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# Ideal Implementation of Facts Device in Shunt for Series Compensated Transmission Line

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## Abstract:

**This paper deals with the ideal location of Unified Power Flow Controllers (UPFCs) and parameters of UPFCs in electrical power systems. The UPFC is one of the best promising FACTS devices in terms of its ability to control power system quantities. Shunt FACTS devices are used for controlling transmission voltage, power flow, reducing reactive losses, and damping of power system oscillations for high power transfer levels. In this paper the ideal location of a shunt FACT device is examined for an actual line model of a transmission line having series compensation at the center. As one of the most promising FACTS devices in terms of its stability to control power system quantities, UPFC Effect of change in degree of series compensation on the ideal implementation of the shunt FACTS device to get the highest possible benefit of maximum power transfer and system stability is studied. The results obtained shown that ideal placement of the shunt FACTS device varies linearly from the center point of the transmission line towards the center with the increase in the level of series compensation.**

## I. Introduction:

Flexible ac transmission system, called FACTS, got in the recent years a well known term for higher controllability in a power system by means of power electronic devices. Several FACTS devices have been introduced for various applications worldwide. A number of new types of devices are in the stage of being introduced in practice. The basic applications of FACTS devices are power flow control, voltage control, reactive power compensation, stability improvement, and the main thing is increase of transmission capability.

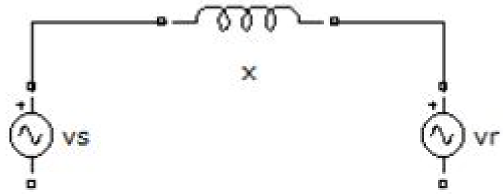
FACTS devices are connected in four different ways to the transmission network. These devices are named, based on the type of connected to the line. Those are shunt controllers, series controllers, combined series-series controllers, combined series-shunt controllers. For example, the static VAR compensator (SVC) and static synchronous compensator (STATCOM) are connected in shunt; static synchronous series compensator (SSSC) and thyristor controlled series capacitor (TCSC) are connected in series; thyristor controlled phase shifting transformer (TCPST) and unified power flow controller (UPFC) are connected in series and shunt compensation.

When the FACTS device is connected in series it acts as a controllable voltage source as well as a series inductance is formed. And when a large current flows causes a large voltage drop. To compensate these losses series capacitors are connected. In shunt compensation, the FACTS device is connected in shunt it works as a controllable current source. The term and definitions are explained in the references clearly [1]-[5].the FACTS technology is not only a single high power controller, but rather a connection of controllers, which can be applied individually or in coordination. The pressure associated with economical and environmental constraints has forced the power utilities to meet the future demand can be achieved by using the FACTS technology. In this paper we are mainly discussing about shunt compensation by using FACTS device. There are two types of shunt compensations at present.

**Shunt capacitive compensation**:

This method is used to improve the power factor of the system. Generally for inductive load the current lags the voltage so that the power is lagging power factor. To compensate the lagging power factor a shunt capacitor is used to draw the leading the current than the voltage source. The net result is improvement in the power factor

Series inductive compensation: This method is used when there is low load or no load at the receiving end. Due to very low or no load, very low current flows through the transmission line .shunt capacitance in the transmission line causes Ferranti Effect. Such that the receiving voltage is doubles than the sending end voltage. To compensate these effect a shunt inductors are connected across the transmission line.



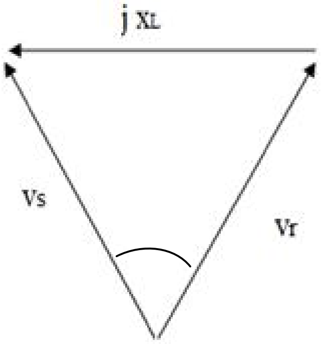


**Fig**1 .Series compensation

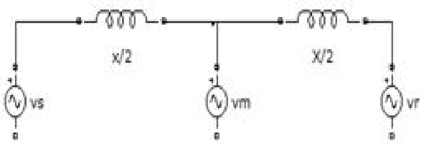
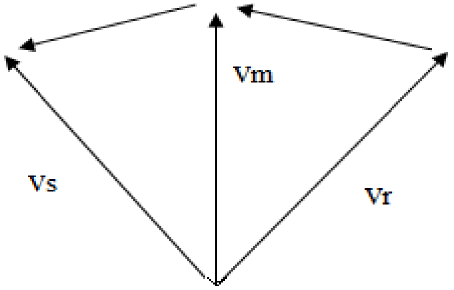


**Fig2.** Shunt compensation

In power systems, the best location for the placement of the FACTS device is very important. The false placement of the device leads to less performance and even be counterproductive. There optimal placement examining should be necessary. The paper deals with the optimal placement of shunt connected facts device in a series compensated long transmission line to get the maximum possible benefit for maximum power transfer and the system stability. It is observed that the optimal location of a shunt FACT device deviates from the centre of the line towards the generator side with the increase in the degree of series compensation. To obtain the maximum power transfer capability and compensation efficiency for the selected rating of the shunt FACTS device a series capacitor is placed at the centre.



## II. TRANSMISSION LINE MODEL:

In this study, lets us consider a transmission line with distributed parameters. The line can be modeled by a 2-port, 4-terminal networks as shown in the figure 3. The figure represents the single line diagram of the transmission line. The below equations shows the relationship between the sending end(SE) and the receiving end(RE) of the transmission line.

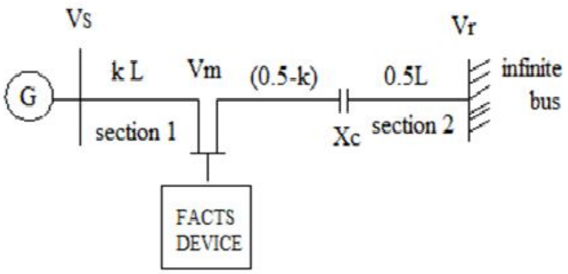


**Fig 3.**2-port, 4-terminal model of a transmission line

$$V_S = AV_R + BI_R \qquad (1)$$

$$I_S = CV_R + DI_R \qquad (2)$$

The ABCD constants of a line of length l. having a series impedance of z $\Omega$/km and shunt admittance of y s/km are given by

A=D=$\cosh(\lambda l)$ $B = Z_C \sinh(\lambda l)$

$$c = \sinh(\lambda l)\,/\,z_c \qquad (3)$$

Where $\gamma = \sqrt{zy}$ and $z_c = \sqrt{z/y}$

The active and reactive power of sending end and receiving end of a transmission line can be written as

$$P_S = C_1\cos(\beta - \alpha) - C_2\cos(\beta - \delta) \qquad (4)$$

$$Q_S = C_1\sin(\beta - \alpha) - C_2\sin(\beta - \delta) \qquad (5)$$

$$P_R = C_2\cos(\beta - \delta) - C_3\cos(\beta - \alpha) \qquad (6)$$

$$P_R = C_2\sin(\beta - \delta) - C_3\cos(\beta - \alpha) \qquad (7)$$

Where $C_1 = AV_S^2/B$

$$C_2 = V_S V_R / B$$

$$C_3 = AV_R^2/B$$

The RE power reaches the maximum value when the angle δ becomes β. However, the SE power becomes maximum at δ = (π-β). In this study, a 345 kV single circuit transmission line (450 km in length), is considered. It is assumed that each phase of line has a bundle of 2 conductors.

## III. SERIES COMPENSATED TRANSMISSION LINE WITH SHUNT FACTS DEVICES

Consider that the line is transferring power from a large generating station to an infinite bus installed with series capacitor at center and a shunt FACT device at point 'm' as shown in Figure.4. The Parameter k is used to locate the fraction of the line length at which FACTS device is connected. The shunt FACTS device can be a SVC or STATCOM and is usually connected to the line through a step-down transformer as shown in Figures 6 and 7.. The transmission line is divided into 2 sections (1 &2), and section 2 is further divided into 2 subsections of length [(0.5-k) & half-line length]. Each section is represented by a separate 2-port, 4-terminal network with its own ABCD constants considering the actual line model.

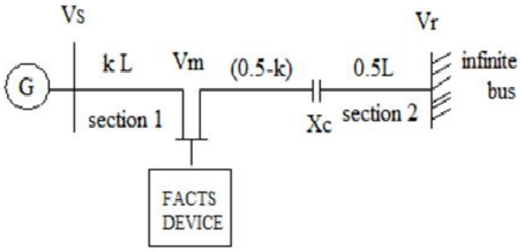


**Fig.4.** Series compensated transmission line with a shunt FACT device.

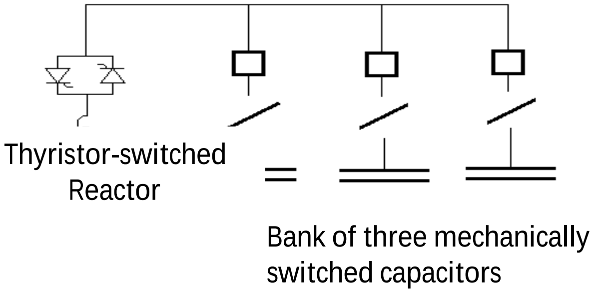


**Fig.5.** Schematic diagram of a SVC.

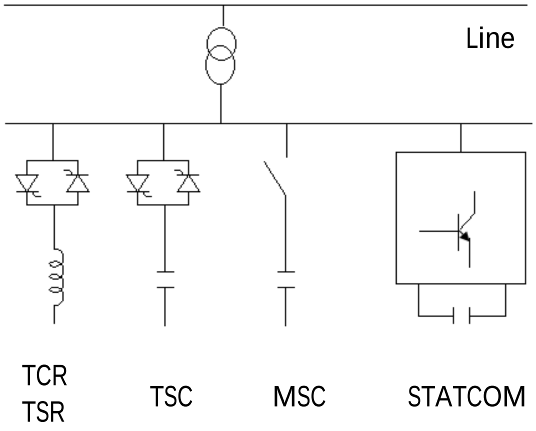


**Fig.6.** Examples of FACTS for shunt compensation

It is assumed that the rating of the shunt FACTS device is large enough to supply the reactive power required to maintain a constant voltage magnitude at bus m and the device does not absorb or supply any active power.

## IV. MAXIMUM POWER TRANSFER CAPABILITY

For a simplified model, when there is no FACTS device connected to the line, maximum power transfer through the line is given by:

$$P=P_m \operatorname{Sin}\delta \qquad (8)$$

Many researchers estimated that the ideal location of shunt FACTS device for a simplified model is at K= 0.5 when there is no series compensation in the line. For such cases maximum power transmission capability ($P^m$) and maximum transmission angle ($\delta^m$) become double. However, for an actual line model power flow is given by Eqs.(4) and (6) instead of Eq.(9) and the above results of this paper is to find the maximum power and corresponding ideal position of shunt FACTS device for different series compensation levels (%S) located at the center of the line. A sophisticated computer program was developed to determine the various characteristics of the system of Figure 4 using an actual model of the line sections.

The constant of the same RE power of section (1) and SE power of sections (2) ($P_{R1}$ = $P_{S2)}$ is incorporated into the problem. In all cases, $V_s = V_R = V_M = 1.0$ p.u. unless specified. The maximum power $P^m$ and corresponding angle $\delta^m$ are prior determined for various values of location (K). Figures 7,8,9 show the variation in maximum RE power ($P_R^m$), maximum sending end power, and transmission angle ($\delta^m$) at the maximum sending end power, respectively, against (K) for different series compensation levels (%S). It can be noticed from Figures 7 & 8 that $P_S^m > P_R^m$ for any series compensation level (%S) because of the loss in the line. , From Figure 7 it can be noticed that when %S = 0 the value of $P_S^m$ increases as the value of (K) is increased from zero and reaches the maximum value of 18.5 p.u. at K = 0.45 (but not at K = 0.5). Slope of the $P_S^m$ curve suddenly changes at K = 0.45 and the value of $P_S^m$ decreases when K >0.45. A similar pattern for $P_R^m$ can be observed from Figure 7 when (%S =0). When series compensation in the line is considered, we observe that the ideal location of the shunt FACTS device will change and shifts towards the generator side. As seen from Figure 7, when %S = 15 then $P_S^m$ increases from 12.5 p.u. (at K = 0) into its maximum value 22 p.u. (at K = 0.375).

When K is further increased then $P_S^m$ decreases. It means that, for maximum power transfer capability, the ideal location of the shunt device will change when series compensation level changes. When %S =30, the ideal location further shifts to the generator side and $P_S^m$ increases from 15.2 p.u. (at K = 0) to its maximum value 26.8 p.u. (at K = 0) to its maximum value 26.8 p.u. (at K = 0.3).

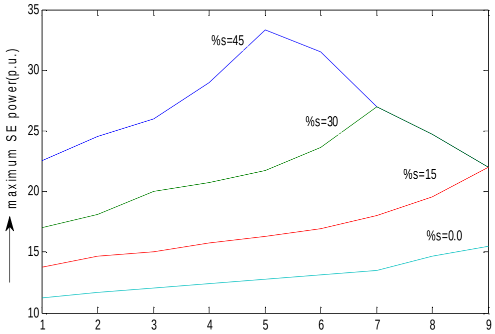


**Fig.7** Variation in maximum SE power for diff. value of %S.

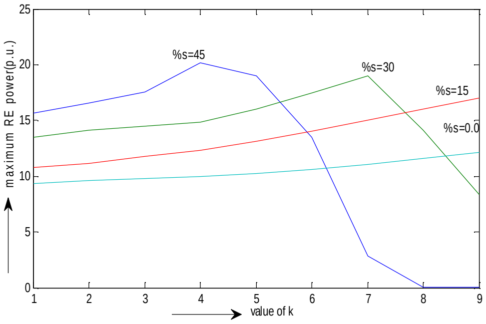


**Fig.8.** Variation in maximum RE power for diff. value of %S.

Similarly, when %S = 45, we obtain the ideal location of the shunt device at K = 0.225. A similar pattern for $P_R^m$ can be observed from Figure 8 for different series compensation levels. In Figure 9, it can be observed that in the absence of series compensation (%S= 0) the angle at the maximum SE power increases from $95.8^0$ at K = 0 to its maximum value $171.1^0$ at K = 0.45. When %S = 45 then $\delta^m$

increases when K is increased and reaches its maximum value 188$^{o}$ for K = 0.225. As the degree of series compensation level (%S) increases, the stability increases and the ideal location of the shunt FACTS device changes.

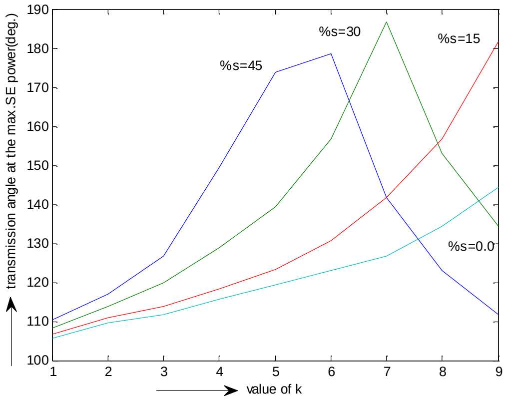


**Fig.9.** Variation in transmission angle at the max. SE power for diff. %S.

## V. IDEAL IMPLEMENTATION OF SHUNT FACTS DEVICES

Figure 8 shows the variation of the maximum SE power of section 1 (PR1m) and the maximum SE power of section 2 (PS2m) against the value of K for different series compensation levels (%S). It can be seen in Figure 8 that for an uncompensated line then maximum power curves cross at K = 0.45 and the crossing point is the transition point.

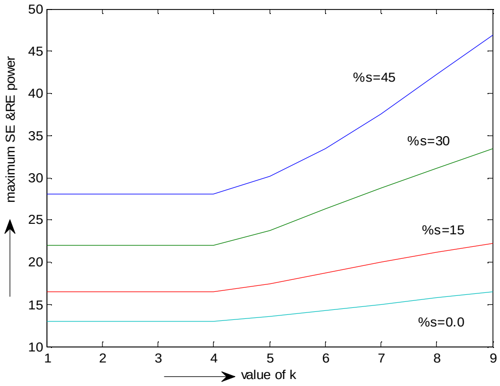


**Fig.10.** Variation in the maximum RE power of section-1 and SE power of section-2 against k for diff. value of %S.

Thus, to get the highest benefit in terms of maximum power transfer capability and system stability, the shunt FACTS device must be placed at K= 0.45, which is slightly away from center. When the series compensation level is taken into account then for %S =15 maximum power curves cross at K=0.375 and maximum power transfer capabilities increases. It means that when series compensation level (%S) is increased then the ideal location of the shunt device shifts towards the generator side. Similarly when %S =30 then the ideal location is at K = 0.3 and for %S=45 it is at K=0.25. Figure 9 shows the variation in optimal away from center location of the shunt FACTS device against the degree of series compensation level (%S) for the given R/X ratio of the line. It can be observed in Figure 9 that the optimal away from center location is 10% for the uncompensated line. When series compensation level (%S) is increased than optimal away from center location increases linearly and reaches its highest value 55% for %S =45. Operation of the UPFC demands proper power rating of the series and shunt branches. The rating should enable the UPFC carrying out pre-determined power flow objective.

## VI. CONCLUSION

This paper examines the effect of series compensation on the ideal location of a shunt FACTS device to get the greatest possible advantage of maximum power transfer and system stability. Various results shown in this paper were found for an actual line model of a series compensated 345 kv, 450 km line. It has been found that the ideal location of the shunt FACTS device is not fixed as reported by many researchers in the case of uncompensated lines but it changes with the change in degree of series compensation. The deviation in the ideal location of the shunt FACT device from the center point of line depends upon the degree of series compensation and it increases almost linearly from the center point of the transmission line towards the generator side as the degree of series compensation (%S) is increased. Both the power transfer capability and stability of the system can be improved much more if the shunt FACTS device is placed at the new ideal location instead of at the mid-point of the line.

The impact of SVC and STATCOM controllers in enabling power system stability has been examined. Though both the devices can provide extra damping to the system, it has been analyzed that STATCOM is very effective in improving system performance in situations where system voltages are very much depressed. Also, STATCOM control is superior to that of SVC because if its fast response time.

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