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PERFORMANCE COMPARISON OF SVC AND TCSC

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Abstract*—Voltage stability in power system is the capability to keep adequate voltages in all buses at normal conditions and even conditions after disturbances. Due to voltage instability, the power system experiences voltage collapses if the post-disturbance equilibrium voltages are below acceptable limits, causing total blackout. It is understood by many experts that the power system will be used with a lesser margin to voltage collapse in the future. Hence, voltage stability is believed to be of bigger concern in the future. Voltage stability of a system is affected by the reactive power limit of the system. FACTS devices improve the reactive power flow in the system, thereby, improving voltage stability. This paper explores the effect of SVC (Static VAR Compensator), TCSC (Thyristor-Controlled Series Capacitor) and Hybrid (combination of both) Controller on static voltage stability. IEEE-14 bus has been used to demonstrate the ability of these FACTS devices in improving the voltage stability margin.

***Keywords*— SVC-*Static VAR* , TCSCN-R, IEEE-14 bus ,Mat lab**

I. INTRODUCTION

Voltage stability issues are always of foremost concern all over the worldwide. One reason is the significant number of blackouts which have occurred and which frequently have implicated voltage stability issues [1]. The blackout on 31st July 2012 was the largest power outage in history [2]. The outage affected more than 620 million people, about half of India's population, spread across 22 states in Northern, Eastern and Northeast India. These kinds of blackouts may occur in the future. It is believed that the existing transmission systems will be utilized more and more due to environmental concerns, which makes it difficult to build new power plants or transmission lines [3].

This research area concerns disturbances in a power system where the voltage becomes uncontrollable and collapses [4]. The voltage decline is often monotonous and small at the onset of the collapse and difficult to detect. A sudden and probably unexpected increase in the voltage decline often marks the start of the actual collapse. It is becoming increasingly important for power system planning and operating engineers to be capable of performing comprehensive voltage stability analyses of the systems. This need is largely due to the recent trends towards operating systems under stressed conditions—as a result of increasing system loads without sufficient transmission and/or generation enhancements.

There have been many failures, due to voltage instability in power systems around the world. In recent years, many researchers have suggested techniques for voltage stability analysis considering both static and dynamic aspects [5]. This paper is mainly concerned with analysis of steady state voltage stability. Much research work is therefore going on worldwide covering many different aspects of system operation where voltage stability is an important feature. Voltage stability deals with the ability to control the voltage level within a limit around normal operating voltage. Equipment and operation control are tuned towards specified set points giving small losses and avoids power variations due to voltage sensitive loads [6]. The Power-flow or load flow analysis is important for planning future expansion of power systems as well as in determining the best operation of existing system. The main information obtained from the power-flow analysis is the real and reactive power flowing in each line, magnitude and phase angle of the voltage at each bus. Newton-Raphson method is the best method for power-flow analysis, because it works faster and is sure to convergence in most cases as compared to Gauss-Seidel method.

The only way to save the system from voltage instability is to reduce the reactive power load or add additional reactive power before reaching the point of voltage collapse. In recent times, the application of Flexible Alternating Current Transmission System (FACTS) devices is a very effective solution to prevent voltage instability due to their fast and very flexible control [7]. This paper mainly focuses on two devices, namely, Static VAR Compensator (SVC) & Thyristor-Controlled Series Capacitor (TCSC). Some researchers compare the study of SVC and TCSC in static voltage stability margin enhancement is presented. Both SVC and TCSC are capable of increasing static voltage stability margin, though SVC provides higher voltage stability margin and better voltage profiles compared to TCSC because the SVC is a shunt compensation device, which inject reactive power the most at the weakest bus where power system requires reactive power the most at this bus.

During the last few decades, there have been one or several large voltage collapses almost every year somewhere in the world. The reason is because of over utilization/exhaustion of the power system leading to decreasing system security. The consumer's demand keeps increasing by the clock but the supply is insufficient. Also, load characteristics have changed tremendously. For stable operation of power equipment's, voltage control of electrical power system is very essential. This will prevent damages like overheating of motors and generator, reduces transmission losses and maintain ability of the system to withstand and prevent voltage unbalance or blackout.

II. Static VAR Compensator

SVC is a shunt controlled FACT device and it is therefore connected in parallel with the transmission line. Thyristor in anti-parallel can be used to switch on a capacitor/reactor unit in step-wise control. When the circuitry is designed to adjust the firing angle, capacitor/reactor unit acts as continuously variable in the power circuit. Capacitor or capacitor & inductor bank can be varied stepwise or continuously by thyristor control. It injects current into the system at the point of connection. If the injected current is in phase quadrative with the line voltage, then SVC either absorbs or supplies variable reactive power [8]. An SVC compromise of one or more banks of fixed or switched shunt reactors and capacitors among which one bank is switched by the thyristor.

It consists of the following types of configurations of SVC:

- Thyristor controlled reactor
- Thyristor controlled capacitor
- Harmonics filters
- Mechanical switched capacitor or reactor

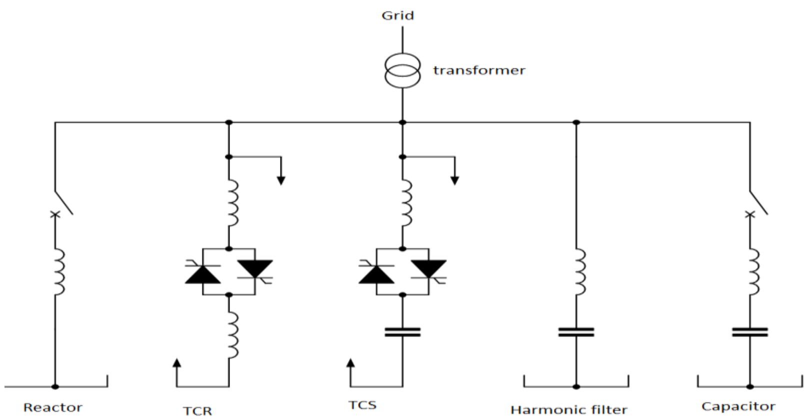

Fig.1 SVC configurations

The purpose of SVC is consequently to increase the transient stability, Thereby, increasing the power transmission capability of the system by a considerable amount [9]. At the same time, SVC provides continuous voltage control under various operating conditions of the system. Static VAR Compensators (SVC) are shunt connected static generators and/or absorbers whose outputs are varied so as to control specific parameters of the electrical power system. The term "static" is used to indicate that SVCs, unlike synchronous compensators, having no moving or rotating main components. Thus, an SVC consists of static VAR generator or absorber devices and a suitable control device.

SVC Model

SVC's are part of the Flexible AC Transmission Systems device family, regulating voltage and stabilizing the system. The most popular configuration for continuously controlled SVC's is the combination of either fixed capacitor (FC) and thyristor controlled reactor (TCR) or thyristor switched capacitor (TSC) and thyristor react (TCR). In this paper, the FC-TCR structure is used for analysis of SVC, which is shown in Fig..2.

A thyristor-controlled reactor (TCR) compensator consists of a combination of six pulse or twelve pulse thyristor-controlled reactors with a fixed shunt capacitor bank. The reactive power is changed by adjusting the thyristor firing angle. TCRs are characterized by continuous control. The control system consists of voltage and current. TCR consists of a fixed reactor of inductance L and a bi-directional thyristor valve that are fired symmetrically in an angle control range of 90^o to 180^o, with respect to the SVC voltage [10]. Through a suitable coordination of the capacitors and controlled reactor, the bus reactive power injected (or absorbed) by the SVC can be continually varied in order to control the voltage or to maintain the desirable power flow in the transmission network either over normal operating or under disturbances condition.

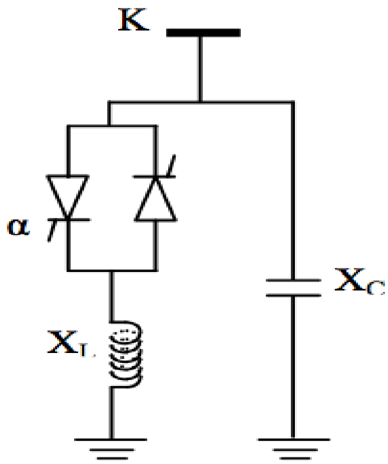

Fig. 2 Basic structure of SVC

The TCR at fundamental frequency can be considered as variable inductance given by:

$X_V = X_L \pi / 2 (\pi - \alpha) + \sin 2\alpha$

Where X_L is the reactance caused by fundamental frequency without thyristor control and α is the firing angle.

Although FC-TCR type SVC can generate higher harmonic currents, existing capacitor bank can be designed as a filter. This is not feasible in the case of TSC-TCR.

III. THYRISTOR-CONTROLLED SERIES CAPACITOR

As discussed earlier section, with increase in load demand it becomes very necessary for the voltage to remain stable. Throughout the operation of a system, FACTS devices are used in parallel with the transmission line. Similarly, there are many other FACT devices which can also used to meet the voltage requirement of the system and one such device is Thyristor-Controlled Series Capacitor (TCSC).

The development of the modern power system has led to an increasing complexity in the study of power system and also presents new challenges to power system stability, and in particular, to the aspects of transient stability. Transient stability plays a significant role in ensuring the stable operation of power systems in the event of large disturbances and faults, and is thus significant area of research. The power system stability improvement is compared with other FACTS devices such as SVC, where it is observed that there is a considerable improvement in the system's performance with the presence of TCSC for which the settling time in post fault period is found to be less.

FACTS devices use power electronic components to improve system performance. TCSC is the power electronic equipment and is also able to control, simultaneously or selectively, all the parameters affecting power flow in the transmission line. It can control both the real and reactive power flow in the line. On connecting TCSC, both active and reactive power increases.

TCSC is considered the most preferable device for improving the system performance over other FACTS family members for its simplicity and ease of operation under normal as well as abnormal condition. TCSC allows rapid and continuous changes of line reactance. It has applications in regulating the power flow in transmission line, damping inter area power oscillations and improving transient stability. Firing angle required for TCSC can be generated using different control methodologies.

Thyristor-Controller Series Capacitor (TCSC) provides powerful means of controlling and increasing power transfer level of a system by varying the apparent impedance of a specific transmission line. A TCSC can be utilized in a planned way for contingencies to enhance power system stability. Using TCSC, it is possible to operate stably at power levels well beyond those for which the system was originally intended without endangering system stability.

TCSC is a series compensating FACTS device using to control power flow in transmission lines and improve transient stability in power system. TCSC controls the power flow in transmission lines varying the impedance of TCSC by controlling the delay angle of thyristor valves. The basic scheme of TCSC is shown in Fig. 3. It consists of the series controlled capacitor shunted by a thyristor controlled reactor.

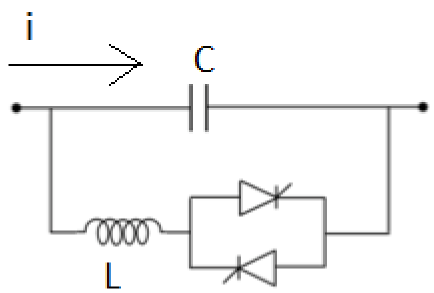

Fig. 3.Basic Scheme of TCSC

There exists a steady-state relationship between firing angle and the reactance X_{TCSC}. This relationship can be determined from the following equation:

$$X_{TCSC}(\alpha) = X_C X_{l(\alpha)} / X_{l(\alpha)} - X_C \quad (1)$$

Where,

$$X_l(\alpha) = X_L \pi / \pi - 2\alpha - \sin\alpha \quad (2)$$

With $X_L = \omega L$

α is the firing angle, X_L is the inductive reactance and X_l is the effective reactance of the inductor at firing angle. The effective series transmission impedance is given by:

$X_{eff} = (1 – K) X_{Line}$ (3)

Where, K is the degree of series compensation

$K = X_{TCSC}(\alpha) / X_{Line}$ (4)

While choosing K, 100% compensation should not be provided to avoid series resonance in transmission line. Practically up to 70% of compensation is chosen for line reactance compensation.Hence, the basic idea behind this concept is that the series capacitive compensation decreases the overall effective series transmission impedance from the source end to the receive end.

Swing Curve

A graph for the swing equation is called swing curve and the curves determine whether the machine remains in synchronism after a disturbance. In the steady state, that is when the speed of the generator rotor is constant at synchronous speed, the rate of change of rotor speed will become zero due to which Eq. 4.10 can be written as

$P_m = P_{max} \sin \delta$ (5)

Since, the mechanical power input P_m and the maximum power output P_{max} are known for a given system topology and load, rotor angle δ can be derived from Eq. 4.11,

$\delta = \sin^{-1} P_m / P_{max}$ or $\pi – \sin^{-1} (P_m/P_{max})$ (6)

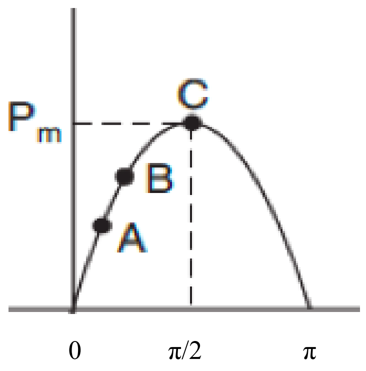

Fig. 4 Swing Curve

Consider the following Power Angle curve graph shown in Fig. 4 Let $P_m$be the mechanical input to the generator and the mechanical output to the motor assuming the other losses to be negligible.

Initially, the power is denoted by point A on the power angle curve. As a small load is added to the motor, the output power of the motor increases as the speed does not changed instantly whereas the input to the motor remains unchanged. Therefore, there is a net torque on the motor tending to retard it and its speed decreases temporarily. As a reduction of speed in the motor speed, the rotor angle δ increases and consequently the power input to the motor increases until finally the input and output are again in equilibrium and steady operation takes place at a new point *B* is being achieved and this new point is higher than that of point A on the power angle curve. The gradual increase of load on motor can be done till the time point C is reached on the power angle curve where $P = P_{max}$ and any further increase of load will result in increase in angle δ but reduction in input power to the motor, and therefore, the motor will decelerates further and it will pull out of step and probably stall. P_{max} is known as the steady state stability limit of the system which means that it is the maximum power that can be transmitted and synchronism will be lost if an attempt is made to transmit power more than this particular limit.

IV. Implementation and results

The power flow problem can also be solved by using Newton-Raphson method. Among the numerous solution methods available for power flow analysis, the Newton-Raphson method is considered to be the most sophisticated and important. Many advantages are attributed to the Newton-Raphson (N-R) approach. It is based on Taylor's series and partial derivatives. It is recent, needs less number of iterations to reach convergence, takes less computer time hence computation cost is less and the convergence is certain. The N-R method is more accurate, and is insensitive to factors like slack bus selection, regulating transformers etc. and the number of iterations required in this method is almost independent of the system size. The drawbacks of this method are difficult solution technique, more calculations involved in each iteration resulting in large computer time per iteration and the large requirement of computer memory but the last drawback has been overcome through a compact storage scheme.

Consider an IEEE-14 bus system to demonstrate the characteristics of SVC, TCSC and Hybrid controllers.

Table I. Line data of IEEE-14 Bus

From bus	**To bus**	**R p.u.**	**X p.u.**	**B/2 p.u.**	**X mer TAP(A)**
1	2	0.01938	0.0529	0.0264	1
1	5	0.05438	0.2234	0.0246	1
2	3	0.04699	0.16797	0.0219	1
2	4	0.05811	0.17632	0.0170	1
2	5	0.05695	0.17388	0.0173	1
3	4	0.069701	0.17103	0.0064	1
4	5	0.01335	0.04211	0	1
4	7	0	0.20912	0	0.978
4	9	0	0.55618	0	0.969
5	6	0	0.25208	0	0.932
6	11	0.9498	0.19890	0	1
6	12	0.12291	0.25581	0	1
6	13	0.6615	0.13027	0	1
7	8	0	0.17615	0	1
7	9	0	0.11001	0	1
9	10	0.03181	0.08450	0	1
9	14	0.1271	0.27038	0	1
10	11	0.8205	0.19207	0	1
12	13	0.22092	0.19988	0	1
13	14	0.34802	0.34802	0	1

Table II. Bus data of IEEE-14 Bus

Bus	Type	V_{sp}	P_{gi}	Q_{gi}	P_{li}	Q_{li}	Q_{min}	Q_{max}
1	1	1.060	0	0	0	0	0	0
2	2	1.045	40	42.4	21.7	12.7	-40	50
3	2	1.010	0	23.4	94.2	19	0	40
4	3	1	0	0	7.5	-3.9	0	0
5	3	1	0	0	7.5	1.6	0	0
6	2	1.070	0	12.20	16.8	7.5	-6	24
7	3	1	0	0	105	0	0	0
8	2	1.090	0	17.4	0	0	-6	24
9	3	1	0	0	44.25	16.6	0	0
10	3	1	0	0	45	5.8	0	0
11	3	1	0	0	42.75	1.8	0	0
12	3	1	0	0	37.65	1.6	0	0
13	3	1	0	0	45.75	5.8	0	0
14	3	1	0	0	5.85	5	0	0

14 bus system is taken as reference of data and with use of Newton Raphson calculations is done. With the use of mat lab a algorithm is executed that will calculate the value of voltage.

Comparison between the voltages of 14 bus system with SVC , TCSC and hybrid is been done with the help of graphs.

Table III. Voltages

BUS NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
VOLTAGE IN P.U.	1.06	0.99	0.96	0.89	0.90	1.02	0.94	1.04	0.91	0.91	0.93	0.96	0.96	0.92

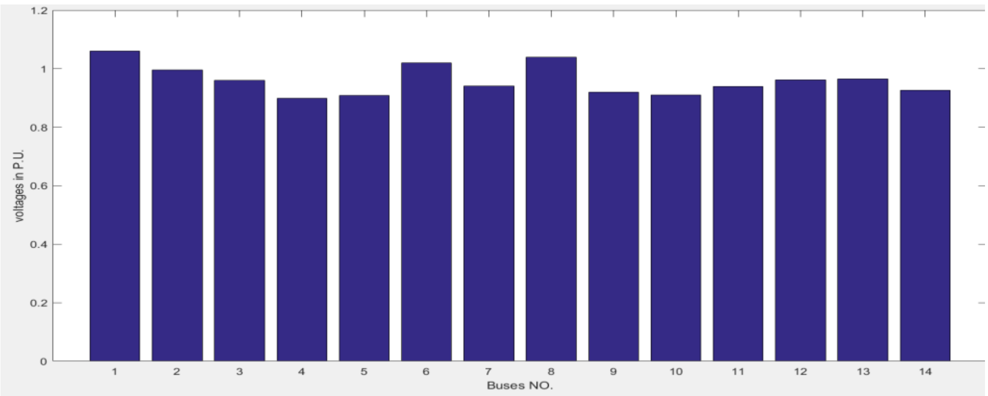

Fig5 Voltage vs bus no.

As from the fig. above 4th bus is the weakest bus thus addition of FACTS devices will be on 4th bus to make voltage near 0.90 p.u. as 0.90 is consider to optimal voltage for operation.

BUS NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
VOLTAGE	1.06	0.99	0.96	0.90	0.90	1.02	0.94	1.04	0.92	0.91	0.93	0.96	0.96	0.92

Table IV. Voltage with SVC

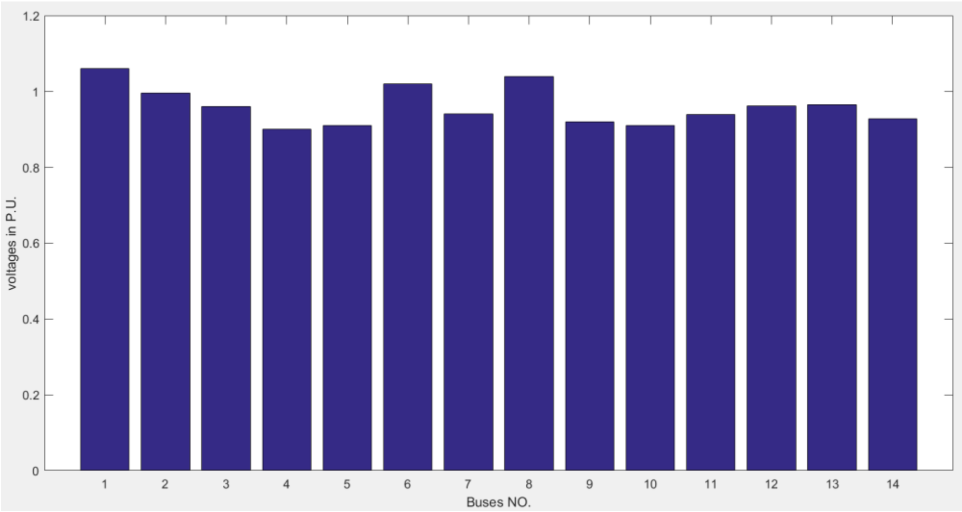

Fig.6 Voltage vs bus no. with SVC.

Table V. Voltages with TCSC

BUS NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
VOLTAGE	1.06	0.99	0.96	0.90	0.91	1.02	0.94	1.04	0.922	0.91	0.94	0.96	0.96	0.92

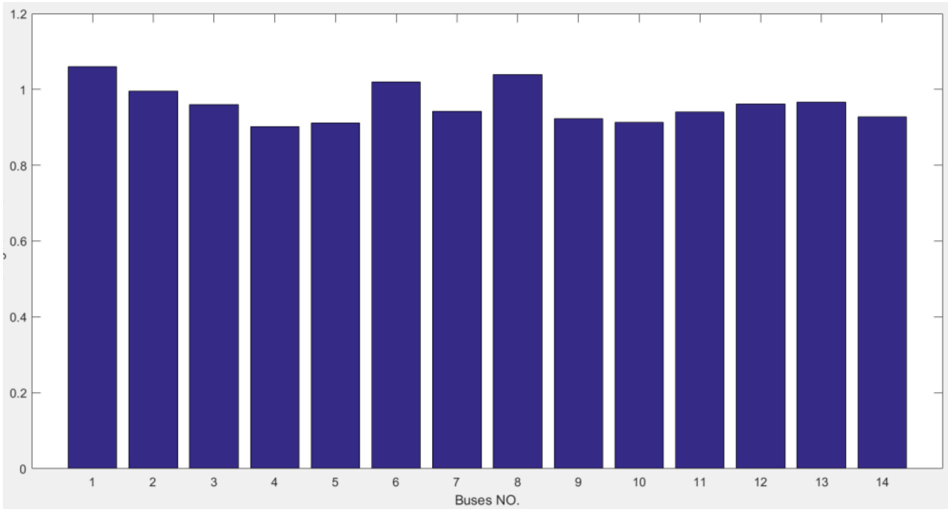

Fig.7 Voltages with TCSC.

Table VI. Voltage with addition of SVC and TCSC.

BUS NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
VOLTAGE	1.06	0.99	0.96	0.90	0.91	1.02	0.94	1.04	0.922	0.91	0.94	0.96	0.96	0.92

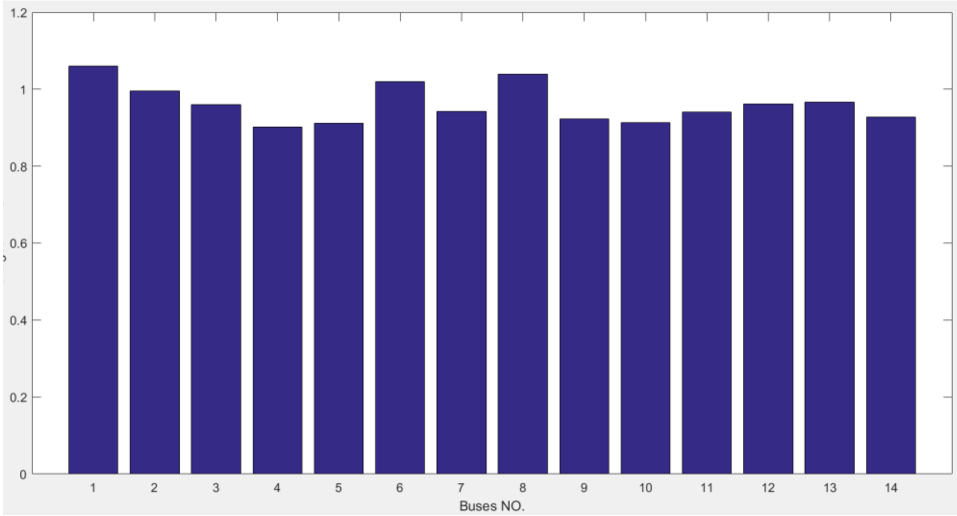

Fig.8 Voltages vs bus no. with addition of SVC and TCSC.

Table VII. Power values without addition of FACTS

Line data	Pre-fault	During fault	Post fault
1-2	35.15	0	17.57
1-5	4.31	0	2.1
2-3	5.6	0	2.8
2-4	5.0	0	2.5
2-5	5.2	0	2.6
3-4	5.04	0	2.5
4-5	19.38	0	9.6
4-7	4.04	0	2.02
4-9	1.4	0	0.74
5-6	3.6	0	1.83
6-11	4.8	0	2.4
6-12	3.8	0	1.9
6-13	7.5	0	3.7
7-8	5.55	0	2.7
7-9	7.8	0	3.9
9-10	9.9	0	4.95
9-14	3.1	0	1.5
10-11	4.44	0	2.22
12-13	4.6	0	2.32
13-14	2.5	0	1.2

Comparison of power flow values for different conditions for the weakest line.

Table VIII. Power values without addition of FACTS

Condition	Pre-fault	During fault	After fault
Without	1.4847	0	0.7424

Table IX. Power Values

Load angle (radians)	Pre-fault	During fault	After fault
0	0	0	0
0.1745	0.2578	0	0.12
0.3491	0.5078	0	0.25
0.5236	0.7424	0	0.37
0.6981	0.9544	0	0.47
0.8727	1.1374	0	0.56
1.047	1.2858	0	0.64
1.22	1.3952	0	0.69
1.3963	1.4622	0	0.73
1.57	1.48	0	0.74
1.74	1.46	0	0.73
1.91	1.39	0	0.69
2.09	1.28	0	0.64
2.2689	1.13	0	0.56
2.44	0.95	0	0.47
2.66	0.74	0	0.37
2.79	0.50	0	0.25
2.96	0.25	0	0.12
3.14	0		0

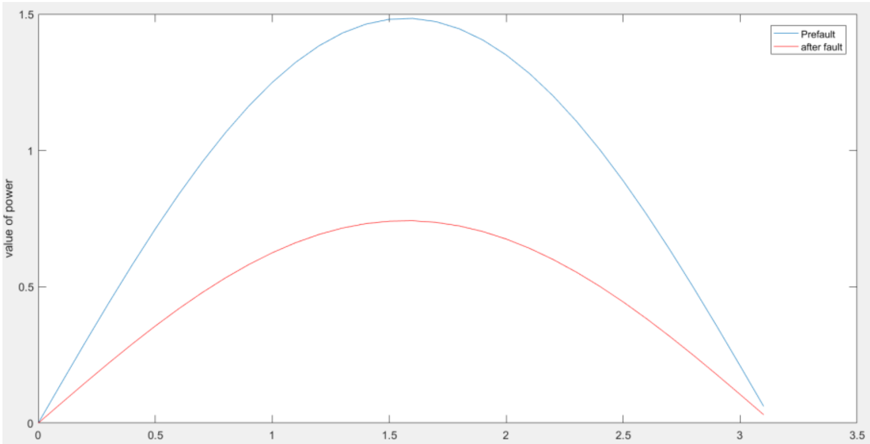

Fig.9 Power values without addition of FACTS

The graph above shows operating points with increasing load angles during pre-fault and after fault condition.

Table X. Power flow values with SVC

Condition	Pre-fault	During fault	Post-fault
SVC	1.4890	0	0.7445

Table XI. Power flow values with SVC

Load angle (radians)	Pre-fault	During Fault	Post fault
0	0	0	0
0.1745	0.25	0	0.12
0.3491	0.50	0	0.25
0.5236	0.74	0	0.37
0.6981	0.95	0	0.47
0.8727	1.14	0	0.57
1.047	1.28	0	0.64
1.22	1.39	0	0.69
1.3963	1.46	0	0.73
1.57	1.48	0	0.74
1.74	1.46	0	0.73
1.91	1.39	0	0.69
2.09	1.28	0	0.64
2.2689	1.14	0	0.57
2.44	0.95	0	0.47
2.66	0.74	0	0.37
2.79	0.50	0	0.25
2.96	0.25	0	0.12
3.14	0	0	0

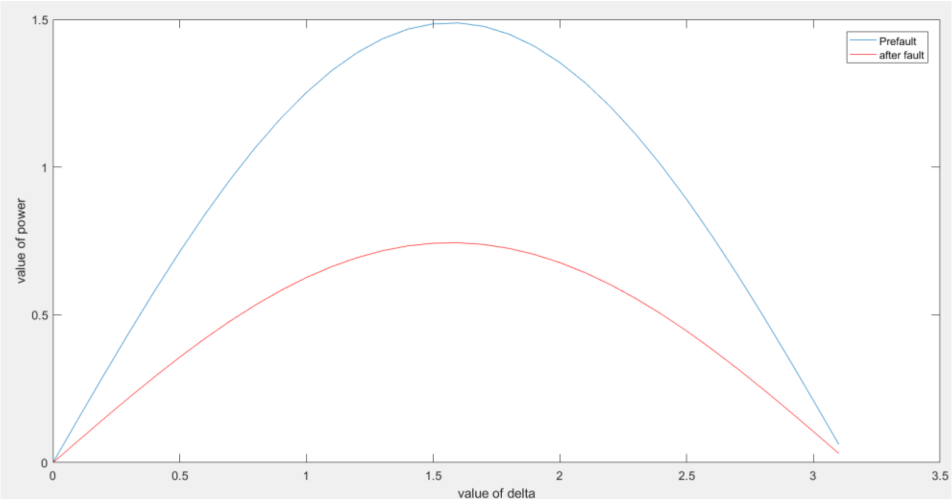

Fig.10 Power Flow values with addition of SVC.

Table XII. Power flow values with TCSC

Condition	Pre-fault	During fault	Post-fault
TCSC	1.4922	0	0.7461

Table XIII. Power flow values with TCSC

Load angle (radians)	Pre-fault	During fault	Post fault
0	0	0	0
0.1745	0.25	0	0.12
0.3491	0.51	0	0.25
0.5236	0.74	0	0.37
0.6981	0.95	0	0.47
0.8727	1.14	0	0.57
1.047	1.29	0	0.64
1.22	1.40	0	0.70
1.3963	1.46	0	0.73
1.57	1.49	0	0.74
1.74	1.46	0	0.73
1.91	1.40	0	0.70
2.09	1.29	0	0.64
2.2689	1.14	0	0.57
2.44	0.95	0	0.47
2.66	0.74	0	0.37
2.79	0.51	0	0.25
2.96	0.25	0	0.12
3.14	0	0	0

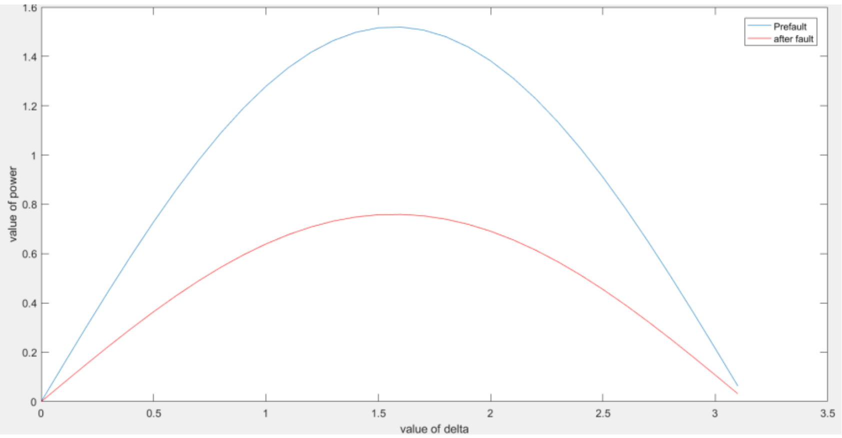

Fig.11 Power flow values with TCSC

Table XIV. Power flow values with SVC and TCSC

Condition	Pre-fault	During fault	Post fault
Hybrid	1.5200	0	0.7600

Table XV. Power flow values with SVC and TCSC

Load angle (radians)	Pre-fault	During fault	Post-fault
0	0	0	0
0.1745	0.26	0	0.13
0.3491	0.51	0	0.25
0.5236	0.76	0	0.38
0.6981	0.97	0	0.48
0.8727	1.16	0	0.58
1.047	1.31	0	0.65
1.22	1.42	0	0.71
1.3963	1.49	0	0.74
1.57	1.52	0	0.76
1.74	1.49	0	0.74
1.91	1.42	0	0.71
2.09	1.31	0	0.65
2.2689	1.16	0	0.58
2.44	0.97	0	0.48
2.66	0.76	0	0.38
2.79	0.51	0	0.25
2.96	0.26	0	0.13
3.14	0	0	0

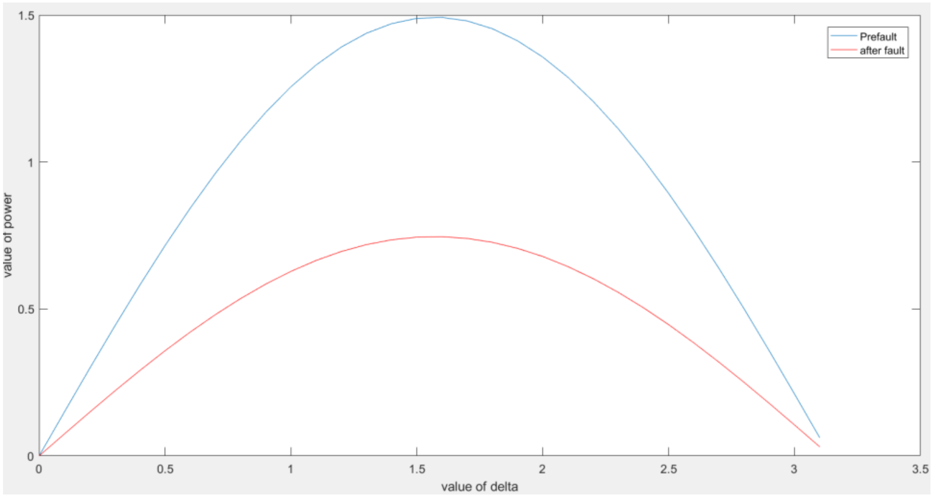

Fig.12 Power flow values with SVC and TCSC

V. CONCLUSION

The voltage and transient stability is improved by connecting FACTS devices. Both SVC and TSCS improved the voltages but the best result is obtained when both are used together which can be seen from graphs above. So with the use of both voltage can be efficiently improved which increases the stability of the system. The system is stable when decelerating area is greater than accelerating area in p-delta curve, which can improved by FACTS devices. So with use of both decelerating area is further increased which tells us that use of hybrid is the best option.

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