New Modeling of SSSC and UPFC for Power Flow Study and Reduce Power Losses

C. Anitha, P. Arul

Abstract: ***Reactive power control is the basic requirement for maintaining the voltage stability of the interconnected power system. The transmission line losses are due to energy dissipated in the conductors, equipment used for transmission Line, Transformer, sub- transmission Line and distribution Line and magnetic losses in transformers. A transmission line loss includes conductor loss, radiation loss, dielectric heating loss, coupling and corona.. The placement of FACTS can help to reduce flows in heavily loaded lines, reduce power system loss and improve the system stability. Static Synchronous series compensator (SSSC) can increase or decrease the overall reactive voltage drop across the line and thereby controlling the transmitted electric power. Unified Power Flow Controller (UPFC) is a shunt and series device connected with the transmission line to improve voltage stability, and reduce the transmission losses. In this work, the Newton Raphson iterative algorithm was adopted due to its ability to converge after a few iterations. Simulation of power flow solutions without and with SSSC was done using MATLAB based program. The model is validated on IEEE 30-bus system.***

Index Terms: FACTS, Power flow, SSSC (Static Synchronous series compensator), Transmission system, UPFC (Unified Power Flow Controller), Voltage stability.

I. INTRODUCTION

The transmission line losses are due to energy dissipated in the conductors, equipment used for transmission Line, Transformer, sub- transmission Line and distribution Line and magnetic losses in transformers. The major amount of losses in a power system is in primary and secondary distribution lines. Main Reasons for Losses are Lengthy Distribution lines, Inadequate Size of Conductors of Distribution lines, Installation of Distribution transformers away from load centers', Low Power Factor of Primary and secondary distribution system .A transmission line loss includes conductor loss, radiation loss, dielectric heating loss, coupling and corona. If a transmission line has a finite resistance there is an un-avoidable power loss. A difference of potential between two conductors of a metallic transmission line causes dielectric heating. Coupling loss occurs whenever a connection is made to or from transmission line or when two sections of transmission line are connected together. In Present scenario the applications of the power electronics devices in power systems are very much augmented. The FACTS devices are introduced in the power system transmission for the reduction of the transmission line losses, Increases Power System Stability and also to increase the transfer capability.

Alternating-current transmission systems incorporating power electronic–based and other static controllers to enhance controllability and increase power transfer capability. In general FACTS controller can be dividing into main four categories [1]: Series controller: TCSC, SSSC, TSSC, TCSR, TSSR, and IPFC. Shunt controller: STATCOM, STATCOM BESS, SVC, SVG or SVA, SVS, TCR, TSC, TSR, TCBR, SMES, BESS, SSG. Series-Series controller: UPFC. Series-Shunt controller: UPFC, TCPST, IPC. The Static Synchronous Series compensator (SSSC) which can be used to generate and insert a series voltage and it can be regulated to change the impedance of the transmission line. In this way, the power flow of transmission line, where the SSSC is connected is controlled .The SSSC can directly control the current, and indirectly the power flowing through the line by controlling the reactive power exchange between the SSSC and the AC system. A SSSC is an electrical device for providing fast-acting reactive power compensation on high voltage transmission networks and it can contribute to improve the voltages profile in the transient state. The main advantage of this controller is that it does not significantly affect the impedance of the transmission system and therefore, there is no danger of having resonance problem. The UPFC is a combination of an SSC and an SSSC, sharing a common dc link. The UPFC can control both the active and reactive power flow in the line. It can also provide independently controllable shunt reactive compensation. By using UPFC, it can control the power flow in transmission lines without rescheduling the generation trend or topological changes in network in a way not to violet the thermal limits, but to increase the loadability of the system, reduce the system losses, improve the stability of the network.

II. OPERATING PRINCIPLE OF FACTS DEVICES

A. Operating Principle of SSSC

The SSSC, sometimes called the S3C, is a series-connected synchronous-voltage source that can vary the effective impedance of a transmission line by injecting a voltage containing an appropriate phase angle in relation to the line current [2]. A series capacitor compensates the transmission-line inductance by presenting a lagging quadrature voltage with respect to the transmission-line current [3]. This voltage acts in opposition to the leading quadrature voltage appearing across the transmission-line inductance, which has a net effect of reducing the line inductance. Similar is the

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operation of an SSSC that also injects a quadrature voltage, *VC* in proportion to the line current but is lagging in phase:

$$V_C = -kX_C I_C$$

Where $V_C \rightarrow$ the injected compensating voltage
$I_C \rightarrow$ the line current
$XC \rightarrow$ the series reactance of the transmission Line
$K \rightarrow$ the degree of series compensation

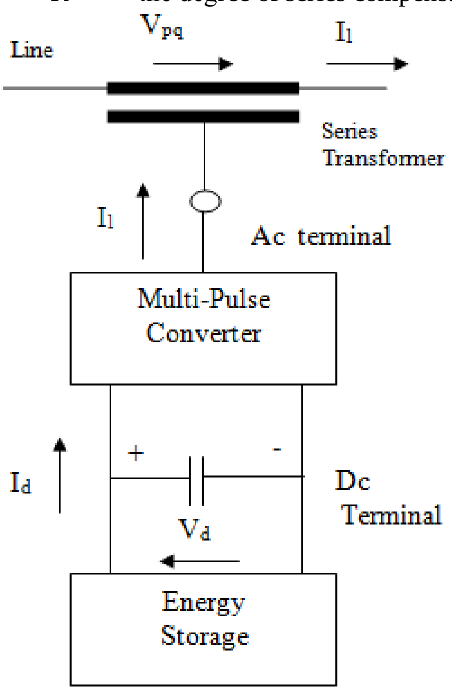

Fig.1. Generalized series-connected synchronous-voltage source employing a multi-pulse converter with an energy-storage device

B. Operating Principle of UPFC

The UPFC is the most versatile FACTS controller developed so far, with all encompassing capabilities of voltage regulation, series compensation, and phase shifting. It can independently and very rapidly control both real- and reactive power flows in a transmission line [3] [4]. It is configured as shown in Fig.2 and comprises two VSCs coupled through a common dc terminal. One VSC—converter 1—is connected in shunt with the line through a coupling transformer; the other VSC—converter 2—is inserted in series with the transmission line through an interface transformer. The dc voltage for both converters is provided by a common capacitor bank. The series converter is controlled to inject a voltage phasor, Vpq, in series with the line, which can be varied from 0 to Vpq max. Moreover, the phase angle of Vpq can be independently varied from 0^0 to 360^0. In this process, the series converter exchanges both real and reactive power with the transmission line. Although the reactive power is internally generated/ absorbed by the series converter, the
real-power generation/ absorption is made feasible by the dc-energy–storage device—that is, the capacitor.

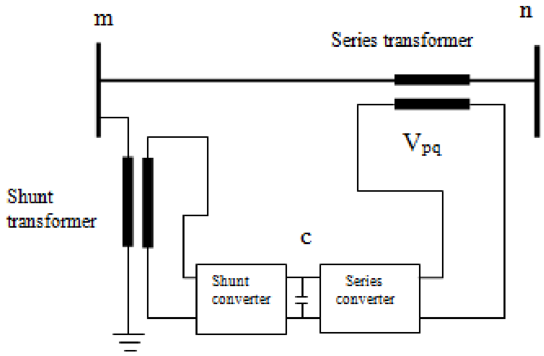

Fig.2. Configuration of UPFC

The shunt-connected converter 1 is used mainly to supply the real-power demand of converter 2, which it derives from the transmission line itself. The shunt converter maintains constant voltage of the dc bus. Thus the net real power drawn from the ac system is equal to the losses of the two converters and their coupling transformers. In addition, the shunt converter functions like a STATCOM and independently regulate the terminal voltage of the interconnected bus by generating/ absorbing a requisite amount of reactive power.

III. MODELING OF FACTS DEVICES

A. Modelling of SSSC

According to the equivalent circuit, suppose $V_{se} = V_{se}\angle\theta_{se}$. The voltage of bus m is taken as the reference vector, $V_m = V_m\angle\theta_m$ [5]. The voltage source, Vse, is the series injected voltage, and it is controllable in both its magnitudes and phase angles and is also the control variable of the SSSC. $V_n = V_n\angle\theta_n$ is the voltage at bus n.

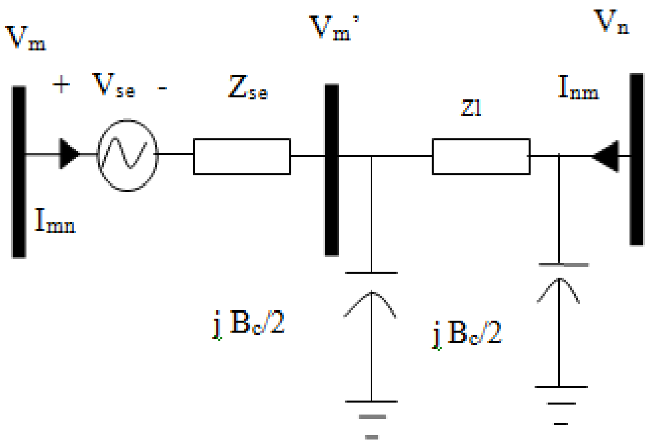

Fig.3. Equivalent circuit of the embedded SSSC using voltage source

$Z_{se} = R_{se} + jX_{se}$ is the impedance of the series coupling transformer [6]. B_c and $Z_l = R_l + jX_l$ are the charging susceptance and the impedance of the line respectively. From Fig.3,

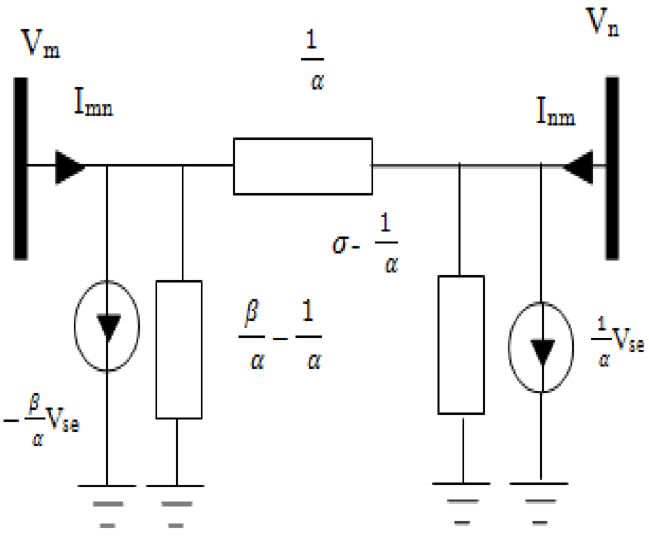

Fig.4. Representation of the SSSC using current source.

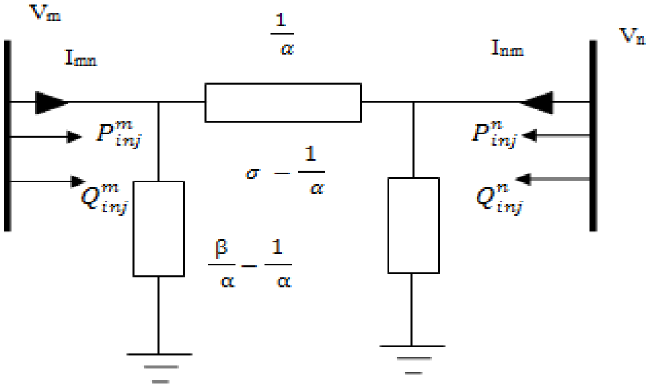

Fig.5. The power injection π-model of embedded SSSC.

$$\alpha = j\frac{B_C}{2} Z_{se} Z_l + Z_l + Z_{se} \qquad (1)$$

$$\beta = \left(1 + j\frac{B_C}{2} Z_l\right) \qquad (2)$$

$$\alpha = Z_{se}\beta + Z_l \qquad (3)$$

From Fig.4, Considering the following vectors:

$$V_{se} = V_{se}\angle\theta_{se}$$
$$V_m = V_m\angle\theta_m$$
$$V_n = V_n\angle\theta_n$$
$$\beta = \beta\angle\theta_\beta$$

From Fig.5 the real and reactive power injections at the sending and receiving bus: P^m_{inj}, Q^m_{inj} , P^n_{inj}, Q^n_{inj} can be calculated as follows:

$$S^{m*}_{inj} = V^*_m\left(-\frac{\beta}{\alpha} V_{se}\right) = -AV_m V_{se}\angle\left(\theta_{se} - \theta_m + \theta_A\right)$$

$$\frac{\beta}{\alpha} = A = A\angle\theta_A \qquad (4)$$

$$P^m_{inj} = -AV_m V_{se}\cos\left(\theta_{se} - \theta_m + \theta_A\right) \qquad (5)$$

$$Q^m_{inj} = -AV_m V_{se}\sin\left(\theta_{se} - \theta_m + \theta_A\right) \qquad (6)$$

$$S^{n*}_{inj} = V^*_n\left(\frac{1}{\alpha} V_{se}\right) = \frac{AV_n V_{se}}{\beta}\angle\left(\theta_{se} - \theta_n + \theta_A - \theta_\beta\right)$$

$$P^n_{inj} = \frac{AV_n V_{se}}{\beta}\cos\left(\theta_{se} - \theta_n + \theta_A - \theta_\beta\right)$$

(7)

$$Q^n_{inj} = \frac{AV_n V_{se}}{\beta}\sin\left(\theta_{se} - \theta_n + \theta_A - \theta_\beta\right) \qquad (8)$$

The admittance Y^u_m and Y^u_n can be written by [9],

$$Y^u_m = \frac{P^u_{mi} - jQ^u_{mi}}{\left(V^u_m\right)^2} \qquad (9)$$

$$Y^u_n = \frac{P^u_{ni} - jQ^u_{ni}}{\left(V^u_n\right)^2}$$

(10)

B. Modelling of UPFC

To obtain UPFC injection model, it is first essential to consider the series voltage source, Figure 6.

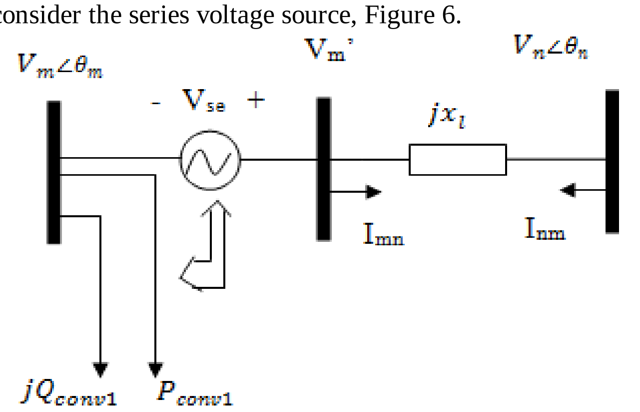

Fig. 6. The UPFC electric circuit [7]

The reactance x_l describes a reactance seen from terminals of the series transformer and is equal to (in p.u. base on system voltage and base power) [8]:

$$x_l = x_k r^2_{\max}\left(\frac{S_B}{S_l}\right)$$

$$b_s = -\frac{1}{x_l}$$

That

x_k: The series transformer reactance.

r_{max}: The maximum value of injected voltage amplitude (p.u.).

S_B: The system base power.

$S_l = S_{conv\,2}$: The nominal rating power of the series converter.

Voltage source connected in series is modeled with an ideal series voltage (Vs) the amplitude and phase is controlled.

$$0 \le r \le r^2_{\max}$$

$$V_s = rV_m e^{j\gamma}$$

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$0 \le \gamma \le 2\pi$

That

r: The value of injected voltage amplitude (p.u.).

γ: The value of injected voltage angle.

The equations of the UPFC injection model (Fig.7.) are given as [4], [8]:

$$P_{lm} = -r b_l V_m V_n \sin(\theta_m - \theta_n + \gamma) \quad (11)$$

$$Q_{lm} = -r b_l V_m^2 \cos(\gamma) + Q_{conv1} \quad (12)$$

$$P_{ln} = r b_l V_m V_n \sin(\theta_m - \theta_n + \gamma) \quad (13)$$

$$Q_{ln} = r b_l V_m V_n \cos(\theta_m - \theta_n + \gamma) \quad (14)$$

$$P_{m1} = -r b_l V_m V_n \sin(\theta_m - \theta_n + \gamma) - b_l V_m V_n \sin(\theta_m - \theta_n)$$

$$Q_{m1} = -r b_l V_m^2 \cos(\gamma) + Q_{conv1} - b_l V_m^2 + b_l V_m V_n \sin(\theta_m - \theta_n)$$

$$P_{n1} = r b_l V_m V_n \sin(\theta_m - \theta_n + \gamma) + b_l V_m V_n \sin(\theta_m - \theta_n)$$

$$Q_{n1} = r b_l V_m V_n \cos(\theta_m - \theta_n + \gamma) - b_l V_n^2 + b_l V_m V_n \cos(\theta_m - \theta_n)$$

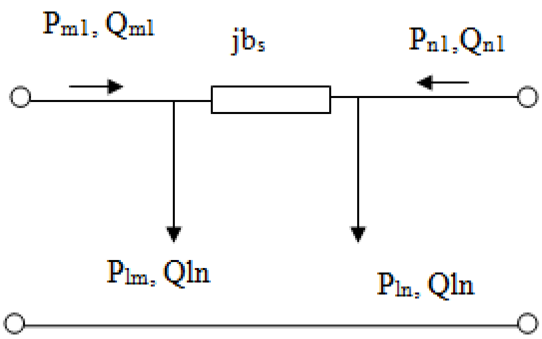

Fig.7. Injection model of the UPFC [13].

The admittance Y_m^u and Y_n^u can be written by [9],

$$Y_m^u = \frac{P_{mi}^u - jQ_{mi}^u}{(V_m^u)^2}$$

$$Y_n^u = \frac{P_{ni}^u - jQ_{ni}^u}{(V_n^u)^2}$$

IV. RESULT

MATLAB based program was developed for the load flow analysis of IEEE-30 bus systems to reduce total power losses in a transmission line with and without FACTS devices.

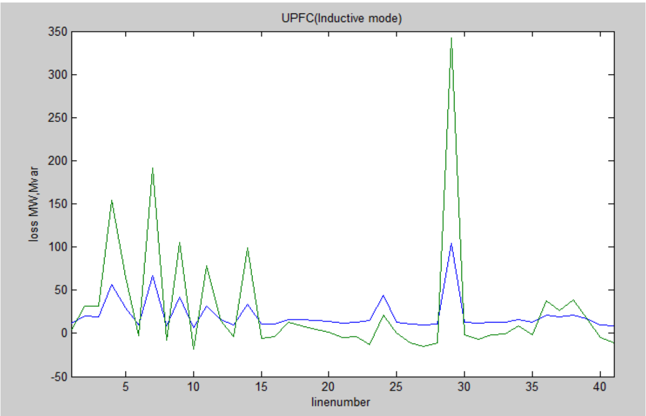

Fig.7.The effect of UPFC in Inductive mode

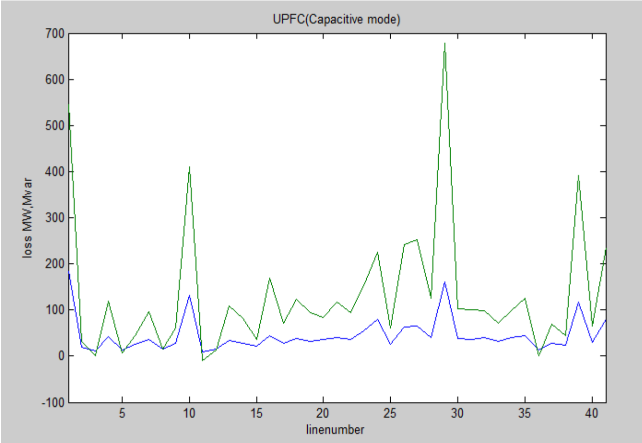

Fig.8.The effect of UPFC in Capacitive mode

The effect of UPFC in Inductive and Capacitive mode is shown in Fig.7 and Fig.8. With UPFC the total power losses in a transmission line will be reduced.

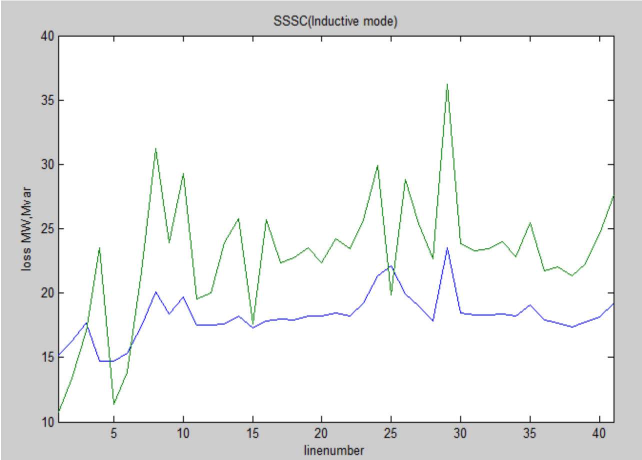

Fig.9.The effect of SSSC in Inductive mode

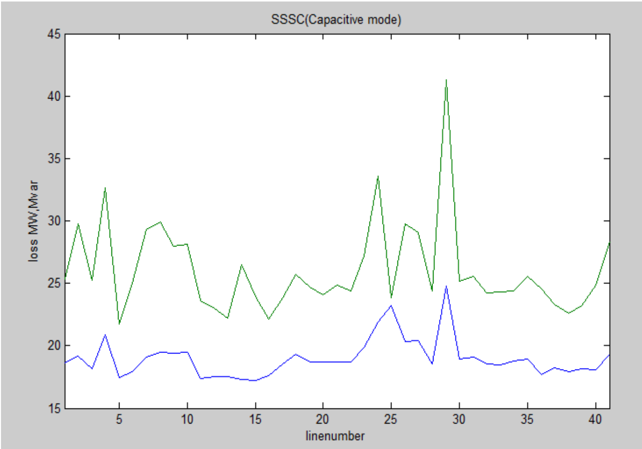

Fig.10.The effect of SSSC in Capacitive mode

It can be seen from Fig.9. and Fig.10. The SSSC device will reduce the losses and improve the efficiency of transmission line.

V. CONCLUSION

In this paper, a power flow analysis was carried out using MATLAB.FACTS devices improves the power transfer capability ,control the power flow and reduces the losses in the power system. The effect of SSSC and UPFC was demonstrated. With the presence of UPFC the total power losses will be reduced . From the result with the presence of SSSC the total power loss is less compared with UPFC.

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