* The conduction angle of the thyristor is small and then the reactance of the capacitor is increased. The firing angle range for capacitive mode is $\alpha_{CLim} \leq \alpha \leq 90$ degrees [1]. Decreasing X_L (α) further the $X_{TCSC}(\alpha)$ becomes capacitive.

d) ***Inductive Mode****:* In this mode the conduction angle of the thyristor is large. The firing angle range for inductive mode is $0 \leq \alpha \leq \alpha_{Lim}$, $X_{TCSC}(\alpha)$ becomes inductive.

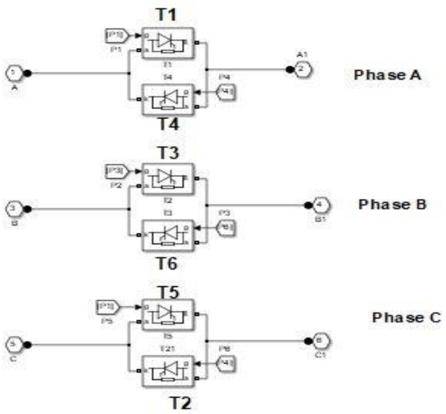

Figure2.1: Back to back thyristors of TCSC

2.2 Modeling of TCSC

The capacitor and inductor of the TCSC device are based on the compensation percentage. The compensation level is based on the thermal limit of the transmission line.

The effective reactance of TCSC is given as

$$X_{TCSC}(\alpha) = \frac{(Xc \times XL(\alpha))}{(Xc - XL)} \qquad (1)$$

Xc is the inductive reactance of the TCSC

The XL(α) is the inductive reactance is a function of firing angle.

$$X_L(\alpha) = \frac{XL}{\pi - 2\alpha - \sin\alpha} \qquad (2)$$

X_L=(ωL) where ω is the angular frequency.

The effective reactance of TCSC, Xtcsc become negative when TCSC is operated under capacitive mode.

The Xtcsc becomes positive when is operates in inductive mode.

Reactive power of TCSC is from [8]

$$Q_{TCSC} = \frac{3(Vtcsc)2}{Xc} \qquad (3)$$

Where

$$V_{TCSC} = XTcsc * I_{Line} \qquad (4)$$

I_{Line} is the line current.

The 'ω' is the boost factor .

$$\omega = \sqrt{(Xc/XL)} \qquad (5)$$

The boost factor range is from 1.1 to 3 from[5] to avoid resonance condition.For the K% of compensation the Xc= K%(X_L) (5)

The compensation considered is 40% for the better voltage profile improvement.The capacitive reactance Xc=0.4*$X_L$from the (6)

At resonance condition the Xc = X_L (α) then theoretically X_{TCSC} becomes infinity [1]. The frequency of TCSC matches with the system frequency at resonance condition.

III.SSSC FACTS DEVICE:

The series FACTS device SSSC is connected in series to the transmission line through the DC link capacitor, Voltage Source Converter (VSC) and series transformer. The series transformer connection is not in TCSC facts device so the cost of TCSC is less compared to SSSC device. The SSSC injects the voltage in quadrature to the line current either lag or lead. The SSSC device injects the voltage lagging to line current it operates in capacitive mode or otherwise operates in inductive mode. The SSSC acts as a controllable voltage source independent of the line current. Thus the SSSC induces or reduces the voltage levels in capacitive or inductive modes.

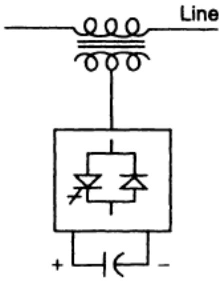

Figure 3: The schematic diagram of the SSSC device [1]

The injected voltage of SSSC is almost sinusoidal and by using SSSC FACTS device power flow control, line reactance control and controls the bus voltage. The DC side capacitor is based on the compensation level required for the system. The high power directly controlled converters are most costly and more difficult to implement, but they provide better flexibility [6].The primary winding of the series transformer is connected in series to the transmission line and secondary winding of the series transformer is connected to the phase shifting transformer of the VSC.

3.1 Voltage source converter (VSC)

The VSC considered for SSSC is 24 pulse GTO based Voltage Source Converter (VSC), thus it is used for high power and high voltage applications and the need of AC filters is reduced by 24pulse VSC. The VSC consists of two 12 pulse GTO converters interlinked via phase shifting Transformer. The voltage across each capacitor is Vdc/2 .The two phase shifting transformer of one of the 12 pulse converter provide +7.5° phase shifting winding each and another set of 12 pulse converter provide -7.5° phase shifting winding.Thus, the phase shifting between two 12 pulse converters is 15° with respect to each other The harmonics present in the output AC side voltage would have 24n±1 order harmonics i.e.; 1/23rd,1/25th,1/47th.1/49th….respectively, of the fundamental AC Voltage [1]. The SSSC with DC power supply further improves the active power flow control compared to without any energy storage device.

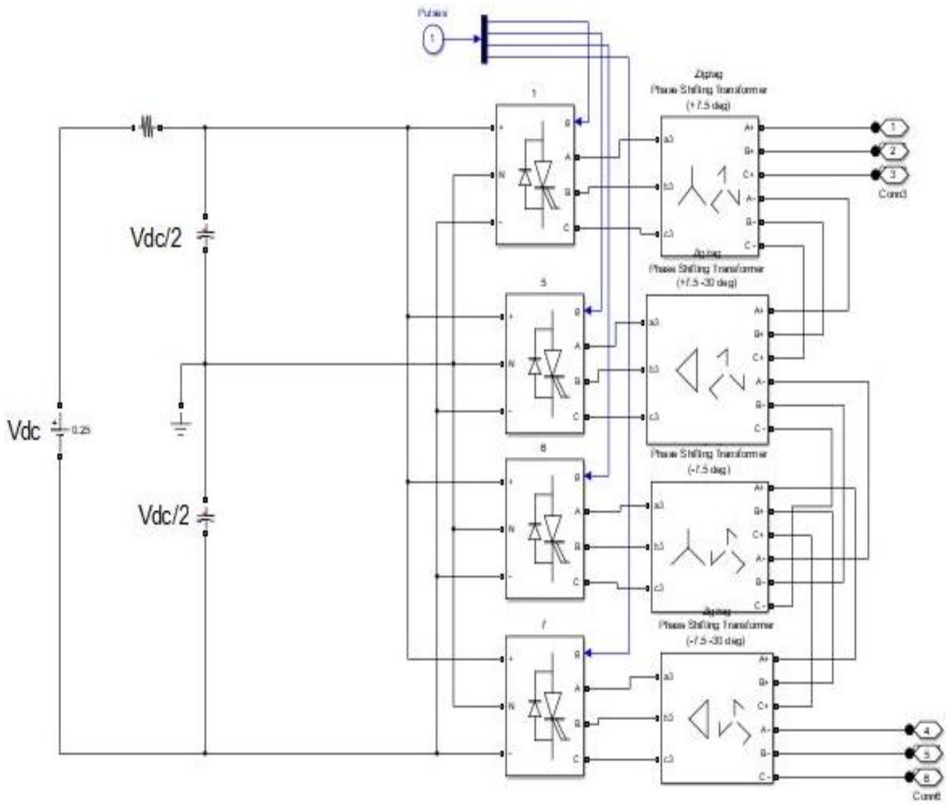

Figure3.1: 24 Pulse GTO based Voltage source converter

3.2 MODELINGOF SSSC FACTS:

The Injected voltage of SSSC is

$V_c = -jK*X_L*I_{Line}$

Where K is the degree of compensation

X_L is the series line reactance

The SSSC injects the compensating voltage in series to the transmission line irrespective of the line current [1].
The active power is given as from [1]

$$p = \frac{v2}{XL(1-K)} \text{Sin}\delta \qquad (6)$$

Properly choosing the compensation K maximum power can be transferred in the line.
The reactive power supplied by the series capacitor is given as from [1].

$$Q = \frac{2V2 \quad K}{X \ K(1-K)2} (1-\cos\delta). \qquad (7)$$

The reactive power flow in the transmission line is also depends on the degree of compensation.
The VA rating of SSSC (solid state converter and coupling transformer) from [1]

VA=Vqmax*Imax

Vqmax is the maximum compensating voltage
Imax is the maximum line current.

IV. SIMULATION RESULTS AND DISCUSSION

Case 1: voltage profile improvement by using TCSC and SSSC series FACTS devices.

The IEEE 14 BUS is considered for the analysis and implemented in MATLAB/SIMULINK platform and data considered for the TCSC is given in appendix table3 The FACTS devices TCSC is incorporated in the line 4-5 as shown in figure 4.1 and SSSC FACTS device is incorporated in the same line 4-5 as shown in figure 4.2 and the data considered for SSSC is from the table4 of the appendix The voltage at bus 5 is 1.0417 P.U without FACTS devices, by placing TCSC the voltage at bus 5 is improved to 1.045 P.U as shown in figure 4.3 and by placing SSSC the voltage at bus 5 is improved to 1.06P.U from the figure 4.4

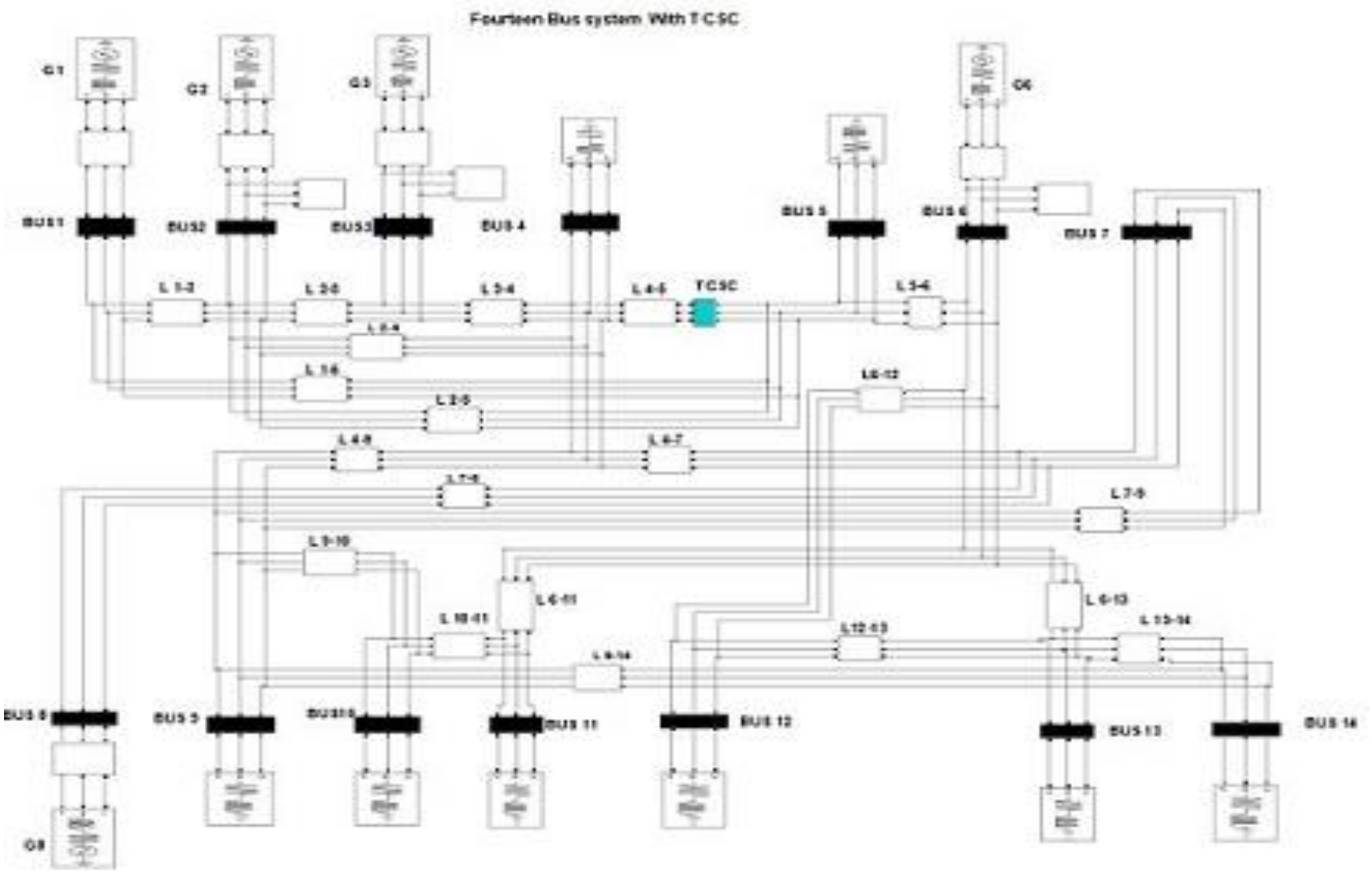

Figure 4.1: Simulink model of IEEE 14 bus test system with TCSC in line 4-5

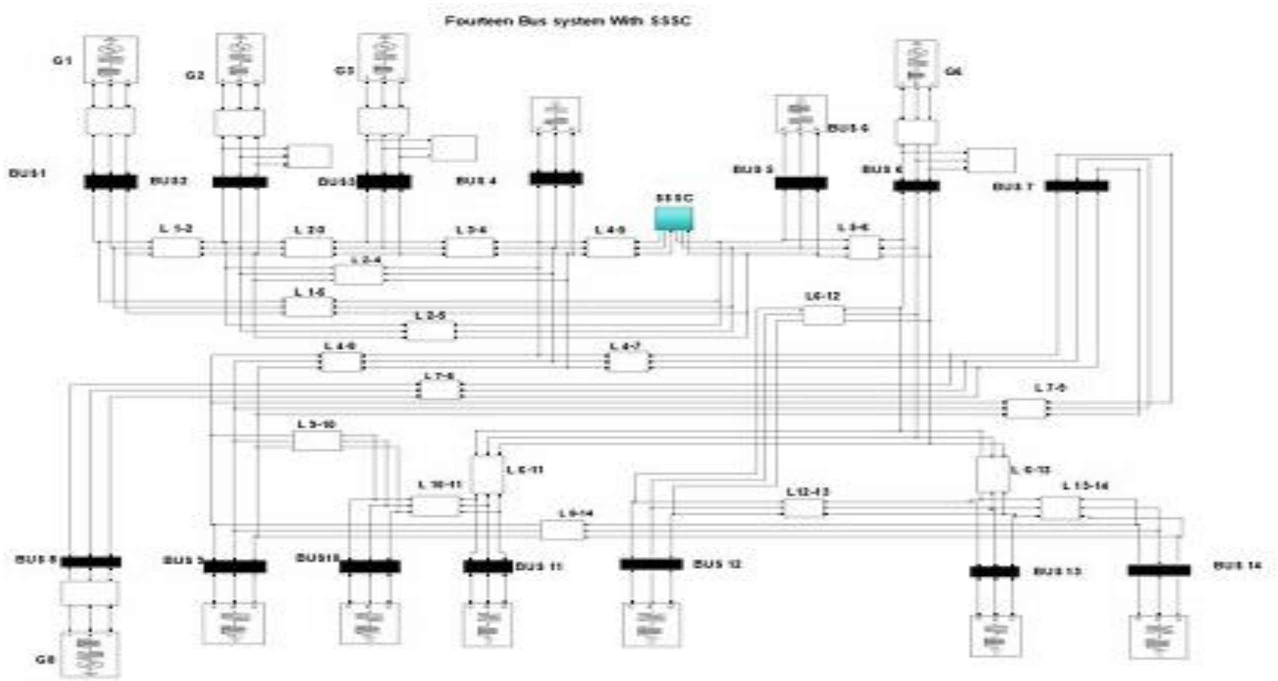

Figure 4.2: Simulink model of IEEE 14 Bus test system with SSSC in line 4-5

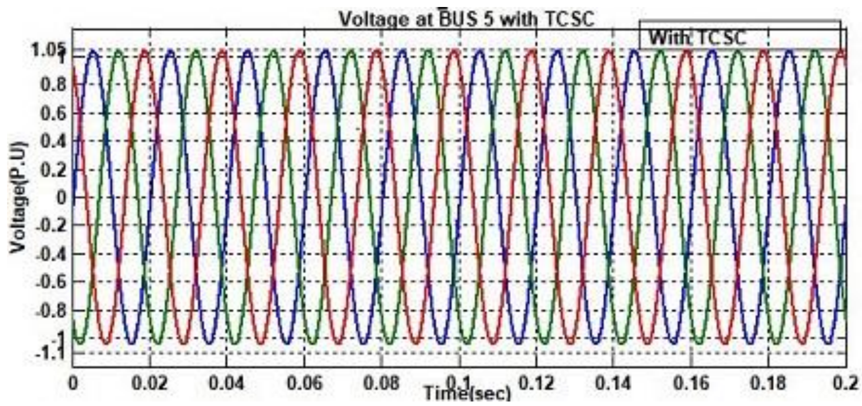

Figure 4.3: voltage waveform at bus 5 is 1.045P.U with TCSC

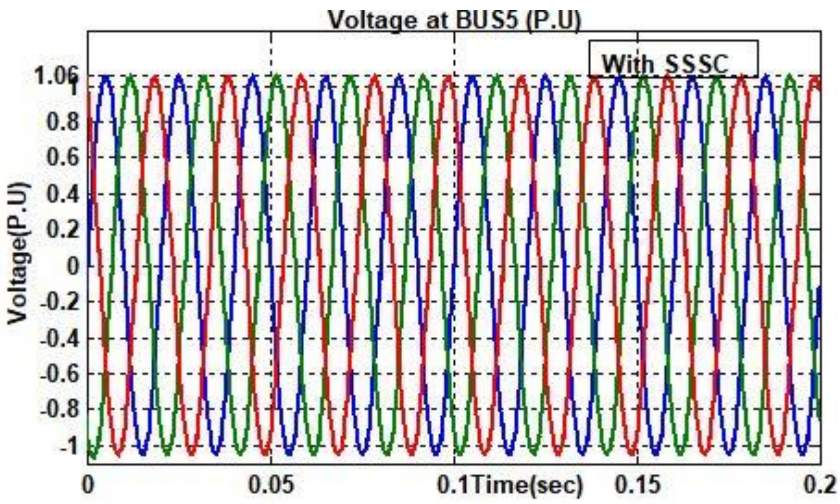

Figure 4.4: voltage waveform at bus 5 is 1.06 P.U with SSSC device

Case 2: Power flow Improvement and Loss reduction by using TCSC and SSSC.

The TCSC and SSSC are placed in line 4-5 by using MATLAB/SIMULINK platform. The active power flow without FACTS device is 24.96MW shown in below figure 4.5 and with TCSC FACTS device is 27.88MW as shown in figure 4.6 and by considering SSSC FACTS device the active power flow is 30.18MW shown in figure 4.7. The thermal limit of the line 4-5 is 45MVA, without FACTS controllers the MVA flow in the line L4-5 is 25.229, with TCSC is 27.877MVA, by considering SSSC is 30.194MVA. Thus the MVA flow in the line is increased by considering TCSC and SSSC.

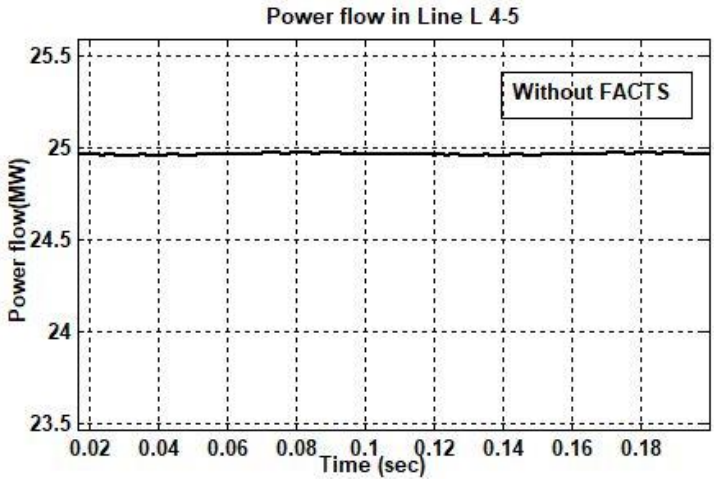

Figure 4.5**:** Active power Flow 24.96MW without FACTS device

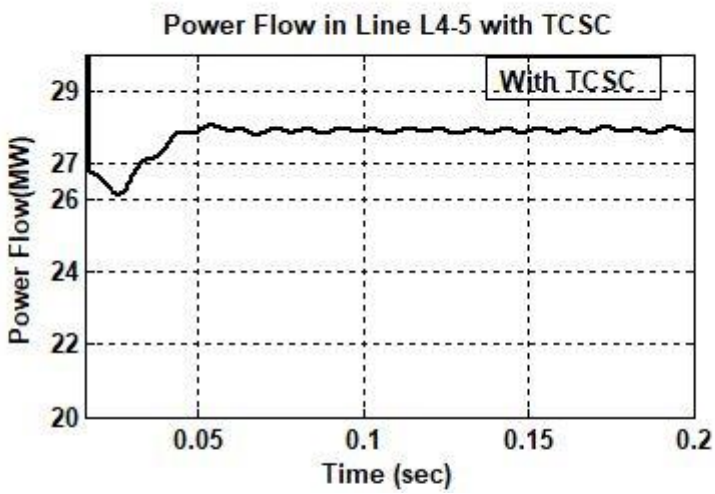

Figure 4.6**:** Active power Flow 27.88 MW with TCSC FACTS device

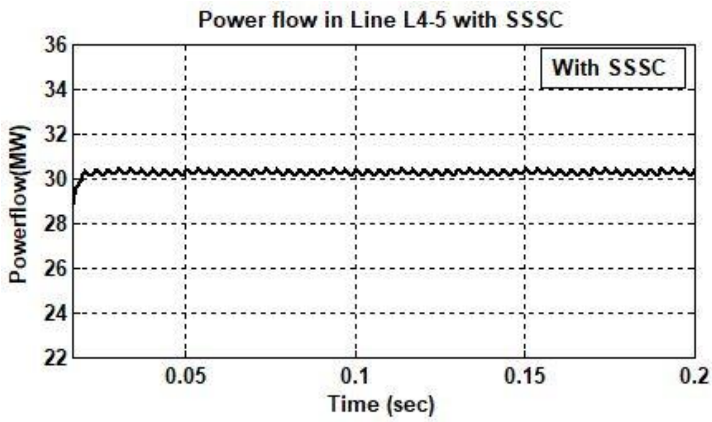

Figure 4.7: Active power flow is 30.18MW in line 4-5 with SSSC

Table1: Comparison of voltage profile, active power flow and losses with TCSC and SSSC

Remarks	Without FACTS	With TCSC	With SSSC
Case 1 (voltage profile)	1.0417 P.U	1.045P.U	**1.06P.U**
Case 2 (Active power flow)	24.96MW	27.86MW	**30.18MW**
Case 2 (power loss)	90KW	28KW	**26KW**

V.CONCLUSION:

This paper shows the power flow improvement, losses mitigation, voltage profile improvement by considering the TCSC and SSSC FACTS device. Thus, FACTS device TCSC gives the voltage 1.045 P.U, active Power Flow is 27.88MW and power loss is 28.3 KW and the SSSC facts device gives 1.06 P.U voltage and active power flow is 30.194MW, Power loss is 26.34 KW and these result are as shown in table1. The active power flow in the line 4-5 increases and the losses got reduced further by the TCSC and SSSC. On comparing the obtained results the SSSC gives better results than TCSC. In future the mitigation of Sub Synchronous Resonance (SSSR) and Power Oscillations Damping (POD) by incorporating the TCSC and SSSC facts device can also be analyzed by these devices.

VI. APPENDIX

Table 2: Three phase Anti parallel Thyristors (TCSC) phase delay (seconds)

Thyristor	Pulse generator Phase delay(seconds)
T1	(α)/(360)*0.02
T4	(α+180)/(360)*0.02
T3	(α+120)/(360)*0.02
T6	(α+300)/(360)*0.02
T5	(α+240)/(360)*0.02
T2	(α+60)/(360)*0.02

Table 3: Data considered for TCSC (P.U)

V_{TCSC}(per phase)	5.52KV
Xc(per unit)	0.0168P.U
X_L(per unit)	0.01169 P.U
Firing angle	145 degrees
Boost Factor(ω)	1.2

Table 4: Variation of Power flow with respective firing angle of TCSC

Firing angle(degrees)	Active Power Flow in L4-5 (MW)
140	27.6
141	27.64
142	27.7
143	27.75
144	27.81
145	27.88

Table 5: Data considered for SSSC Facts device

Series Transformer	45MVA,69/17.25KV
Voltage source Converter(VSC)	24 pulse Type
Capacitor	188millifarads
DC voltage	0.25P.U

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