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Investigation of TCSC and SSSC Controller Effects on the Power System

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Abstract

Electrical power systems have been growing due to the increased demand and various loads and it is getting more and more difficult to provide stability and control. It is possible to increase line transmission capacities and to control these systems by providing reactive power compensation. In the recent years, FACTS (Flexible Alternative Current Transmission System) devices have been used as reactive power compensation elements. The study utilized rapid responding TCSC (Thyristor Controlled Series Capacitor) and SSSC (Static Synchronous Series Compensator) FACTS devices that are formed by power electronics elements. The effects of these devices on voltage stability, on the powers carried on the lines and the losses that occur on the lines were investigated with the simulation and its results.

1. Introduction

In today's society demands for power have increased. However, it is getting more difficult to establish new energy production centers and transmission networks due to environmental effects and economic reasons [1]. One of the most important problems in the control of energy transmission systems is the reactive power compensation. Reactive power causes the increase in the transmission systems losses, decrease in power capacity carried in the transmission lines and the changes in the voltage amplitude at the end of the lines. Hence it is necessary to provide reactive power compensation in order to increase transmittable power, decrease losses and provide voltage amplitude stability [2]. Reactive power compensation is often used as the most effective method both for transmission capacity and amelioration of voltage stability [3]. Reactive power compensation studies and implementations have been widely used for this aim.

It is difficult to improve the large, powerful and rapid power factors of loads by traditional electromechanical compensation mechanisms. This is due to the lack of rapid response in traditional compensation systems to reactive power demand. This creates a situation in which the required capacitive reactive cannot be met through the compensation system [4]. Due to this reason, it is getting more important to provide rapid compensation systems for energy transmission and distribution. Power electronics elements are often preferred in compensation implementations today since their switching speed is high. In the case compensation in power systems is done by semiconducting switches voltage sags can be prevented and transient and dynamic stability can be improved [5]. FACTS devices whose basic structures are formed by reactive power compensation elements of power electronics can theoretically be connected to any point in the energy conveyor line and undertake the control functions in a rapid manner.

This study utilized SVC and STATCOM reactive power sources from FACTS devices in the six bus power system with a series connection to the line. Results were obtained by using Power System Analysis Toolbox (PSAT) [6] program to analyze static case performances such as voltage stability, load transport capacity of the system.

2. FACTs Devices

Use of FACTS devices that form modern compensation methods gain importance when we consider their rapid response times, controllability of each phase separately and their ability to compensate for unstable loads [7]. Since FACTS are power electronics based in terms of control, they can provide rapid responses. When these devices are used appropriately they increase stability limits of transmission lines. FACTS have two main purposes. The first one is to increase the transport power of the transmission systems and the second purpose is to control the power flow on the lines [8]. Today, many flow controllers have been developed under the title FACTS. The most commonly used ones are Static VAR Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), Static Compensator (STATCOM), Unified Power Flow Controller (UPFC), Phase Shifter and Static Synchronous Series Compensator (SSSC).

2.1. TCSC

TCSC is considered to be a rapid FACTS device. It provides the control for voltage amplitude, phase angle, line flow along with the increase in the active power transfer of with the help of the series impedance on the line. [9]. As can be seen from Fig. 1, TCSC consists of thyristor controlled reactor and capacitors that are parallel to it [10].

Characteristic of TCSC depends on the relationship between capacities and thyristor line. The workings of TCSC in terms of voltage stability are provided with TCSC impedance control. TCSC impedance can be adjusted to three modes:

Block Mode: thyristor is not triggered, TCSC impedance is equal to power capacity reactance and power factor is forward.

By-pass mode: thyristors are activated and since $X_L=X_C$ are equal to each other flow and voltage is in the same phase.

Capacitive mode can be $X_L<X_C$ and inductive mode can be $X_L>X_C$. In this case, TCSC works either as inductive or capacitive. This mode is the mode in which TCSC is used dynamically [11, 12].

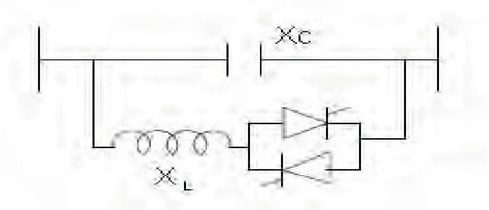

Fig. 1. Configurations of TCSC

2.2. SSSC

SSSC is in the form of a synchronous voltage source connected to transmission line. It changes the impedance of the line by providing voltage to the transmission line suitable to the phase angle. It can exchange active and reactive power with the line. If the voltage applied to the line and the flow received from the line are both large at the same time there is an exchange of active power. When the angle between the flow and the voltage is 90°, the power transfer will be in the form of reactive power exchange. Reactive power is either provided to or received from the system depending on the forward or backward status of the flow.

Fig. 2 and Fig. 3 display the schemata and equivalent value of SSSC element [10].

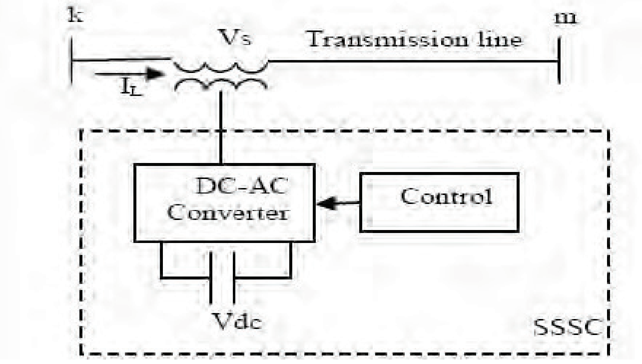

Fig. 2. Simplified diagram of SSSC

As can be seen in Fig. 2, SSSC is formed of a inventor voltage source connected to transmission line series. Here SSSC works as a controllable series reactance and series capacitor. The main difference is injected directly to the voltage and can be controlled.

This important feature shows that it can be used both with low loads as well as high loads [13].

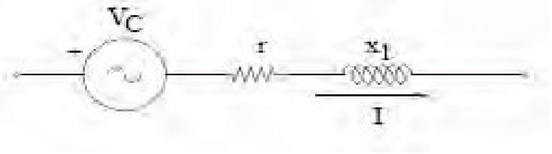

Fig. 3. Equivalent circuit

V_C in the Fig. 3 is used to regulate the voltage size load flow. Series is connected with r and x_l which are respectively the resistance of connection transformer and voltage source with fault reactance. In addition to the reactive components of the voltage in the system, reactive components are also controlled [14].

3. Simulation Work

This study was undertaken based on λ-V curves in the load buses in the system and by using PSAT program in the 6 bus system. λ here represents the load increase ration called loading parameter. Parameters that belong to the system and to FACTS controllers exist in the PSAT program. Fig. 4 displays the general structure of the six bus system.

First of all, the continuous power flow analysis of the six bus power system was undertaken to identify the maximum loading parameters without TCSC and SSSC. Later the weakest buses of the system in terms of voltage stability were connected to TCSC and SSSC to obtain $\lambda - V$ change curves. In order to determine the effects of TCSC and SSSC on the static stability of the power system, the simple form (basic condition) of the six bus system was used to draw $\lambda - V$ curves which helped to identify static loading limits (max λ). Here loading parameters can help to obtain active and reactive power. Equations related to these are given below:

$$P_L = P_{LO}(1+\lambda) \tag{1}$$

$$Q_L = Q_{LO}(1+\lambda) \tag{2}$$

Here, P_{L0} and Q_{L0} represent the initial or basic power. P_L and Q_L are active and reactive power whose value at the bus determined by λ [15]. The active and reactive power losses were also examined with this work that was undertaken in the system.

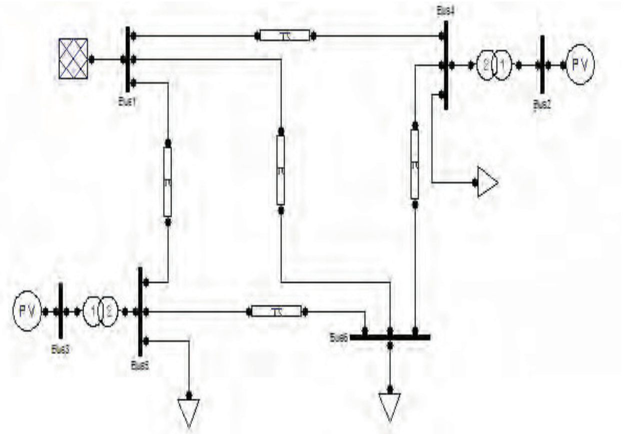

Fig. 4. General schema of six bus sytem

The system provided in Fig. 4 is the reference bus that is identified as bus 1 slack bus. This bus is accepted to be strong enough to keep bus voltage constant at all times. Power angle is zero. Buses 2 and 3 represent P-V or voltage controlled buses. The warnings of these generators are affected to keep the voltage constant. Buses 4,5 and 6 are P-Q or load buses. These buses are the ones which feed the cities or the industry.

Table 1 displays the $\lambda - V$ curves in Fig. 5 caused by continuous power flow of the power system whose normal loading values are given and the bus voltage values of Fig. 6.

Table 1. Generator and loading values of the system

Bus type	Bus No	Voltage pu (kV)	Active power (MW)	Reactive power (MVAr)
Slack	1	1.06 (230 kV)	-	-
Generator	2	1.04 (20 kV)	150	-
Generator	3	1.03 (20 kV)	100	-
Load	4	-	100	70
Load	5	-	90	30
Load	6	-	160	110

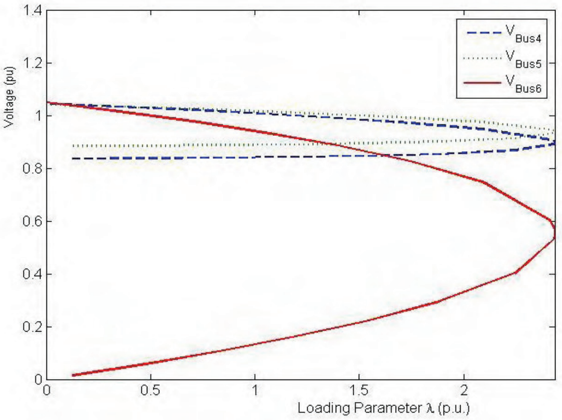

Fig. 5. λ –V curves obtained as a result of a continuous load flow in the load buses.

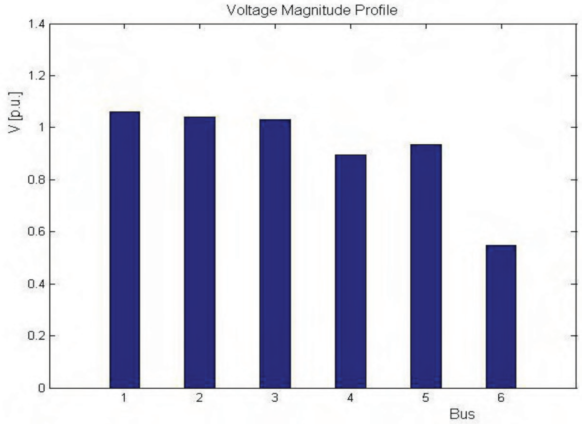

Fig. 6. Voltage values obtained as a result of a continuous load flow in the system buses

Table 2 shows the values of bus 6 which was found to be most critical bus as a result of the load flow

Table 2. critical load bus values in the power system

Bus	λmax (pu)	Voltage (pu)	MegaWatt Margin (pu)
6th bus	2.43	0.56	3.89

3.1. TCSC Analysis

The upper limit in series compensations is accepted to be 80% in practice. If this ratio is selected in higher limits, even small distortive effects can cause big fault flows [16]. In all the implementations for the sample system this ratio was selected to be 60%.

Amelioration needs to be undertaken in bus 6 which seems to be the most critical in terms of voltage stability in the system. Hence TCSC elements were connected separately on the lines that feed the bus 6 in order to study load flow. Also, TCSC was placed on all lines that feed bus 6 to observe the changes that took place in the system. In Fig. 7, TCSC was added among buses 1-6. The parameter values of TCSC controller added to the system were selected as shown in Table 3.

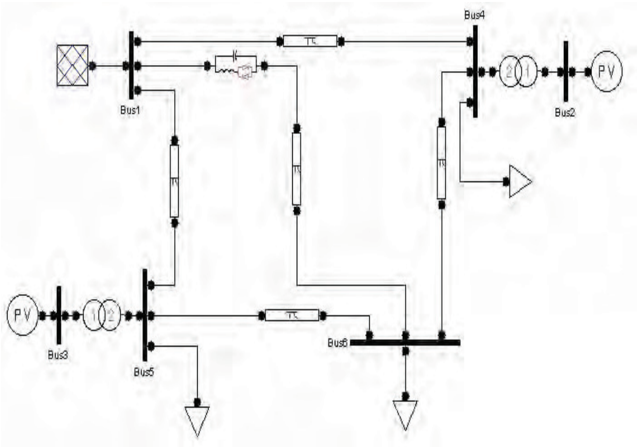

Fig. 7. Adding TCSC among buses 1-6

Table 3. Parameters for TCSC controller

S (MVA)	V (pu)	f (hertz)	Tr (s)	Kr (pu/pu)	Series Compensation (%)
100	230	60	0.01	10	60

By adding TCSC among buses 1-6 caused obtaining λ –V as a result of continuous load flow and voltage values of the buses in the sample power system. Obtained curves and the graphics are given in Fig. 8 and Fig. 9.

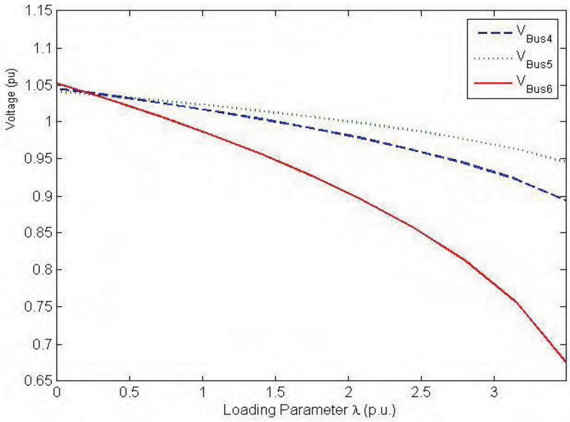

Fig. 8. λ –V curves obtained by adding TCSC among buses 1-6

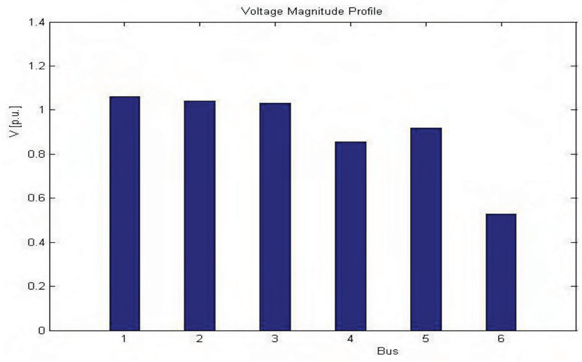

Fig. 9. Voltage values obtained by adding TCSC among buses 1-6

Table 4 shows the values obtained by connecting TCSC controllers separately to the lines that feed the 6 bus and connecting TCSC to these lines at the same time.

Table 4. Critical load bus values in the power system

Line	λ_{max} (pu)	Gerilim (pu)	MegaWatt Margin (pu)
Base case	2.43	0.55	3.89
1-6	3.49	0.67	5.58
4-6	3.13	0.65	5.01
5-6	3.13	0.54	5.05
All	5.00	0.55	8.00

3.2. SSSC Analysis

Bus 6 was identified as the most critical bus in terms of voltage stability in the condition of the load flow study in which no controllers were connected to the system. This bus needs to be improved. In this case, implementations were undertaken by connecting SSSC elements on the lines that feed bus 6. Also system changes were observed by placing SSSC on all lines that feed bus 6. In Fig. 10, SSSC addition to the 1-6 buses is seen. Parameter values of the SSSC controller added to the system was selected as seen in Table 5.

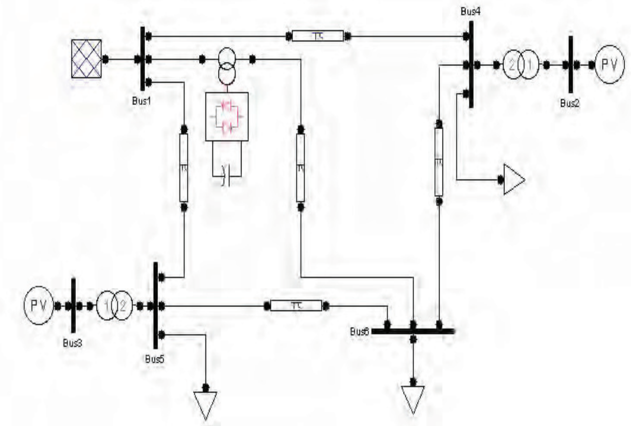

Fig. 10. Adding SSSC among 1-6 buses

Table 5. Parameters of SSSC controller

S (MVA)	V (pu)	f (h)	Tr (s)	Max-Min Voltage (pu)	Series Compensation (%)
100	230	60	10	1.0-0.6	60

By adding SSSC among buses 1-6 caused obtaining $\lambda-V$ as a result of continuous load flow and voltage values of the buses in the sample power system. Obtained curves and the graphics are given in Fig. 11 and Fig. 12.

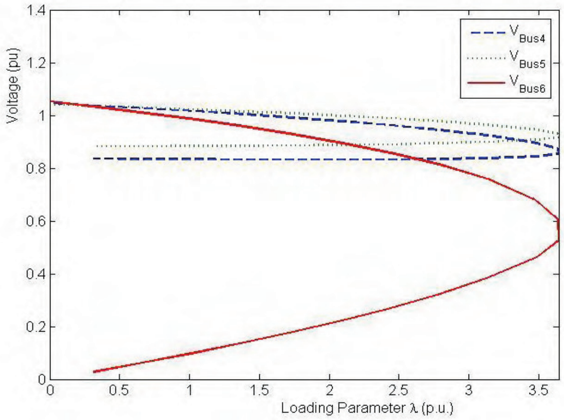

Fig. 11. $\lambda-V$ curves obtained by adding SSSC among buses 1-6

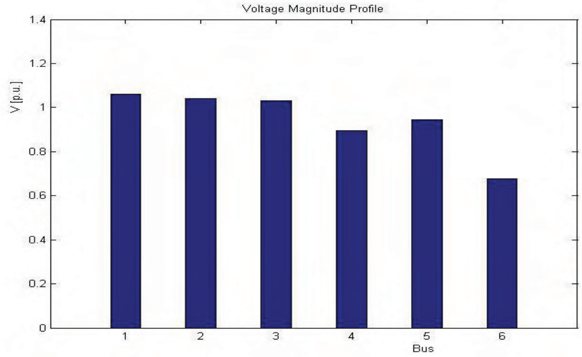

Fig. 12. Voltage values obtained by adding SSSC among buses 1-6

Table 6 shows the values obtained by connecting SSSC controllers separately to the lines that feed the 6 bus and connecting SSSC to these lines at the same time

Table 6. Critical load bus values in the power system

Line	λ_{max} (pu)	Voltage (pu)	MegaWatt Margin (pu)
Base case	2.43	0.55	3.89
1-6	3.64	0.53	5.83
4-6	3.12	0.65	5.00
5-6	3.16	0.54	5.06
All	4.13	0.40	6.11

4. Conclusions

All results obtained by adding TCSC and SSSC to the sample system of six bus.

Table 7. Critical load bus values in the power system

Line	λ_{max} (pu)		Voltage (pu)		MegaWatt Margin (pu)	
	TCSC	SSSC	TCSC	SSSC	TCSC	SSSC
Base case	2.43	2.43	0.55	0.55	3.89	3.89
1-6	3.49	3.64	0.67	0.53	5.58	5.83
4-6	3.13	3.12	0.65	0.65	5.01	5.00
5-6	3.13	3.16	0.54	0.54	5.05	5.06
All	5.00	4.13	0.55	0.40	8.00	6.11

According to the results, it was observed that TCSC and SSSC controllers; two of the FACTS devices; were effective in increasing the static load limits in the power system. It was also observed that connecting controllers between the bus 6 and slack bus caused the best situation in terms of load limits. In this condition, transferable active power value changed from 3.89 pu to 5.58 pu and 5.83 pu for TCSC and SSSC respectively. These values show approximately 50% increase in the power transfer capacity. Connecting FACTS controllers to all the lines at the same time increased the load limits up to 60-100%.

When the system was examined in terms of voltage stability, improvements related to power increase were detected. It was seen on the voltage stability curves that voltage stability limits are rather favorable when same capacity load is transferred.

In the light of these observations, positive improvements were found that were caused by TCSC and SSSC controllers, 2 of FACTS devices, in the increase of energy transmission lines capacity and amplifying voltage stability limits.

5. References

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