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FACTS Devices: A Comprehensive Review

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Abstract*— The greater need for uninterrupted power supply greed higher quality of power. Flexible AC Transmission Systems (FACTS) controllers/devices are quickly becoming a crucial part of modern power systems; these devices are utilized to expand the potentiality of transmission and enhance the stability as well as the quality of power supply. Several FACTS devices along with the hierarchy of the FACTS family are described in this paper. The properties, benefits, and applications are also addressed here. Among the various devices, STATCOM has the advantage of very quick response, low cost, and low losses. However, its dynamic capability is limited and it faces difficulty in controlling the steady-state power flow. UPFC being the union of SVC and STATCOM, do involve in managing the active/reactive power hence improving the stability of the system. Though it bears a wide dynamic range and improved stability but more complex and expensive than STATCOM. The Static Var Compensator (SVC) is a shunt-type FACTS device that is used to control the reactive power flow and voltage profile. The SVC is expensive and difficult to operate. In conclusion, FACTS devices are important components of modern power systems due to their ability to improve power system stability and power quality. This paper deals with an overview of various FACTS devices used in finding solutions to issues in power system quality.

***Index Terms*— Power Quality, System Stability, Voltage Regulation, Settling time.**

I. INTRODUCTION

FACTS (flexible AC transmission systems) devices help to improve system performance and reduce losses while ensuring a secure and reliable supply of power. This paper will discuss the various types of FACTS devices that are in use today and their respective advantages and disadvantages. It will also explore the potential applications of these devices and the challenges associated with their implementation. The FACTS devices can decrease power flow in highly loaded lines, increasing lowering system loss and enhancing stability. decreased manufacturing costs because of the network. To accomplish these goals, a number of FACTS regulators are suggested [1] - [2] and put into practice. The STATCOM, SSSC, generalized unitary power flow controllers (GUPFC), IPFC, and other devices are associated with the FACTS controller family [3] - [4]. The FACTS controllers are the electrical components used for the optimization in transmission networks or used as power flow controllers. They are used to increase system efficiency/stability and to improve power quality.

The long transmission lines are prone to stress and transient instability that leads to mild to severe faults. These defined problems are added as transmission-limiting variables [5]. Transient stability is said to be the ability of the power system to overcome/sustain synchronous operation even after happening of various interruptions such as line switching, failures (short-circuit), etc. [6]. Using a FACTS characteristic we can increase a complicated power system's voltage stability, steady and transient stability. Apart from this, several applications are served by these devices including, power flow scheduling, oscillations damping, reduction in a net loss as well as unsymmetrical components, short circuit current limiting, and clearing sub-synchronous response (SSR), etc., [7] [8].

Indeed, the advantages of implementing FACTS controllers mainly include improved system stability, increased system efficiency, and improved power quality. Furthermore, they help in reducing transmission losses and increase the reliability of the system. These devices are accustomed to various challenges associated with the implementation of FACTS devices, such as the high cost of installation, the need for trained personnel, and the potential for unforeseen system impacts. In conclusion, FACTS devices are the foremost/dominant part of the modern power system, allowing optimized control over a power flow in the transmission networks. These devices provide numerous advantages, such as improved system stability, increased system efficiency, and improved power quality.

II. THE HIERARCHY OF FACTS DEVICES, WORKING AND APPLICATIONS

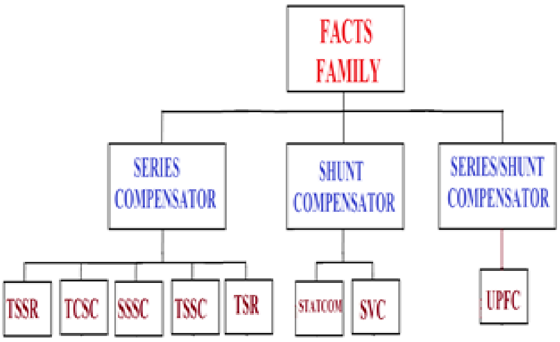

Fig.1 The Hierarchy of FACTS controllers/devices

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Fig. 1 depicts the FACTS family along with the types of FACTS devices and various members of the FACTS family. The description of each member along with the equivalent circulatory and applications are stated as follows:

A. Series Compensator

1. TSSR: Known as Thyristor Switched Series Reactor depicted in Figure 2 is a member of the series compensator and widely known for its capacity of precise voltage regulation. It is used to achieve stepped series inductance and also smooth variable inductive reactance.

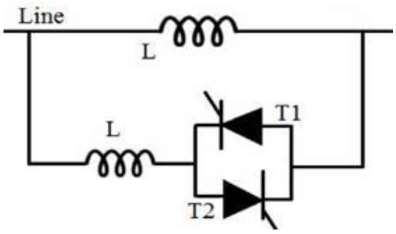

Fig. 2 Equivalent TSSR circuit

It is a power electronic device used in electrical transmission networks that mainly have check on flow of reactive power which is so designed to recompense reactive power and fluctuations in voltage associated to grid. TSSR consists of a series reactor connected in line with a thyristor-based switching circuit. The aim of series reactor is to avail required impedance for compensation of reactive power. On the other hand, the thyristor switches are used to have control over effective reactance and hence enables rapid adjustment of power flow (reactive only). This makes voltage management and reactive power compensation possible, enhancing the overall power quality and preserving system stability, the quick response time and great degree of flexibility of TSSR are two of its main benefits.

The thyristor switches can be rapidly turned on or off, allowing for quick adjustments to the reactive power flow based on system conditions and requirements. This dynamic control capability makes TSSR particularly suitable for applications where there are frequent changes in reactive power demand, such as in systems with significant renewable energy integration. TSSR technology offers several benefits, including increased transmission capacity, voltage stability enhancement, and reduction of power losses.

2. TCSC: Thyristor Controlled Series Capacitor:

In power systems, the TCSC is generally preferred in order to gain or maintain dynamic stability.

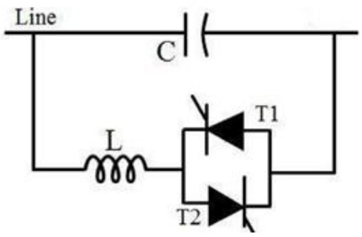

Fig. 3 Equivalent TCSC circuit

It is commonly used in various other applications like damping of oscillations, compensation of reactive power and wide power transmission. In order to achieve the controlled power flow in the line, the power system engineers select TCSC as a prime tool. The idea of putting a capacitor in series to a transmission line to start functioning of TCSC is made obvious as shown in Fig. 3. Where thyristor switches are utilized to turn the capacitor ON and OFF.

When the switches (thyristor) are activated, connect the controlling capacitor to the line. During the off condition of thyristor switches, the capacitor is disconnected from the line, preventing current from flowing. TCSC is suitable for regulating power flow, reducing losses, and stabilizing power systems. Also, used for controlling the voltage level of the transmission line (by absorbing or releasing reactive power), reducing the amount of harmonic distortion. Along with the stated uses of TCSC in power transmission, it is always economical to use it in distributed generation systems. TCSC proves to be an invaluable asset for power system engineers as it effectively ensures grid stability and delivers a dependable energy supply.

3. SSSC: Called a Static Synchronous Series Compensator is basically a series version of STATCOM (an equivalent diagram is depicted in Fig. 4. It helps in controlling the line impedance. The SSSC is the sole compensator that independently controls current and voltage. It is also very much useful in controlling the series compensation and also capable of damping the power oscillation if any.

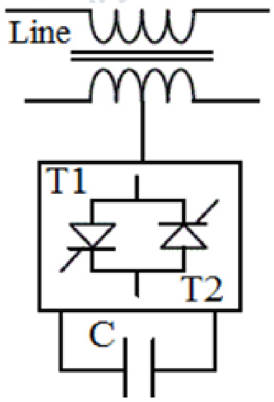

Fig. 4 Equivalent SSSC circuit

A series transformer, a DC capacitor and SVC (voltage source converter) are some of the essential parts that make up the SSSC. The VSC, which commonly uses IGBT (Insulated-gate Bipolar Transistors), permits two-way power flow and supports the systems voltage. By managing the VSC, the impedance of series transformer can be dynamically controlled by SSSC. The firing angle and amplitude of the converters output voltage may be changed which allows SSSC to modify the series reactance and so regulate the voltage magnitude and phase angle. Voltage management and power flow regulation are made possible by SSSC's quick and precise ability to inject/absorb reactive power into the system. By injecting reactive power, it can help maintain voltage levels within acceptable limits and compensate for voltage drops. Conversely, by absorbing reactive power, it can alleviate voltage rise and improve system stability. One of the major advantages of the SSSC is its ability to provide rapid response and precise control. It can quickly adjust its output to counteract fluctuations.

The SSSC offers various benefits, including improved voltage stability, increased transmission capacity, and enhanced power system controllability. The SSSC helps optimize the utilization of existing transmission infrastructure and improves the overall reliability and efficiency of the electrical network.

4. TSSC: Thyristor Switched Series Compensator:

It comprises many capacitors that are individually switched by a series of reverse parallel linked thyristors that form a suitable rated bypass value (shown in Fig. 5).

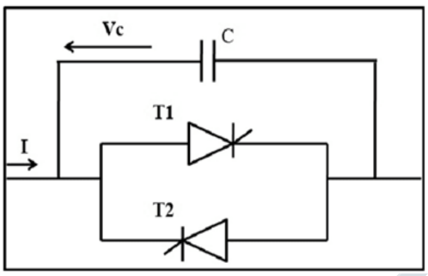

Fig. 5: TSSC equivalent circuit

It resembles the circuitry of the GCSC that is operated consecutively. The TSSC provides the following ensuring advantages,

- The line compensation level may be changed more often, giving the power flow more control.
- An extremely quick reaction time.
- Quick expansion of the power transfer backup capability in the event of tie-line failure.
- Very less or no harmonic distortion.

Used when continuous control is preferred.

5. TSR: Thyristor Switched Reactor (Fig. 6) is highly recommended in limiting the short circuit current. It acts as a VAR absorber and helps in exchanging the inductive and capacitive current and ultimately maintains the quality and systems stability.

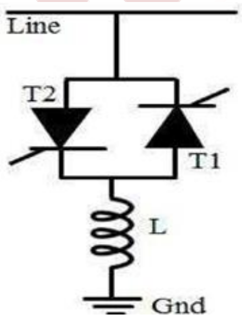

Fig. 6 TSR equivalent circuit

It is a powerful electronic device that combines the characteristics of a thyristor switch and a reactor. The advantages of TSR technology lie in its flexibility and responsiveness. The thyristor switches can be switched on or off rapidly, enabling quick adjustments to the reactive power flow based on system requirements. This dynamic control capability makes TSR suitable for applications where there are frequent changes in reactive power demand, such as in systems with renewable energy sources. TSR devices offer several benefits, including improved voltage stability, reduced power losses, and enhanced power system reliability. By effectively managing reactive power, TSR helps optimize power transmission, maintain voltage levels within acceptable limits, and minimize voltage fluctuations.

B. Shunt Compensator

1. STATCOM: It is primarily a shunted device that employs VSC (Voltage Source Converters) with power electronics as the basis. It has the ability to sustain dynamic voltage while also regulating, managing, and correcting reactive power and power imbalance.

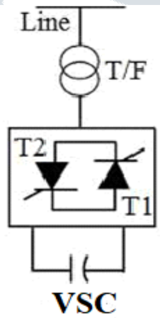

Fig. 7 Equivalent circuit of STATCOM

Inverter is powered by a DC capacitor, which stores energy and provides reactive power to regulate voltage. The STATCOM also contains a control unit, which monitors the system and adjusts the output of the inverter as needed. It is also used to provide dynamic voltage support, which can help reduce system losses and improve overall power quality. Static Synchronous Compensator (STATCOM) shown in Fig. 7, is an advanced form of FACTS controller with very fast response time that can inject or absorb reactive power in a short time and is mostly used in transmission and distribution systems for overall improvement in the dynamic performance of the system. Following are the some of the worthy applications of STATCOM.

- Voltage Regulation: STATCOM is used to regulate voltage, especially in areas of low voltage due to heavy load demand.
- Load Balancing: STATCOM is used to balance reactive power demand between two or more load points, thus reducing the amount of reactive power needed from the supply source.
- Power Factor Correction: STATCOM is used to correct power factor for improving system efficiency

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- Harmonic Mitigation: STATCOM is used to reduce harmonic distortion in power systems by injecting high-frequency current pulses.
- Reactive Power Compensation: STATCOM is used to compensate for reactive power imbalance in transmission and distribution systems.

2. SVC: A Static Var Compensator, It uses reactive power to balance out the voltage and current in a power line. SVCs (depicted in Fig. 8) are used in industrial and commercial settings, such as power plants, substations, and transmission lines. An SVC is composed of two main components: a capacitive bank (used for supplying reactive power to the line) and a thyristor-controlled reactor (TCR). The capacitive bank is made up of capacitors linked in series or parallel. Reactive power flow is managed using a variable inductance called TCR. The SVC will modify its parts to balance the voltage and current in the line when a power line experiences a voltage drop or an increase in the current. While the TCR modifies the amount of reactive power generated by the capacitive bank, the capacitive bank will create reactive power to offset any voltage decrease or increase in current. This aids in preserving the power line's voltage and ensuring that it remains within the required range.

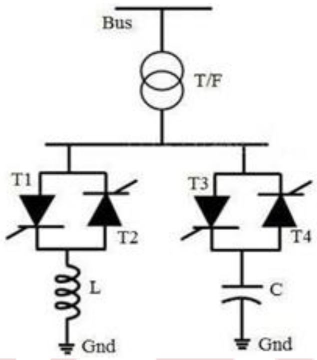

Figure 8: Equivalent circuit of SVC

C. Series/ Shunt Compensator

1. UPFC: It is advanced equipment used to maintain the voltage profile, and power flow, and improve the transient stability. The UPFC is the result of a combination of STATCOM, TCSC, and SVC.

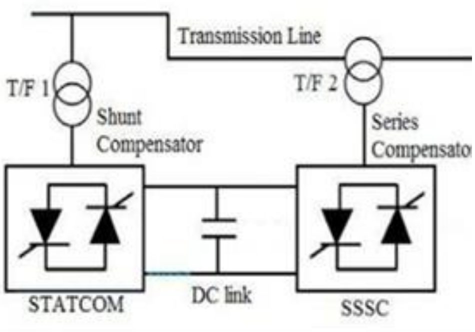

Fig. 9 Equivalent circuit of UPFC

UPFC operates by regulating active and reactive power transmission within transmission lines. It comprises two interconnected converters and two sets of parallel filter circuits. These converters namely, VSC & CSC (Current Source Converter) has their own practical existence where the VSC is responsible for generating the necessary reactive power, while the CSC generates the required active power. The UPFC injects the designated power precisely where it is needed within the system. There are two modes of operation: series and shunt. The UPFC institutes the power at the common-coupling point in the series mode while, the power is injected directly into the line at a specific location when UPFC is operated in shunt mode. Additionally, the UPFC provides control over the line's magnitude and phase angle, allowing for effective management of active and reactive power flows. Furthermore, it may be utilized to dampen power oscillations, stabilize the system against disturbances, and power system to be run near to its optional state, enhancing system dependability and efficiency.

III. IPFC AT A GLANCE

Interline Power Flow Controller (IPFC) techniques offer both actual power transmission and independent management of reactive power among the already compensated line. The two SSSCs (converter based) are coupled (back-to-back) to form a basic IPFC device. This combination helps in transferring the actual power to the line. Each of these SSSCs grants the production of controlled AC voltage that too at the fundamental power frequency. This produced voltage is synchronized lately to the transmission lines voltage level. The use of IPFC is remarkably affordable when it is preferred to use in multilane line. It also avails wide accuracy in power flow balancing across transmission lines and for transferring power from overburdened to underloaded lines. In Fig.10, a multiline IPFC is depicted.

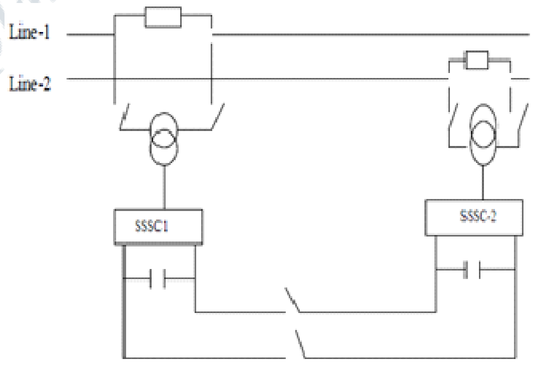

Fig 10: Layout of IPFC controller

Following are few of the major applications of IPFC,

- Improving transient stability,
- Damping of the power oscillation control
- Helps in increasing voltage stability
- Real-time power flow control
- Enhances rotor angle stability, etc.

IV. REAL TIME COMPARATIVE ANALYSIS OF VARIOUS FACTS DEVICES

A. Comparison based on technical benefits

Table 1. Comparison based on technical benefits [18]

FACTS devices	(Voltage Control)	(Transient Stability)	(Load Flow Control)	(Dynamic Stability)
SVC	Highest	Less	Less	Intermediate
TCSC	Highest	Intermediate	Less	Intermediate
STATCOM	Less	Highest	Intermediate	Intermediate
UPFC	Highest	Intermediate	Highest	Intermediate

B. Comparison based on cost

Table 2. Comparison based on cost [18]

FACTS device	COST (Rs)/kVar
Shunt Facts devices (Capacitor)	590
Series Facts devices (capacitor)	1304
STATCOM	3080
UPFC/IPFC	3080
TCSC/SVC	2490

C. Comparison-based Critical Clearing Time

Table 3. Critical Clearing Time [19]

Devices	System	Critical Clearing Time (Sec)
SVC	SVC only	0.26
	SVC +UPFC	0.248
STATCOM	Short circuit fault	0.325
	Large loading	0.764
TCSC	0% Compensation	0.3761
	80% Compensation	0.4062
	With 2 TCSC	0.51

The critical clearing time can be stated as the period of time when a fault must be fixed before it can harm the power system. It is basically the longest amount of time a power system can experience a fault without losing stability. Table III & IV indicates the comparative analysis of the critical clearing time and settling time of prime FACTS devices.

D. Comparison-based Settling Time

Table 4. Settling Time [19]

FACTS device	System	Settling Time (Sec)
SVC	Without	41
	With SVC	32
STATCOM	Along Hybrid Control	4.7
	Fuel cell with hybrid	4.6
TCSC	TCSC	17.164
	SSSC-AGC	22.93
	TCPS -AGC	37.29

V. CONCLUSION

FACTS technology plays a vital and immortal role in order to get electricity from power plants to consumers. FACTS technology is widely used in transmission and distribution that offers quick, accurate control of the power flow among both generating stations and load centers that helps to increase the efficiency, dependability, and stability of the power system. Power losses in the transmission system can be minimized. Thanks to FACT technology, which also allows for more precise control of the power flow. Additionally, FACT systems increase system adaptability by enabling quicker responses to shift loads and by supplying more power transfer capacity. In many parts of the world, the electricity transmission network makes extensive use of FACT technology. This paper is aimed to provide a thorough examination along with a comparison of several FACTS components that are crucial to preserving the stability, reliability, and quality of the power system.

REFERENCES

[1] P. Moore et al., "Flexible AC Trans. System" AFC (Advanced FACTS Controllers), PE Journal, vol. 12, pp 95-100, April (1998).
[2] R. G. Zaher, T. U. Okeke, "FACTS System", ICNCSC 2013, (SmartMILE), Gijion, (Spain), IEEE, pp. 1-4, Dec 2013.
[3] E. Handschin, and M.Yao et al. " Modelling of a Generalized Unified Power Flow (GUPFC) in Nonlinear Interior Point OPF" IEEE Trans. Power System, vol. 16, pp. 367-373, Aug 2001.
[4] B. Mwinywiwa et al., "Multi-terminal UPFC for power system deregulation", IEEE Power Engineering Society Winter Meeting, Singapore, pp. 2916-2921, 2000.
[5] R. Mihalic, and P.Zunko et al., "Improvement of transient Stability using Unified Power Flow Controller", IEEE Transaction Power Dele, vol. 11, pp. 485-492, Jan 1996.
[6] K. R. Padiyar, "Power System Dynamics and Stability" Second Edition, BS publications, Hyderabad 2002.
[7] P. Mattevelli and G. C. Verghese et. al., "Phasor Dynamics of Thyristor-Controlled Series Capacitor Systems", IEEE trans. Power Syst. vol. 12, pp. 1259-1267, Aug 1997.
[8] A. D. Del Rosso and C. A. Canizares et. al., "A Study of TCSC Controller Design for Power System Stability Improvement" IEEE Trans. Power Syst., vol. 18, pp. 1487-1496, Nov 2003.