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Review, Comparison and Similarities of Static Var Compensator (SVC) and Thyristor Control Series Capacitor (TCSC) With Other (Facts) Devices

AMEH B V[1], ONYEDIKACHI N S[2]

[1,2,] *Department of Electrical Engineering, Nnamdi Azikiwe university Awka.*

Abstract -- The effective and economical means of solving problems of transient stability, dynamic stability, steady state stability and voltage stability in long transmission lines cannot be over emphasized in electrical power network system. The major factor contributing to voltage instability is the voltage drop that occurs when both active and reactive power flow through the inductive reactance of a transmission network, thereby making the network unable to meet the reactive power demands. This limits the capabilities of the transmission network, in terms of power transfer and voltage support [1]. To solve these problems, FACTS are recent technologies that employ high speed thermistors for switching in and out of transmission line components such as capacitors, reactors or phase shifting transformers to attain certain system desirable performance criteria [2]. IEEE defines FACTS as a power electronic based system and other static equipment that provide control of one or more ac transmission system parameters to enhance controllability and increase power transfer capability. This Paper investigates, reviews, compare similarities of the variable of different Facts devices as it concerns the role each of these facts device play in transient stability, dynamic stability, steady state stability and voltage stability in both short and long transmission lines of of electric power system network

Indexed Terms: COMPARISON, SIMILARITY, SVC, TCSC

I. INTRODUCTION

In securing maximum power transfer in transmission line from the generation station to load buses with acceptable voltage and higher stability level, a number of methods have been proposed by various authors. These include among many others: lost reduction, application of adequate reactive resources, supply of reactive power near to the loads (for loads that need reactive power), proper usage of on-load tap changing transformers, optimizing placement of generations, applying distributed generations, network structural modifications and creation of lines with lower resistance and reactance.

A review of previous studies on flexible alternating current transmission systems (FACTS) devices for improving power transfer capacity and voltage stability reveals that with proper combination of the basic FACTS devices, the security, stability and reliability of the power system can be guranteed to a reasonable extent.

These studies were not without operational constraints, such as stability, voltage security and thermal limits [4]. The study by Quaintance, et al.[5] aims to utilize some new technologies such as voltage instability predictor, to raise energy transfer capability in certain corridors. Other research directions aim to utilize FACTS components such as SVC, TCSC to enhance certain line transfer capability [4].

A study conducted by Anulekha, Priyanath, & Ajoy [6] for instance, reveals that the ennhancement in voltage stability margin as well as improvement in the power transfer capability in power system can be realized by the incoporation of Fixed Capacitor, Static Synchronous Compensator (STATCOM), and Static VAR Compensator (SVC). A very effective voltage regulation was also achieved by Rudrangshu, et al.[7] using STATCOM. On the other hand, Raju & Kori [8] presented a comprehensive review on the developments in the power system stability enhancement using FACTS damping controllers..

Reactive power support at weak bus helps to reduce congestion and thereby increases transmission line loadability. Placement of STATCOM device can reduce or increase line reactance and thereby increases or decreases MW power flow in line; voltage profile is also improved as a result in addition to congestion reduction. The use of STATCOM creates fast response and requires less space as passive elements are eliminated [9].

Vishnu, et al.,[10] suggests the use of Particle Swarm Optimization (PSO) based algorithm to determine the optimal location and setting of FACTS devices as a way of improving the capacity loads margin as well as voltage stability and small signal stability [11] in their paper, aimed at the benefits of utilizing FACTS devices with the purpose of improving the operation of an electrical power system. [13] Presents a method to compute the transmission line load ability that is consistent with the reactive power supply limits, voltage magnitude and voltage static stability limit. They also considered the load voltage characteristic in this work. Static VAR Compensators (SVC) and Thyristor Controlled Series Compensator (TCSC) are used to increase the load ability through the use of Ordinal Optimization Approach [13].

The result of the comparison of FACTS devices by [13] shows that a two-area power system with TCSC improves the power system stability as well as enhance power transfer capacity.

[14] Presents a report on modeling of the standard IEEE 14 bus system by using power system toolbox (PST) package. FACTS controllers were modeled and tested to show the effect of these controllers on stability margins under both small and large disturbances.

[15] Investigate the effects of line compensation using FACTS controller on power system stability. The effects of line compensation of Single Machine Infinite Bus (SMIB) power system using FC-TCR type TCSC or SVC for transient stability enhancement was described, and a novel method for analysis of line compensation by SVC was also presented. Their findings shows that the effectiveness of SVC in enhancing the stability of power system is dependent on the degree of compensation.

[11], in their work, highlights that TCSC is an effective and economical means of solving problems of transient stability, dynamic stability, steady state stability and voltage stability in long transmission lines. And being the first generation of FACTS, can control the line impedance through the introduction of a thyristor controlled capacitor in series with the transmission line.

II. COMPENSATION IN POWER TRANSMISSION LINES

According to [16], reactive power compensation is the generation or absorption of a suitable quantity of reactive power devices, either capacitive or inductive; to achieve one or more desired effects in an electric power system. These effects include improved voltage profiles, enhanced stability, and increased transmission capacity. The devices are either in series or in shunt (parallel) with the load(s) at one or more points in the power system network. Consumer loads (residential, commercial and industrial sectors) impose real and reactive power demand, depending on their characteristics.

Good quality power supply requires the voltage and current waveform of the ac system to be with little or no distortion. Unfortunately, due to the presence of these non-linear loads, the waveforms end up being distorted. However, a power system is expected to operate under varying conditions, from no-load to overloading to short-circuit with the quality of supply maintained over these range of conditions [2]. As system loads vary, the reactive power requirements of the transmission system varies expectedly. Since reactive power cannot be economically and effectively transmitted over long distances, voltage control has to be effected by using special devices dispersed throughout the system [17]. Again, rotational and inductive loads like motor require reactive power to convert the flow of electrons into useful work and provide the needed coupling fields for energy devices. Unfortunately, the presence of insufficient reactive power supply and reserve limits voltage and under such condition, it may be impractical to meet system power demand through the transmission corridor [7][18]. So to alleviate some of these problems associated with reactive power, compensation has to be incorporated manually or automated into the system to guarantee an efficient delivery of real power through transmission lines to the loads and to maintain the voltage at the load buses[7].

A. Static VAR Compensators (SVCs)

SVCs are shunt-connected static generators and/ or absorbers with varied output used to control specific parameters of the electric power system [17]. According to [3], there are shunt connected static VAR generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage).

Fast control of reactive power is important for maintaining security during power system operation. The conventional form of reactive power control is achieved mechanically by switching shunt capacitors and reactors. This according to [19] is limited only to maintaining the desired voltage profile for a slowly changing load condition. [19] also stated that under system disturbances such as line switching or generator tripping resulting in system instability and voltage problem, the need for fast control of reactive power is critical especially when the system is to be operated close to stability limits (margin) in steady state.

The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. If the power system's reactive load is capacitive (leading), the SVC will use reactors (usually in the form of Thyristor-Controlled Reactors) to consume VARs from the system, lowering the system voltage to nominal. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage.

According to [19][16][11] SVCs are used for:

- Increasing power transfer in long transmission lines.
- Stability improvement of the ac power system (both at steady and transient states) with fast acting voltage regulation.
- Damping of low frequency oscillations (corresponding to electromechanical modes).
- Smoothening flicker voltage when placed near high and rapidly varying loads, such as arc furnaces.
- Improving the dynamic stability performance of a power system with a suitable signal injection.
- Decrease of terminal voltage fluctuations during load changes
- Control of dynamic over-voltages resulting from large system disturbances.

B. Thyristor-Controlled Series Capacitor (TCSC)

Thyristor Controlled Series Capacitor (TCSC) is one of the important members of FACTS family that is increasingly applied to long transmission lines of power system by modern utilities. It can have various roles in the operation and control of power systems, such as scheduling power flow; decreasing unsymmetrical components; reducing net loss; providing voltage support; limiting short-circuit currents; mitigating sub-synchronous resonance (SSR); damping the power oscillation; and enhancing transient stability [13].

TCSC is a series controlled capacitive reactance with a combination of TCR and a fixed capacitor which allow the capacitive reactance to be smoothly controlled over a wide range to provide continuous control of power on the ac line[11].

III. FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS (FACTS)

FACTS are recent technologies that employ high speed thyristors for switching in and out of transmission line components such as capacitors, reactors or phase shifting transformers to attain certain system desirable performance criteria [2]. The Institute of Electrical Electronics Engineering, IEEE defines FACTS as a power electronic based system and other static equipment that provide control of one or more ac transmission system parameters to enhance controllability and increase power transfer capability.

FACTS devices are found to be very effective in the utilization of existing facilities of a transmission networks without sacrificing the desired stability margin [23]. The main objectives of FACTS devices according to [2] [24] is to replace the existing slow acting mechanical controls required to react to the changing system conditions with fast acting power electronic devices that carry out conversion or switching operations. In other words, it can be effectively used for improved system stability limit, power flow control, load sharing among parallel corridors, voltage regulation, and enhancement of transient stability. It can also be used to improve the transmission system security and provide strategic benefits for better utilization of the existing power system and mitigation of system oscillations. By giving additional flexibility, FACTS controllers can enable a line to evacuate power closer to its thermal rating [21]. Then according to [26], the basic purpose is to minimize the bottlenecks in existing transmission systems and improve the availability, reliability, stability, and quality of the power supply.

The mechanical controls require power system operators and designers to provide generous margins to assure a stable and reliable operation of the system. As a result, the existing systems cannot be utilized to their full capacity. However, with the use of fast acting controls, the power system margins could be reduced and power system capability could be more fully utilized while maintaining the present levels of quality and reliability [2]..

FACTS technology is not a single high-power controller, but rather a collection of controllers, which can be applied individually or in coordination with others to control one or more of the system parameters [2].

The development of FACTS controllers as cited by [2] has followed two different approaches:

The first approach employs the use of non-conventional thyristor-switched capacitors and reactors as switches (control elements) and reactive impedance or quadrature tap-changing transformers. Examples of such combinations are Thyristor-Controlled Static VAR Compensator (TCSVC), Thyristor-Controlled Series Capacitors (TCSC) and Thyristor-Controlled Phase Shifter (TCPS).

The second category employs self-commutated static switching converters as controlled synchronous voltage sources, e.g. Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controllers (UPFC) and Interline Power Flow Controller (IPFC).

The concept of FACTS as explained by Wadhwa (2013) is as follows:

The power transfer between two systems interconnected through a tie-line is given as $P_R=|V_S||V_R|/X \sin\delta$, from the equation, power flow can be controlled by three parameters; the voltage at the two systems, the reactance of the tie-line and the difference in the voltage angles at the two ends. FACTS devices can be used to control one or more of these parameters.

A. Types of FACTS Controllers

In general, FACTS controllers can be divided into four categories [21]:

Series Controllers

Series controllers inject voltage in series with the line. If the voltage is in phase quadrature with the line, the series controllers only supplies or consumes variable reactive power [21][23][3]. They include SSSC, IPFC, TCSC, TSSC, TCSR and TSSR. They can be effectively used to control current and power flow in the system and to damp system's oscillations [24][23][3].

Shunt Controllers

In practice, all shunt controllers inject current into the system at the point of connection. Even variable shunt impedance connected to the line voltage cause a current flow and hence represent injection of current into the line. The reactive power injected can be varied by varying the phase of the current. They may be variable impedance, variable source or a combination of the two [23]. The examples are Static Synchronous Generator (SSG), Static VAR Compensator (SVC).

Combined series-series controllers

This could be a combination of separate series controllers, which are combined in a coordinated manner in a transmission system with multi lines or an independent reactive power controller for each line of a multiline system. It could also be a unified controller in which series controller provides independent series reactive compensation for each line but also transfer real power along the line via the power link. Example of such controller is the interline power flow controller (IPFC)[23].

Combined series-shunt controllers

This could be a combination of separate shunt and series controllers which are connected in a coordinated manner or a unified power flow controller with shunt and series elements [23]. Examples of such controllers are UPFC and Thyristor- Controlled Phase-Shifting Transformer (TCPST)[3].

TCSC is a series controlled capacitive reactance with a combination of TCR and a fixed capacitor which allow the capacitive reactance to be smoothly controlled over a wide range to provide continuous control of power on the ac lin e[11].

IV. METHODOLOGY

To achieve the objectives of this study, the following stepwise approaches were adopted and followed:

- Compute the list of facts controllers in tabular
- Showing the similarities, difference and different controlled variable in table 1.0
- Compute the list of fact devices in tabular form.
- Showing the different applications of different facts devices in Table 2.

V. CONCLUSION

This paper has investigated by reviewing the different types of facts devices. In doing so, Static Var Compensator (SVC) was compared with Thyristor-Controlled Series capacitor (TCSC) in relations to the roles that each play in Electric power system network. While Static Var Compensator SVC play major active role of improving voltage profile at buses as shunt compensator, the Thyristor -controlled series capacitor (TCSC) plays its active role at the transmission lines as series compensator giving room for more real power at the transmission corridor.

From the table 1. In the appendix, the paper compares and contrast the role of different facts controllers and the variables that are being controlled, while table 2. In the appendix shows the results of the different types of Facts devices and their applications respectively. By this, the review, comparison, Similarities and differences of Static Var Compensator (SVC), Thyristor controlled series compensator (TCSC) and other facts devices investigated by the paper worth it.

Table 1: FACTS Controllers and their controlled variables [25][26].

0	FACTS CONTROLLERS	CONTROL VARIABLES	
		SIMILARITY	DIFFERENCES
1	Static Synchronous Compensator (STATCOM)	Voltage stability,VAR Compensation,Damping oscillation,Voltage Stability	
2	Static Var Compensator (SVC)	Voltage control, VAR compensation, damping oscillations, voltage stability	transient and dynamic stability
3	Unified Power Flow Controller (UPFC)	voltage control, VAR compensation, damping oscillations, voltage stability,	Active and reactive power control, transient and dynamic stability, fault current limiting, impedance, and/or angle (power)
4	Convertible Series Compensator (CSC)		Voltage, impedance, and/or angle (power)
5	Inter-phase Power Flow Controller (IPFC)		Voltage, impedance, and/or angle (power)
6	Static Synchronous Series Controller (SSSC)	damping oscillations, voltage stability,	Current control, transient and dynamic stability, impedance, and/or angle (power)
7	Thyristor Controlled Series Compensator (TCSC)	damping oscillations, voltage stability,	Current control, transient and dynamic stability, fault current limiting, impedance.
8	Thyristor Controlled Phase Shifting Transformer (TCPST)	, damping oscillations, voltage stability,	Active power control, transient and dynamic stability, and angle.
9	Super Conducting Magnetic Energy Storage (SMES)		Voltage and power
10	Thyristor-controlled series reactor (TCSR)	damping oscillations, voltage stability	Current control, transient and dynamic stability, fault current limiting

Table 2. Different types of FACTS devices and the Different applications[27].

S/N0	ISSUE	PROBLEM	CORRECTIVE ACTION	CONVENTIONAL SOLUTION	FACTS DEVICE
1	**Voltage Limits**	Low voltage at heavy load	Supply reactive power	Shunt capacitor, series capacitor	SVC, TCSC, STATCOM
		High voltage at light load	Remove reactive power supply	Switch EHV line and/or shunt reactor	SVC, TCSC, STATCOM
			Absorb reactive power	Switch shunt capacitor, shunt reactor	SVC, STATCOM
		High voltage following outage	Absorb reactive power	Add shunt reactor	SVC, STATCOM
			Protect equipment	Add arrestor	SVC
		Low voltage following outage	Supply reactive power	Switch shunt capacitor, reactor, series capacitor	SVC, STATCOM
			Prevent overload	Series reactor, PAR	TCPAR, TCSC
		Low voltage and overload	Supply reactive power and limit overload	Combination of two or more devices	TCSC, UPFC, STATCOM, SVC
		Line or transformer overload	Reduce overload	Add line or transformer	TCSC, UPFC, TCPAR
				Add series reactor	SVC, TCSC
2	**Thermal limits**	Tripping of parallel circuit (line)	Limit circuit (line) loading	Add series reactor, capacitor	UPFC, TCSC
		Parallel line load sharing	Adjust series reactance	Add series capacitor/reactor	UPFC, TCSC
			Adjust phase angle	Add PAR	TCPAR, UPFC
3	**Loop flows**	Post-fault sharing	Rearrange network or use "Thermal limit" actions	PAR,series capacitor/reactor	TCSC. UPFC, SVC, TCPAR
		Flow direction reversal	Adjust phase angle	PAR	TCPAR, UPFC
4	**Short circuit levels**	Excessive breaker fault current	Limitshort circuit current	Add series reactor, new circuit breaker	SCCL, UPFC, TCSC
			Changecircuit breaker	Add new circuit breaker	
			Rearrange network	Split bus	
5	**Sub-synchronous resonance**	Potential turbine/generator shaft damage	Mitigate oscillations	Series compensation	NGH, TCSC

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