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COMPARATIVE ANALYSIS OF SERIES AND SHUNT TYPE FACTS CONTROLLER FOR VOLTAGE STABILITY ENHANCEMENT

Amit G. Patel[1], Vaishali Y. Patel[2], Satish D. Patel[3]
[1,3]P.G. Student EE, [2]Assistant Professor
Merchant college of Engineering Basna

Abstract: ***In recent years, much attention has been attracted to the problems of voltage quality for the electrical power systems. Because of continuous increase of power demands and large scale system interaction as well as the consideration of both the economic benefit and the environment protection, modern power system are operated more and more close to the their maximum operating conditions. As a consequence, some transmission lines are heavily loaded and the system stability becomes a power transfer-limiting factor. Electricity utility companies try to minimize the voltage interruption problem like swell, sag, harmonic and many more in their system, to ensure that they provide the high quality, reliability and availability of electric power to their customers. A few second of power interruption can cost losses more than hundred thousand dollar. "Voltage stability" is a key word to ensure the high power quality of the system. The basic mean of voltage stability is the ability of the system to maintain voltage at their range under normal operating mode and after being subjected to the disturbance. In these days, voltage of the system can be control in many ways and the latest technology by using power electronic device that we call as FACTS-devices. It has lot of configuration like series, shunt etc. TCSC is series type and SVC is shunt type controller. In this paper both the devices are compared for voltage stability enhancement.***

Keywords: Voltage Stability, FACTS, TCSC, SVC, Voltage Control, CPF analysis.

I. INTRODUCTION

The recent studies reveal that FACTS controllers could be employed to enhance power system stability in addition to their main function of power flow control. The literature shows an increasing interest in this subject for the last two decades, where the enhancement of system stability using FACTS controllers has been extensively investigated. TCSC is one type of FACTS devices which resembles in many respects a series compensator used for voltage control and reactive power compensation. The TCSC can increase transmission capacity, damping low frequency oscillation, and improving transient stability. [1-9] A review on the research and developments in the voltage stability improvement by using FACTS controllers. In this paper several technical issues related to FACTS installations have been highlighted and performance comparisons of different FACTS controllers have been discussed. It also includes the main causes of voltage instability and power scenario in India. In order to deal with the voltage stability problem, the solutions with FACTS-controllers provide voltage support and/or appropriately co-ordinate control actions. It can be said that the FACTS devices are capable of solving the voltage stability problems of the power system [1]. When system voltage are below of the range, the system must be inject with reactive power while when system voltage are high of the range, the reactive power must be absorb from the system. Authors discuss the TCSC's capability to enhance transient voltage stability. A TCSC model that is suitable for transient voltage stability analysis is proposed. This model is tested on a multi-machine system including all the key elements relevant to system voltage performance. The simulation shows that angle -stability-enhancement-like TCSC controllers offer little help for certain transient voltage stability crises.[2]. TCSC and SVC can able to enhance different power system issues, besides in increasing power transfer in transmission lines. TCSC's different advantages can be classified as steady-state and transient ones. During a fault, TCSC can enhance power quality by limiting the current and help to keep the voltage as high as possible. In this paper, the application of TCSC to enhance one of the important power quality issues, i.e., voltage sag is investigated[3].Authors present detailed steady state models with control of TCSC to study their effect on voltage collapse phenomena in power system. Based on the result at the point of collapse design strategies are proposed for controller, so that their location, dimensions and controls can be optimally defined to increase system loadability [4]. Voltage regulation is achieved by controlling the production, absorption and flow of reactive power throughout the network. Reactive power flows are minimized so as to reduce system losses. Sources and sinks of reactive power, such as shunt capacitors, shunt reactors, rotating synchronous condensers and SVC's are used for this purpose. Shunt capacitors and shunt reactors are either permanently connected to the network, or switched on and off according to operative conditions. They only provide passive compensation since their production or absorption of reactive power depends on their ratings and local bus voltage level [8]. This paper [8] discusses Flexible AC Transmission System (FACTS) technology, with which a power system can be operated effectively and flexibly. Among the FACTS devices, the Static VAR compensator and Thyristor Controlled series Compensators (TCSC) are versatile devices that controls the reactive power injection at a bus using power electronic switching components. Systematic procedure for modeling, simulation and optimal tuning of

TCSC controller for enhancing power system stability. A MATLAB/SIMULINK model is developed for single machine infinite bus system with TCSC. The controller is tested on sample power system (SMIB) for small and large disturbances[8]. The best possible locations of the FACTS devices are found to vary with the location of the fault and the operating criteria of the devices. In some cases, the FACTS device may have some adverse effect on system stability. Also an increase in compensation by the FACTS devices does not ensure an enhanced stability margin. Therefore, evaluation of the system stability condition and best possible location for FACTS device are required for better and safer system operation. In paper [9] authors present various Voltage Stability Indices (VSI) from which condition of voltage stability in a power system can be known. In paper [10] authors review some static voltage stability indices to study voltage collapse. These VSI present reliable information about the closeness of the power system to voltage collapse and identification of weakest bus, line and area in the power system network. Also P-V curve and Q-V curve are used for analysis of voltage stability. Dr. N Kumar, Dr. A Kumar, P.R. Sharma, discussed the Determination of optimal amount of location of series compensation and SVC for an AC Transmission System [20]. They have determined the optimal location of series compensation and SVC for a given transmission system, for this they have developed generalized expression for maximum receiving and power, compensation efficiency and optimal value of series compensation have been developed in terms of line constants and capacitive reactance used for different schemes of series compensation. On the basis of steady-state performance analysis, they have determined that in the compensation scheme the series compensation and SVC are located at the midpoint of the transmission line and yielded maximum receiving end power and maximum compensation efficiency.

El-Sadek, et al, presented the work on Series capacitor combined with static VAR compensator for enhancement of steady-state voltage stability .They discussed the nonlinear dynamic controller for a combination of static series capacitor compensation and power system stabilizer, for enhancement of both voltage and transient stability of power system. The proposed controller implements speed deviation signal and generator terminal current deviation signal. The proposed Scheme is validated using a sample single machine infinite bus power system loaded by a frequency dependent voltage dependent nonlinear dynamic load type.[21]

II. VOLTAGE STABILITY AND VOLTAGE CONTROL

A. Voltage Stability

The quality of the power depend on voltage because most of the time the controlled quantity is voltage. To ensure high quality of the power, the stability of the voltage must be take care. Power system stability be define as the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variable bounded so that system integrity is preserved [8]. The power system stability can be classified into three type that are rotor angle stability, frequency stability and voltage stability. The Figure 1 shows the classification of power system stability.

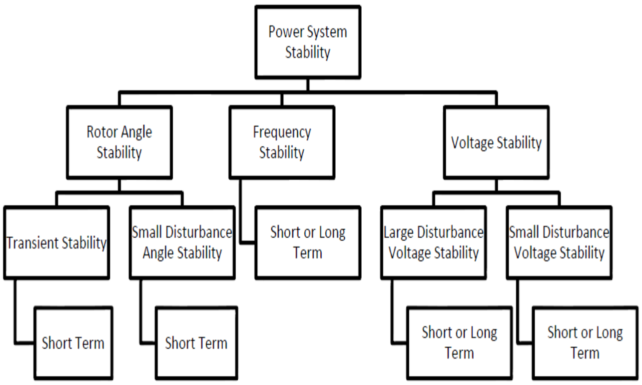

Figure 1: Classification of Voltage Stability

In voltage stability there are four important term that be used to describe the voltage stability; large disturbance voltage stability, small disturbance voltage stability, short term voltage stability and long term voltage stability. The large disturbance voltage stability refers to the system ability to maintain steady voltage following large disturbance such as fault, loss of generation or circuit contingencies. This ability is determined by the system load characteristic and the interaction of both continuous and discrete control and protection. The study period of interest may extend from a few seconds to ten of minutes. The small disturbance voltage stability is concerned with a system ability to maintain steady voltage when subjected to small perturbation such as incremental changes in system load. This form of ability is influence by the characteristic of load, continuous controls and the discrete controls at a given instant of time. Both large and small disturbance voltage stability can occur in short or long term. The short term being define as the times frame of interest voltage stability problem vary a few second while for the long term the times frame of voltage stability problem may extend to several or many minutes. Voltage stability being define as ability of a power system to maintain steady voltage at all buses in the system under normal operating conditions and after being subjected to a disturbance. Instability voltage may result in form of fall or rise of voltage of some buses and it can happen due to loss of load or loss of integrity of the power system. The main factor that contributed of voltage instability is usually the voltage drop that occurs when the active and reactive power flow through inductive reactance associated with the transmission network [8].

B. Voltage Control

In power system, control the system voltage play important role to ensure the voltage interruption like swell, sag and harmonic can be minimize and furthermore increase the power quality, reliability and availability. The importance of voltage control can be divided into three main reasons that is: (a)Both customers and power system equipment is design to operated within

specific voltage range value. If the equipments be supply by voltage above their range than equipment life time will be shorted, and if the voltage supplied below the specific range the equipment will not function properly.
(b) The production of the reactive power in generator can limit the real power be produced.
(c) The moving reactive powers in transmission line are one of factor loss of energy in the line. From voltage standard that made by International Electro technical Commission (IEC) the voltage range that be allow to provide to customer are ±6% from the nominal voltage value.
Voltage and reactive power in power system are related to each other for example if the reactive power injected into the system, the voltage will be increased and while the reactive power absorbed from the system, the voltage will be decreased. Therefore voltage control is accomplished by managing the reactive power of the system.

Method of Voltage Control

The voltage can be control in three ways that is:
(a) By inject the reactive power (static shunt capacitors and reactor or by static series capacitors and or by using synchronous compensators.)
(b) By using tap changing transformer. (off load tap changer & On load tap changer)
(c) By using FACTS devices.

III. THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC) AND STATIC VAR COMPENSATOR (SVC)

Thyristor controlled series compensator or known as TCSC are one of flexible alternating current transmission system (FACTS) device family. FACTS- devices defined by the IEEE as "a power electronic based system and other static equipment that provide control of one or more AC transmission system parameter to enhance controllability and increase power transfer capability , The basic applications of FACTS-devices are:
(a) Power flow control
(b) Increase of transmission capability
(c) Voltage control
(d) Stability improvement
(e) Reactive power compensation
(f) Power quality improvement
Besides the advantages of voltage control in power system, the use of FACTS-device also gives benefit to our environment. The FACTS-device is made up from non hazardous material and when it operates it does not produces any pollution or waste. In economy view, use of FACTS-device has reduces need of addition of transmission line to support the increase of power demand. In general, FACTS controller can be dividing into four categories:[6]
(1) Series controllers
(2) Shunt Series controllers
(3) Combined series-series controllers
(4) Combined shunt-series controllers

A. Basic concept of TCSC Controller:
The basic TCSC module

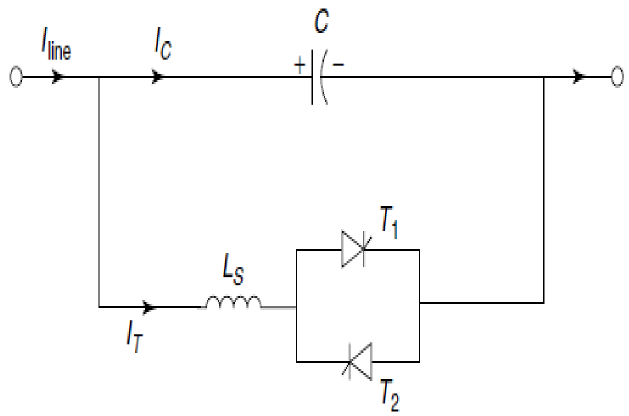

Figure 2: The basic TCSC module

The basic conceptual TCSC module comprises a series capacitor, C, in parallel with a thyristor-controlled reactor, LS, as shown in Fig.2. However a practical TCSC module also includes protective equipment normally installed with series capacitors. An actual TCSC system usually comprises a cascaded combination of many such TCSC modules, together with a fixed-series capacitor.

B. Modes Of TCSC Operation

There are essentially three modes of TCSC operation.
(1)Bypassed-Thyristor Mode
(2)Blocked Thyristor Mode
(3) Partially Conducting Thyristor or Vernier Mode

C. Applications of TCSC:

The major objective in applying TCSC is to increase power transfer capacity in critical transmission lines (typically tie lines) under contingency conditions. In the restructured electricity supply regime, it is used to increase the Available Transfer Capability (ATC).

D. Basic structure of SVC

An SVC is a shunt-connected static generator and/ or absorber of reactive power in which the output is varied to maintain or control specific parameters of an electrical power system. The SVC provides an excellent source of rapidly controllable reactive shunt compensation for dynamic voltage control through its utilization of high-speed thyristor switching/controlled reactive devices.
An SVC is typically made up of the following major components:
1. Coupling transformer
2. Thyristor valves
3. Reactors
4. Capacitors (often tuned for harmonic filtering)
In general, the two thyristor valve controlled/switched concepts used with SVCs are the thyristor-controlled reactor (TCR) and the thyristor-switched capacitor (TSC). The TSC provides a "stepped" response and the TCR provides a "smooth" or continuously variable susceptance.

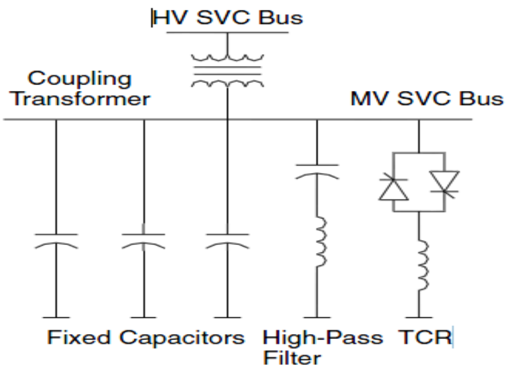

Figure 3: Basic structure of FC-TCR Type SVC

E. Characteristics of SVC

The SVC can be operated in two different modes: In voltage regulation mode and in var control mode (the SVC susceptance is kept constant) when the SVC is operated in voltage regulation mode, it implements the following V-I characteristic. As long as the SVC susceptance B stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (Bcmax) and reactor banks (Blmax), the voltage is regulated at the reference voltage Vref. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the Figure.4.13. The V-I characteristic is described by the following three equations:

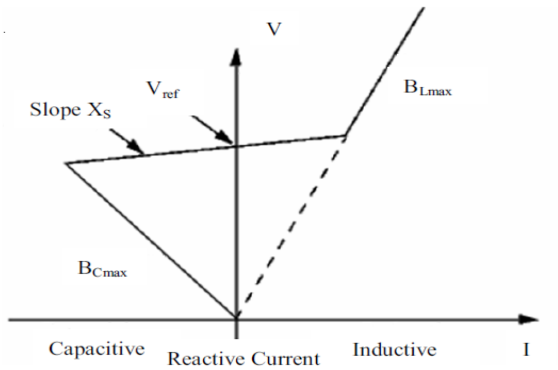

Figure 4: V-I Characteristic Curve of SVC

Above figure shows characteristics of SVC. It can operate incapacitive as well as inductive region. SVC is in regulation range (-Bmax< B <BLmax)

IV. TEST SYSTEM SIMULATION

This section will discuss about the test system that is used to analyze the work in purpose of studying the effect of TCSC and SVC in increasing the voltage stability of the system and its optimal location. IEEE 9 bus system is use in the project simulation and it is done by using Power System Analysis Toolbox (PSAT). Several steps have been achieved the objectives, the step that had been recognized were:

(a) Modeling the system by using PSAT
(b) Perform the congested case
(c) Perform the power flow analysis to analyze the Performance of the system.
(d) Perform the CPF and draw PV curve to determine weak bus of the system. SVC is placed at this bus.
(e) Identify the suitable line to place TCSC so it gives optimal Performance.

The single line diagram of IEEE 9 bus system is shown in Figure 3, while the data of test system is shown in Table I to Table III.

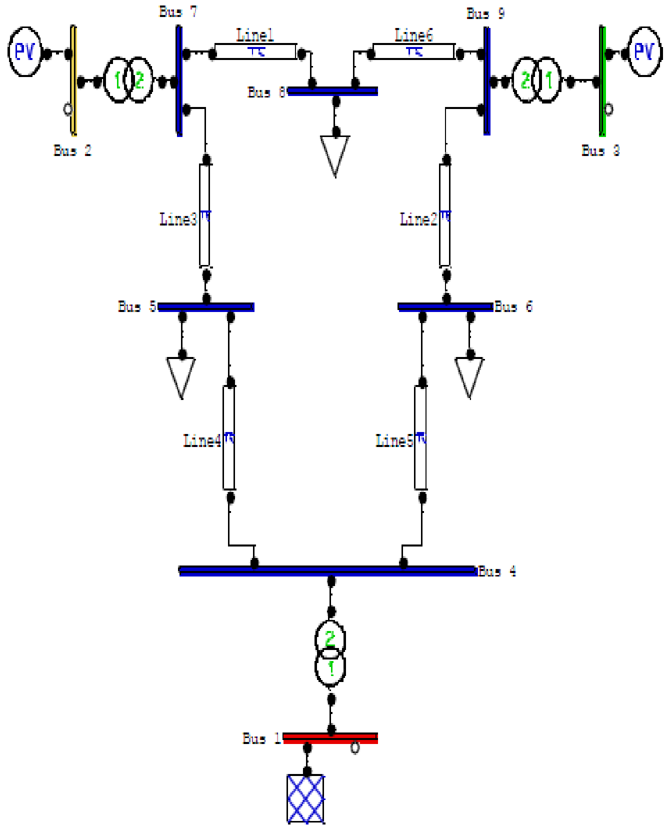

Figure 5: IEEE – 9 Bus System

TABLE I Bus Data of IEEE – 9 Bus System

Bus No.	Bus Type	Voltage Magnitude (pu)	Phase Angle (rad)	Active Power (pu)	Reactive Power (pu)
1	Slack	1.04	0.00	0.80	---
2	PV	1.025	---	1.63	---
3	PV	1.025	---	0.85	---
5	PQ	---	---	1.87	0.75
6	PQ	---	---	1.70	0.80
8	PQ	---	---	1.00	0.35

TABLE II: Transformer Data of IEEE – 9 Bus Systems

Line	S (MVA)	V (KV)	KV / KV	R (pu)	X (pu)
1 – 4	100	16.5	16.5 / 230	0.00	0.0576
2 – 7	100	18	18 / 230	0.00	0.0625
3 – 9	100	13.8	13.8 / 230	0.00	0.0586

TABLE III Transmission Line Data of IEEE – 9 Bus Systems

Line No.	From Bus – To Bus	Resistance R (pu)	Reactance X (pu)	Susceptance B (pu)
1	7 – 8	0.0085	0.072	0.149
2	6 – 9	0.039	0.170	0.358
3	5 – 7	0.032	0.161	0.306
4	4 – 5	0.01	0.085	0.176
5	4 – 6	0.017	0.092	0.158
6	8 – 9	0.0119	0.1008	0.209

V. RESULT AND DISCUSSION

This section will tabulate and discuss the result implemented. The discussion on IEEE-9 bus system will be focused on how to determine the optimal location of TCSC in power system.

A. Weak bus Identification

The optimal location of TCSC and SVC can be achieved by determining the weakest voltage bus of the system. This can be done by continuation power flow analysis, The P-V curve plotted from continues power flow analysis can be use to determine the weakest bus of the system. Figure 6 shows the P-V curve of IEEE - 9 Bus systems.

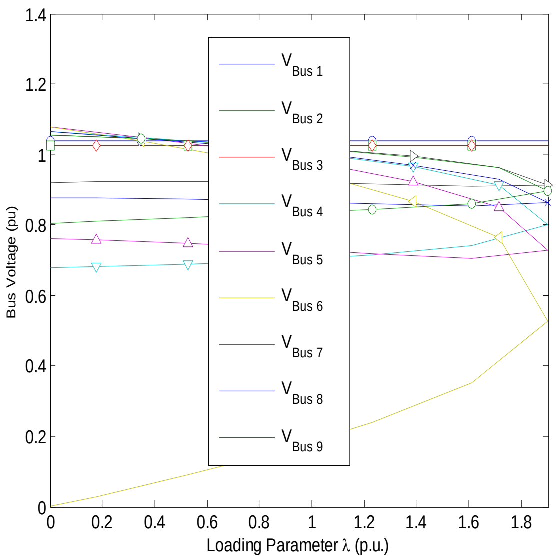

Figure 6: P-V curve of IEEE - 9 Bus system

From figure 6, P-V curve of bus -6 voltage (yellow colour) is the weakest bus among all the buses of the system.

B. Optimal Location of TCSC

Most of the weakest bus has more than one transmission line connected to it. This cause difficulties in choosing the best line to install TCSC. It has been proposed that TCSC should be placed at the line which gives smaller results in power system losses. The result of bus 6 voltage and total losses of IEEE 9 bus system with and without using TCSC series compensation is shown in Table

TABLE IV. Bus Voltage and Total Losses of IEEE 9 Bus System with application of TCSC

Sr. No.	Location of TCSC		Bus – 6 Voltage (pu)	Total Losses (pu)	
	Line	From bus To bus		Real Power	Reactive Power
1	No TCSC		0.52675	0.72267	6.10114
2	Line – 2	9-6	0.74088	0.51270	3.2408
3	Line – 5	6-4	0.82989	0.27571	0.20554

From above table best location of TCSC is on line 5 because it gives lowest power losses on the system when TCSC be install at that particular also it give better improvement in bus 6 voltage.

Application of SVC in IEEE 9 Bus system

Now SVC is connected at weak bus 6 to see its effect. Variation in bus 6 voltage and total losses of IEEE-9 bus system with placement of SVC is shown in following table.

TABLE: V Variation in bus 6 voltage and total losses with placement of SVC

Sr. No.	Location of SVC	Bus–6 Voltage (pu)	Total Losses (pu)	
			Real Power	Reactive Power
1	No SVC (Base Case)	0.52675	0.72267	6.10114
2	SVC at bus-6	1.0236	0.07647	0.59566

From table we can conclude that with placement of SVC at bus 6 give considerable improvement in bus-6 voltage as well as reduction in total system losses.

Comparison of TCSC &SVC with different loading condition

Comparison of TCSC and SVC in IEEE 9 bus system with different loading condition at weak bus is shown in following table; also sub sequent figure shows its graphical representation. Active and reactive load on specified bus is increased gradually and CPF is run for base case, With TCSC at line -5 which is best location, and SVC at bus -6. Result obtained is tabulated for comparison also graphical representation will help to for comparison

Case – I Load on bus -6 (P= 1.70 pu & Q= 0.80 pu) – Base case

TABLE: VI: Variation in bus 6 voltage and total losses in case-I

Sr. No.	Location of FACTS device	Bus–6 Voltage (pu)	Total Losses (pu)	
			Real Power	Reactive Power
1	Base case (No FACTS device)	0.52675	0.72267	6.10114
2	TCSC at line -5	0.82989	0.27571	0.20554
3	SVC at bus - 6	1.0236	0.07647	0.59566

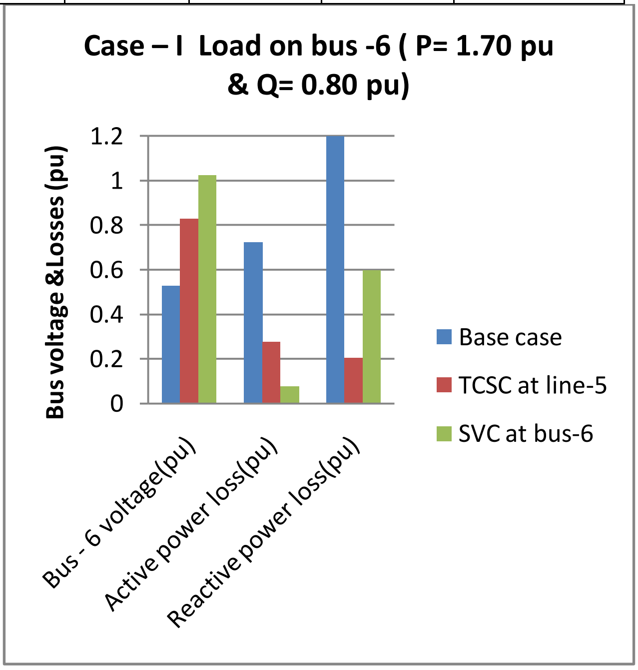

Figure 7: Graphical comparision of TCSC & SVC for case-I

Case – II Load on bus -6 (P= 1.80 pu & Q= 0.85 pu)

TABLE VII: Variation in bus 6 voltage and total losses in case-II

Sr. No.	Location of FACTS device	Bus–6 Voltage (pu)	Total Losses (pu)	
			Real Power	Reactive Power
1	Base case (No FACTS device)	0.72928	0.37395	2.7222
2	TCSC at line -5	0.79039	0.33574	4.3297
3	SVC at bus - 6	1.0239	0.07666	0.59614

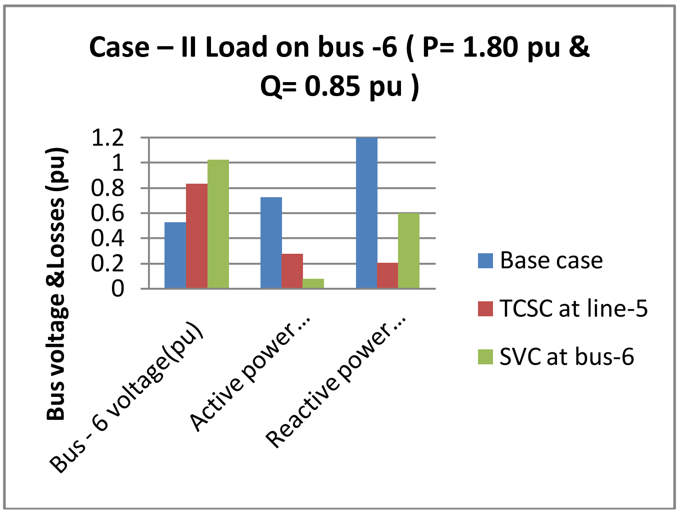

Figure 8: Graphical comparison of TCSC & SVC for case-II

Case – III Load on bus -6 (P= 1.90 pu & Q= 0.85 pu)

TABLE VIII: Variation in bus 6 voltage and total losses in case-II

Sr. No.	Location of FACTS device	Bus–6 Voltage (pu)	Total Losses (pu)	
			Real Power	Reactive Power
1	Base case (No FACTS device)	0.32758	1.0927	8.4051
2	TCSC at line -5	0.81242	0.28447	3.6723
3	SVC at bus - 6	1.0246	0.07433	0.62527

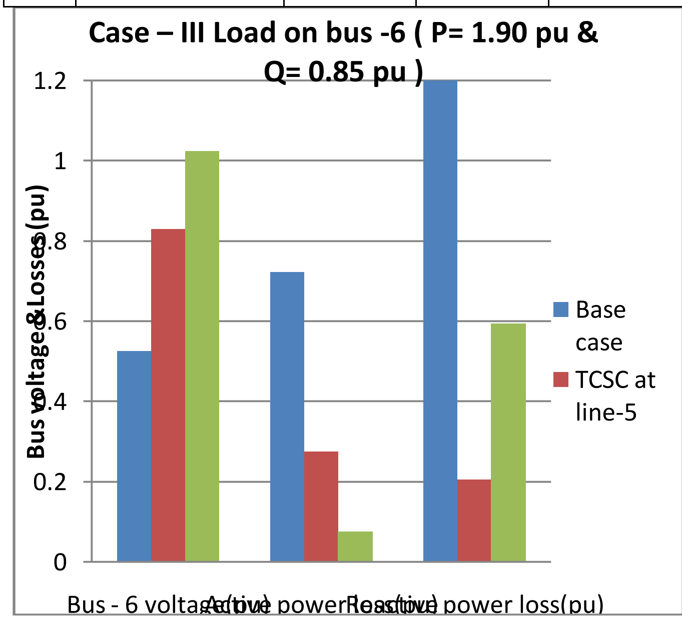

Figure 9: Graphical comparison of TCSC & SVC for case-III

VI. CONCLUSION

Following conclusion are drawn from the work:_

- Optimal placement of TCSC &SVC can give better result.
- TCSC and SVC improve voltage stability
- It also performs reliably under variable load condition.
- SVC give better result in comparison to TCSC as it give better Voltage profile and reduce more losses

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