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Power Flow Control in Power System using Static Synchoronous series compensator (SSSC): A Review

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Abstract:

The world's electric power supply systems are widely interconnected. We need these interconnections because, apart from delivery, the purpose of the transmission network is to pool power plants and load centre in order to minimize the total power generation capacity and fuel cost. Today's power system demand have been increase with loads, it is more difficult to provide stability and control. In this paper analysis of power flow control in power system using Thyristor controlled series compensation and performance of SSSC is given. FACTS technology new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. In this paper the study of of SSSC with capacitive and Inductive mode of operation and applications, advantages of FACTS. Thyristor controlled series compensation consist of series capacitor shunted by back to back thyristor. By changing the firing angle of this back to back thyristor possible to vary the reactance of the SSSC as per SSSC characteristics. This compensation controls the transmission line reactance to improve the real power flow. SSSC in capacitive region power flow increasing and in capacitive region power flow decreases.

Keywords **— Flexible AC Transmission System (FACTS), Power Flow analysis, SSSC..**

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I. INTRODUCTION

Electricity is an everyday as it was an essential part of our life and need to get electricity to the consumer in reliable and specified quality. Transmission of electricity in the interconnected cooperating electricity system is steadily increasing due to increasing growth in consumption and electricity generation. World-wide transmission systems are undergoing continuous changes and restructuring. They are becoming more heavily loaded. The transmission systems must be flexible to react to more diversified generation and load patterns. The three control parameters such as voltage magnitudes, phase angle and line reactance Governs flow of power in the transmission system. Considering a symmetrical lossless transmission line of Fig. 1 between two areas, the power flow P in the transmission line can be expressed as:

Whereas |Vs| & |Vr| are the sending end and receiving end voltage magnitudes and (δs – δr) are phase angle between the two ends. Considering resistance and susceptance as negligible, XTL is defined as reactance of the transmission line.

Either by controlling voltage magnitudes, phase angle or line reactance, power flow in the transmission line can be governed effectively and system can be operated reliably and securely. By improving the sending end or receiving end voltage profile (|Vs| & |Vr|), both real and reactive power flow of the transmission line can be enhanced. The absolute magnitude of _sending-end' and _receiving-end' voltages governs the reactive power flow in the transmission line. If

|Vs| > |Vr|, then reactive power flows from sending end to receiving end side i.e., from area-1 to area-2 as shown in Fig. 1 and vice versa. The Real Power flow, on the other hand is governed by the phase angles difference (δs – δr) between sending end and receiving end voltages in the transmission Line. If the difference between the phase angles (δs – δr) are large and positive, then real power flow in the transmission line is large and power flows in the direction from area-1 to area-2 as shown in Fig. 1 The power flow is vice versa for negative value of phase angle difference. the real power flow in transmission line is also inversely proportional to transmission line reactance XTL and thus can be improved by compensating inherent line reactance partially. These three parameters to improve power flow in the transmission line. The power (P and Q) at the receiving end bus as shown in equation 1.1 and 1.2

$$\text{Active Power}\quad P = \frac{Vs\, Vr\, Sin\,(\delta s-\delta r)}{XTL} = \frac{V^2\, \mathrm{Sin}\delta}{XTL} \quad \cdots (1.1)$$

$$\text{Reactive Power}\quad Q = \frac{VsVr\,[1-Cos(\delta s-\delta r)]}{XTL} = \frac{V^2(1-\cos\delta)}{\mathrm{XTL}} \quad \cdots (1.2)$$

$$\delta = \delta s - \delta r \quad \cdots (1.3)$$

II. INTRODUCTION OF FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it. Flexible AC Transmission system technology opens up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. The FACTS devices are certainly an improvement over the conventional methods as they are fast and control these parameters efficiently to manage power flow effectively in transmission system. These opportunities arise through the ability of FACTS Controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle, and the damping of oscillations at various frequencies below the rated frequency. In general, FACTs controller may divided into four categories as shown in figure. 2

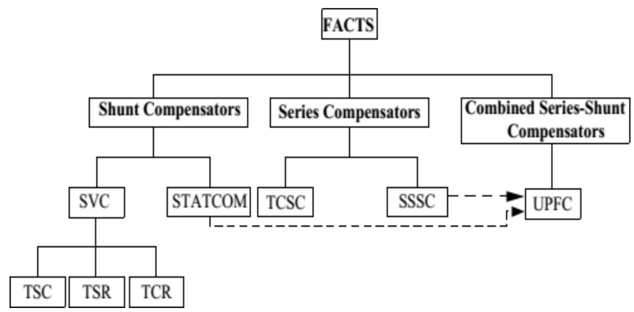

Fig.2. Classification of FACTS controllers.

Each FACTS device can individually or collectively control. The Static VAR Compensator (SVC) and Static Synchronous Compensator (STATCOM) improve the power flow of the transmission line by increasing the voltage profile at the point of connection. The Thyristor Controlled Series Compensator (TCSC) and Static Series Synchronous Compensator (SSSC) is series compensator switch Compensator. The transmission line reactance to improve the real power flow. In addition, SSSC regulates the phase angle of the transmission system. The Unified Power Flow Controller (UPFC) is the only device which can be employed to govern all three parameters of given transmission line, however cost and complexity is an important issue.

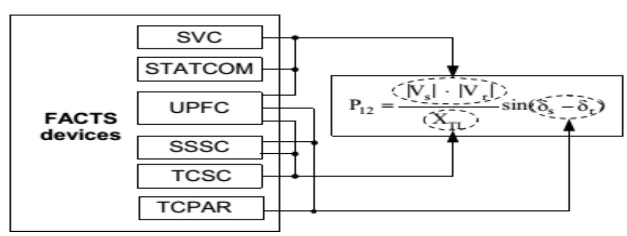

Fig. 3:Representation of different type's controllers controlled different parameters of transmission line.

The basic applications and advantages of FACTS devices are:

1. Power flow control
2. Voltage control
3. Reduce system losses
4. Reactive power compensation
5. Enhance power system stability
6. Power quality improvement.
7. Flicker mitigation Power conditioning
8. Increased system security and reliability
9. Rapid, continuous control of the transmission line reactance
10. Optimizing load sharing between parallel circuits

III. SSSC AND POWER FLOW CONTROL

FACTS controllers are incorporated in power systems. Significant device from the group FACTS is a SSSC, It is a static synchronous generator operated without an external electric energy source as a series compensator. it is independent of the line current for changing the overall reactive voltage drop. It has an energy absorbing devices to increase the dynamic behavior of the system by adding real power to awhile change in real voltage drop in the transmission line. SSSC can inject voltage lagging or leading the current. This is applicable to solving many problems in power system. SSSC in order to provide a smoothly variable series capacitive reactance . SSSC controller can be used to control the power flow in transmission line, increase the transmission limit or can greatly enhance the stability of the network and also provide the continuous variable and impedance. The main principles of the SSSSC concept are Two; firstly, to provide electromechanical damping between large electrical systems by changing the reactance of a specific interconnecting power line. Secondly the SSSC will change its apparent impedance for sub-synchronous frequencies. Such that a prospective sub synchronous resonance is avoided. A Basic SSSC Configuration and equivalent circuit of Static Synchonous Series compensator are show in figures.

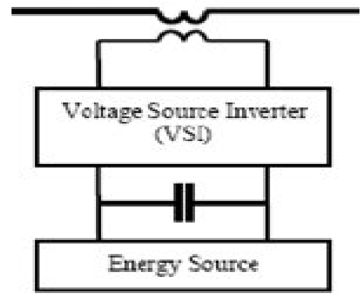

Fig. 3: Basic SSSC Configuration

The basic scheme of the SSSC is shown in Fig. 3. The compensator is equipped with a source of energy, which helps in supplying or absorbing active power to or from the transmission line along with the control of reactive power flow. As the name suggests, SSSC is a series compensator. It is connected in series with the transmission line. Three phase series transformers are used to connect the compensator in series with the power system. Fig.3 shows a functional model of the SSSC where the dc capacitor has been replaced by an energy storage device such as a high energy battery installation to allow active as well as reactive power exchanges with the ac system. The SSSC's output voltage and phase angle can be varied in a controlled manner to influence power flows in a transmission line. The phase displacement of the inserted voltage Vpq with respect to the transmission line current line I , determines the exchange of real and reactive power with the ac system

IV. OPERATING MODE OF SSSC

Due to the almost ideal voltage source characteristic of the VSC, the SSSC can provide capacitive or inductive compensating voltage independent of the line current, up to its specified voltage rating. Thus, the SSSC can maintain the rated maximum capacitive or inductive compensating voltage in the face of changing line current,

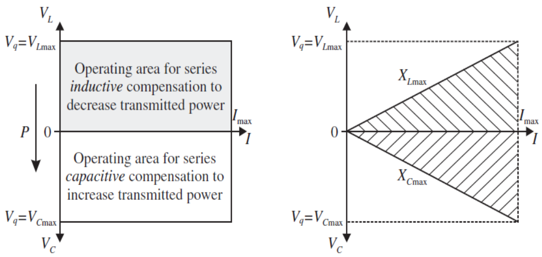

Fig. 4: Operating range characteristics of SSSC

theoretically in the total operating range of 0 to Imax. The practical minimum is the line current value at which the SSSC is still able to absorb enough power to replenish its operating losses [2].

The SSSC has two operating modes:

1. **Control of voltage compensation,** where the SSSC operates so as to maintain the capacitive or inductive compensation voltage at a maximal value, regardless of the current variations in the transmission line between 0 and Imax.
2. **Control of reactance compensation**, where the SSSC operates so as to maintain the capacitive or inductive compensation reactance at a maximal value, when the current in the line varies between 0 and Imax

In principle, an SSSC is able to exchange active power and reactive power with the transmission grid. If considering only reactive power compensation, then the size of the power source can be relatively small. In this case, it will only control the magnitude of the voltage phasor, which is kept perpendicular on the line current phasor, leading or lagging it by 90◦. This means that, in the case of the SSSC, the magnitude of the compensating voltage, at fixed +90◦ or –90◦ angle, can be controlled continuously in the operating domain of the VSC.

If the power source has real power control capability, then the injected voltage could be controlled both in magnitude and phase. The behavior of an SSSC is the same as that of a series capacitor and a series reactor, both controllable. The main difference is that the voltage generated by the SSSC can be controlled independently of the line current because it does not depend on it. Consequently, an SSSC can operate both in the cases of increased and decreased line loads.

Since the SSSC emulates the line compensation of the series capacitor by the direct injection of the required compensating voltage at the fundamental system frequency, without reproducing the impedance versus frequency characteristic of a physical capacitor, it is, in contrast to the series capacitor, unable to form a classical series resonant circuit with the inductive line impedance to initiate subsynchronous oscillations.

In other words, independent of whether the SSSC is operated in the capacitive or inductive compensation domain, it is seen by the system as a (zero-impedance) voltage source in series with a small inductive impedance (the leakage impedance of the coupling transformer). Because of its fast response, the SSSC could theoretically provide effective damping of subsynchronous oscillation by suitable control, should the condition for subsynchronous oscillation be established by (existing) series capacitors.

V. OPERATING PRINCIPLE OF SSSC

The SSSC is a series connected synchronous voltage source that can vary the effective impedance of the transmission line by injecting a voltage containing an appropriate phase angle in relation to the line current. It has tha capability of exchanging both activa and reactive power with tha transmision system. The SSSC Comprises a multi phase VSC with a dc energy storage controller and functional representation of active reactive power flow. Here the Controller is connected in series with the SSSC are illustrated in figure

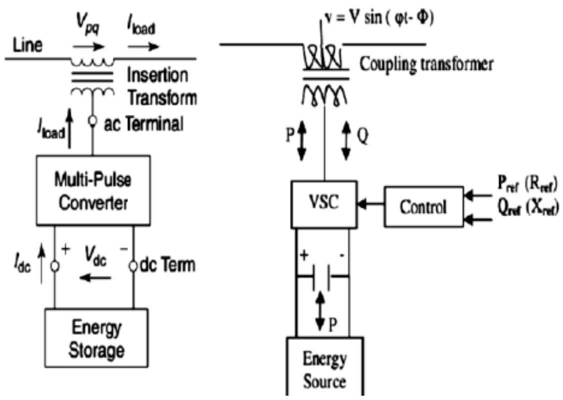

Fig. 5. Series connected synchronous voltage employing multi pulse converter with an energy storage device.

The basic operating principle of the SSSC is to inject the voltage Vinj in quadrature (i.e., at ±90◦) with respect to the transmission line current as illustrated in Figure in below. Therefore, the SSSC exchanges only reactive power with the transmission line. The SSSC has the effect of changing the equivalent line impedance and therefore only the magnitude of the line current. As shown in Figure 6 a, with Vinj = 0,

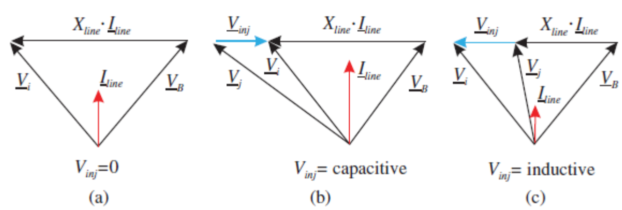

Fig. 6. SSSC inserted voltage with respect to the line current: (a) neutral, (b) capacitive and (c) inductive.

The magnitude of the line current is unchanged; with capacitive Vinj the line current magnitude is increased (as shown in Figure 6 b), and with inductive Vinj the line current magnitude is decreased (as shown in Figure 6 C).

The control of the magnitude of the line current, in effect, controls the real power flow P (MW) in the transmission line. That is, the real power flow can be increased or decreased from the nominal (uncompensated) line power flow by the polarity of the injected voltage. In fact, the real power flow in the line can be reversed depending on the achievable change in the line current magnitude (or the rating of the SSSC) with respect to the nominal (uncompensated) line power flow value.

The SSSC is implemented with a VSC connected in series with the transmission line. The basic operation of the VSC is essentially to convert the DC voltage at their

DC terminals into an AC voltage output, in accordance with a vector reference that defines:

- ➢ the ratio between the DC-side and AC-side fundamental voltage;
- ➢ the phase angle of the AC output voltage.

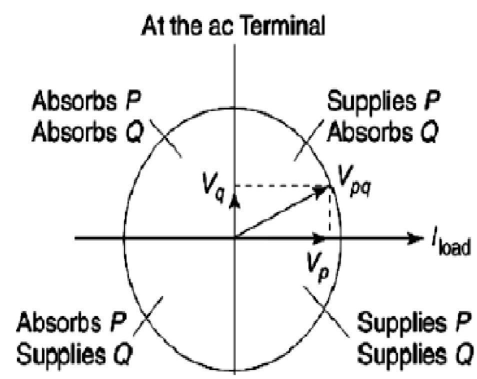

Fig. 7. The different operating modes of SSSC for real and reactive power exchange

VI. CONCLUSIONS

In this paper, the used of SSSC in power flow control between two ends of the transmission line to maintain the voltage magnitude, phase angle and line impedance. The study of Series compensation SSSC device to controlling the power flow through the transmission line by changing the effective reactance of the system. The SSSC can be operated in generally two modes as inductive and capacitive mode. The various FACTS controller with its classification. The advantages of FACTS devices in power system and various operating modes of TCSC are specified. This paper work can be extended in future for SSSC modelling and simulation with a number of bus system for controlling the power flow.

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