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A REVIEW ON POWER FLOW AND CONTROL ANALYSIS OF FACTS DEVICES

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ABSTRACT

In this paper, the modeling of Thyristor Controlled Series Compensator and modeling of Thyristor Controlled Phase Angle Regulator 'TCPAR' for power flow studies and the role of that modeling in the study of Flexible Alternating Current Transmission Systems (FACTS) for power flow control are discussed. FACTS devices, especially series FACTS like TCSC and TCPAR are considered one such technology which can reduce the transmission congestion and leads to better using of existing grid infrastructure. This paper presents the comparative analysis of TCSC & TCPAR. In order to investigate the impact of TCPAR on power systems effectively, it is essential to formulate a correct and appropriate model for it. The TCPAR, thus, makes it possible to increase or decrease the power forwarded in the line where it is inserted in a considerable way, which makes it an ideal tool. The TCSC, in injection model injects a certain amount of active and reactive power to a node where as TCPAR does not inject any active power, it offers a good solution with a less consumption.

Keywords: Controller, FACTS, Power Flow Control, TCPAR, TCSC, Voltage Regulation

I. INTRODUCTION

FACTS technology opens up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. The possibilities that current through a line can be controlled at reasonable cost enables a large potential of increasing the capacity of existing lines with larger conductors and use of one of the FACTS controllers to enable power to flow through such lines under normal and contingency conditions. Often, ac transmission systems are thought of as being "inflexible". Power flow in ac networks simply follows Ohm's law and ordinarily cannot be made to flow along specific desired paths [1][2]. As a result, ac network suffer from "loop flows". A fundamental notion behind FACTS is that it is possible to continuously vary the apparent impedance of specific transmission lines so as to force power to flow along a "desired path". This is the brand new concept for many system planners. 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. These constraints cannot be overcome, while maintaining the required system reliabilities, by mechanical means without lowering the usable transmission capacity. The 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 interrelated system parameters mentioned above [4]. A well chosen FACTS controller can overcome the specific limitation of a designated transmission line or a corridor. A planner could foresee progressive scenario of mechanical switching means and enabling FACTS controllers such that the transmission lines will involve a combination of mechanical and FACTS controllers to achieve the objective in an appropriate, staged investment scenario.

II. FACTS DEVISES

In recent years, the fast progress in the field of power Electronics and microelectronics has resulted into a new opportunity for more flexible operation of power system. The FACTS devices have made the present transmission and distribution of electricity more reliable, more controllable and more efficient [3].

The types of FACTS devices are

2.1 Static Var Compensators (SVCs)

2.2 Thruster Controlled Series Compensators (TCSC)

2.3 Static Synchronous Compensators (STATCOMs)

2.4 Unified Power Flow Compensators (UPFC)

2.5 Thyrisyor Controlled Phase Angle Regulator (TCPAR)

2.1 Static Var Compensator (SVC)

A 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 [4]. A static VAR compensator is an electrical device for providing fast –acting reactive power on high voltage transmission network. The term static refers to the fact that SVC has no moving part, other than circuit breakers which do not move under normal conditions. It is an automated impedance matching device, designed to bring the system closer to unity power factor. If the system's reactive load is capacitive, the SVC will use reactor to consume VAR from system and lowering the system voltage. Under inductive load, capacitor banks are switched in and generate VAR providing higher system voltage. This is the most important FACTS device, has been used for a number of years to improve transmission lines economics by resolving dynamic voltage problems. SVCs are used to dampen power swings, improve transient's stability and reduce the system losses by optimized reactive power control. But it requires large inductive and capacitive components to provide inductive or capacitive reactive power to high voltage transmission system.

2.2 Thyristor Controlled Series Compensators (TCSC)

It is an extension of conventional series capacitors method by adding thyristor controlled reactor. it is placed in parallel with a series capacitor [5]. The combination of thyristor controlled reactor and capacitor allow the capacitive reactance to be smoothly controlled over a wide range. It is an effective and economical means of solving problems of transient stability, dynamic stability, steady state stability and voltage stability in transmission lines. A TCSC is series controlled capacitive reactances that can continuous control power in ac transmission line. So TCSC increases the energy transfer, dampening of power oscillation and control line power flow.

2.3 Static Synchronous Compensators (STATCOM)

A static synchronous compensator is a regulating device used on alternating current transmission lines. Static synchronous compensator is a custom power device based on a voltage –source converter and can act as either a source or sink of reactive ac power to an electricity network [6]. It can provide ac active power if connected to a source of power. STATCOM is installed to support networks that have poor power factor and poor voltage regulation. Compared with SVCs, STATCOMs do not require big inductor or capacitor to provide inductive or capacitive reactive power to high voltage transmission system. Thus it requires smaller land requirements and provides higher reactive output at low system voltage.

2.4 Unified Power Flow Compensator (UPFC)

Unified power flow compensator is the most promising device in the FACTS category. It is a combination of static synchronous compensator (STATCOM) and a static series compensator (SSSC) which is coupled via a common dc link to allow bidirectional flow of real power between series output terminals of SSSC and shunt output terminals of STATCOM and are controlled to provide real and reactive series line compensation without an external electric energy source. The UPFC is a device which can control simultaneously / independently all the three parameters of line power flow that is line impedance, voltage and phase angle between two buses [7]. The UPFC performs this through the control of in phase voltage, quadrature voltage and shunt compensation. It is the most versatile and complex power electronic device that is used for control and optimization of power flow in transmission lines. The features of STATCOM and static synchronous series compensators are combined in this UPFC. It offers major advantages for static and dynamic operation of transmission lines. UPFC is able to control, simultaneously or selectively all the parameters affecting power flow in transmission lines.

2.5 Thyristor Controlled Phase Angle Regulator (TCPAR)

TCPAR is also a thyristor based compensator which makes it possible to increase or decrease the power forwarded in the line where it is inserted in a considerable way [5]. TCPAR does not inject any active power in the network but it can charge some lines and discharge other to alter the powers of transit through the network. The disadvantage of this device is the voltage drop that causes in the network although it is not significant. Even then SVC is inserted in the network to compensate the voltage drop.

III. COMPARATIVE ANALYSIS OF TCSC AND TCPAR

This analysis is performed to know the comparative performance of the TCSC & TCPAR. In order to investigate the impact of TCPAR on power system, it is essential to formulate a correct and appropriate model for it. Following is the modeling of each

3.1 Modeling of TCSC

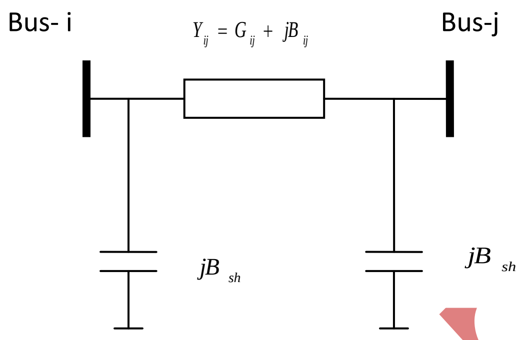


Figure 1(a). Model of Transmission Line

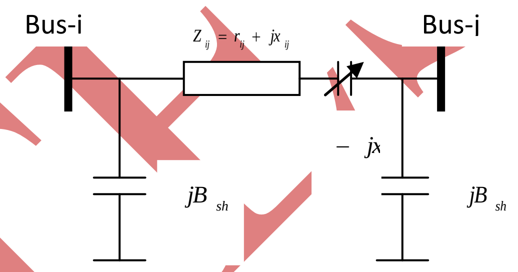


Figure 1(b). Model of TCSC

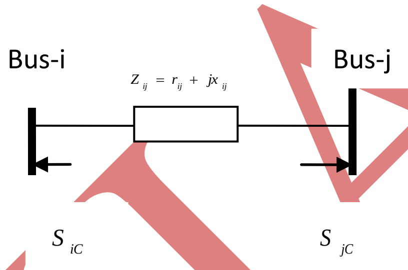


Figure 1(C). Injection Model of TCSC

$$P_{ij} = V_i^2 G_{ij} - V_i V_j [G_{ij} \cos(\delta_{ij}) + B_{ij} \sin(\delta_{ij})] \tag{1}$$

$$Q_{ij} = -V_i^2 (B_{ij} + B_{sh}) - V_i V_j [G_{ij} \sin(\delta_{ij}) - B_{ij} \cos(\delta_{ij})] \tag{2}$$

$$P_{ji} = V_j^2 G_{ij} - V_i V_j [G_{ij} \cos(\delta_{ij}) - B_{ij} \sin(\delta_{ij})] \tag{3}$$

$$Q_{ji} = -V_j^2 (B_{ij} + B_{sh}) + V_i V_j (G_{ij} \sin \delta_{ij} + B_{ij} \cos \delta_{ij}) \tag{4}$$

$$P_{ij}^{C} = V_i^2 G_{ij}^{'} - V_i V_j (G_{ij}^{'} \cos \delta_{ij} + B_{ij}^{'} \sin \delta_{ij}) \tag{5}$$

$$Q_{ij}^{C} = -V_i^2 (B_{ij}^{'} + B_{sh}) - V_i V_j (G_{ij}^{'} \sin \delta_{ij} - B_{ij}^{'} \cos \delta_{ij} \quad (6)$$

$$P_{ji}^{C} = V_j^2 G_{ij}^{'} - V_i V_j (G_{ij}^{'} \cos \delta_{ij} - B_{ij}^{'} \sin \delta_{ij}) \quad (7)$$

$$Q_{ji}^{C} = -V_j^2 (B_{ij}^{'} + B_{sh}) + V_i V_j (G_{ij}^{'} \sin \delta_{ij} + B_{ij}^{'} \cos \delta_{ij}) \quad (8)$$

The active and reactive power losses in the line

$$P_L = P_{ij} + P_{ji} = G_{ij}^{'} (V_i^2 + V_j^2) - 2 V_i V_j G_{ij}^{'} \cos \delta_{ij} \quad (9)$$

$$Q_L = Q_{ij} + Q_{ji} = -(V_i^2 + V_j^2)(B_{ij}^{'} + B_{sh}) + 2 V_i V_j B_{ij}^{'} \cos \delta_{ij} \quad (10)$$

Where

$$G_{ij}^{'} = \frac{r_{ij}}{r_{ij}^2 + (x_{ij} - x_C)^2} \quad \& \quad B_{ij}^{'} = \frac{-(x_{ij} - x_C)}{r_{ij}^2 + (x_{ij} - x_C)^2}$$

3.2 Modeling of TCPAR

For a TCPAR introduced at the bus m of a transmission line as shown in figure 1, the equation which defines the relationship between the currents injected into the line and the voltages [9] at buses *t* and *k* is:

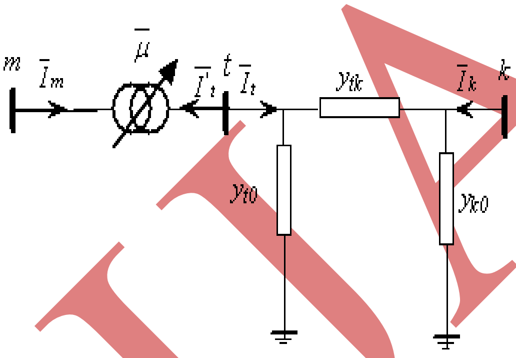


Figure 2. TCPAR Inserted In a Line

$$\bar{I}_T^{t} = Y_{tt} \bar{V}_t + Y_{tk} \overline{Vk} \quad (11)$$

$$\bar{I}_k = Y_{kt} \bar{V}_t + Y_{kk} \bar{V}_k \quad (12)$$

Here

$$Y_{tt} = Y_{tk} + Y_{to}$$

$$Y_{KK} = Y_{tk} + Y_{ko}$$

$$Y_{tk} = Y_{kt} = -Y_{tk}$$

$$\bar{I}^{t}{}_{t} = \bar{I}_{m}\bar{\mu}$$

$$\overline{Im} = \frac{Y_{tt}}{\bar{\mu}}\overline{V_m} + \frac{Y_{tt}}{\bar{\mu}}\bar{V}T_r + \frac{Y_{tk}}{\bar{\mu}}\bar{V}k \qquad (13)$$

$$\bar{I}\bar{k} = \frac{Ykt}{\bar{\mu}}\overline{V_m} + Y_{kk}\bar{V}k \qquad (14)$$

The admittance matrix of the new line has the form:

$$\begin{bmatrix} \bar{I}_m \\ \bar{I}_K \end{bmatrix} = [Y] \begin{bmatrix} \bar{V}_m \\ \bar{V}_{Tr} \\ \bar{V}_k \end{bmatrix}$$

IV. RESULT AND DISCUSSION

Figure 3 shows the 5 bus test system used in this paper, where the bus bars are numbered from 1 to 5 and the lines from 1 to 7. The bus bar 1 is the slack bus, bus bar 2 is a P, V and buses 3 to 5 are a P, Q buses. The Newton Raphson algorithm is applied in power flow calculation

Figure 3. IEEE 5 Bus Bar Test System

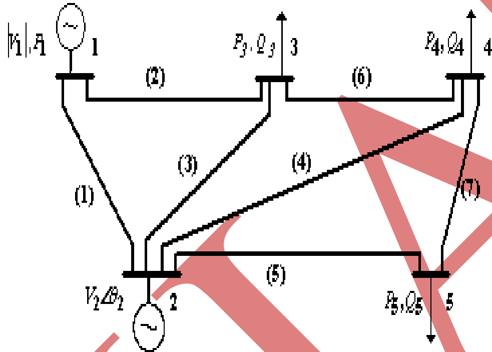


Table1. Generator and Load data of TCPAR

Bus	V (pu)	δ (°)	Generation		Load	
			P (pu)	*Q* (pu)	*P* (pu)	*Q* (pu)
1	1.000	0.000	0.000	0.000	0.000	0.000
2	1.020	0.000	0.400	0.000	0.200	0.100
3	1.000	0.000	0.000	0.000	0.450	0.150
4	1.000	0.000	0.000	0.000	0.400	0.050
5	1.000	0.000	0.000	0.000	0.600	0.100

Table 2. Line data of TCPAR

Line (pu)	1-2	1-3	2-3	2-4	2-5	3-4	4-5
R	0.0200	0.0800	0.0600	0.0600	0.0400	0.0100	0.0800
X	0.0600	0.2400	0.1800	0.1800	0.1200	0.0300	0.2400
B	0.0600	0.0600	0.0400	0.0400	0.0300	0.0200	0.0600

Table 3. Line data for TCSC

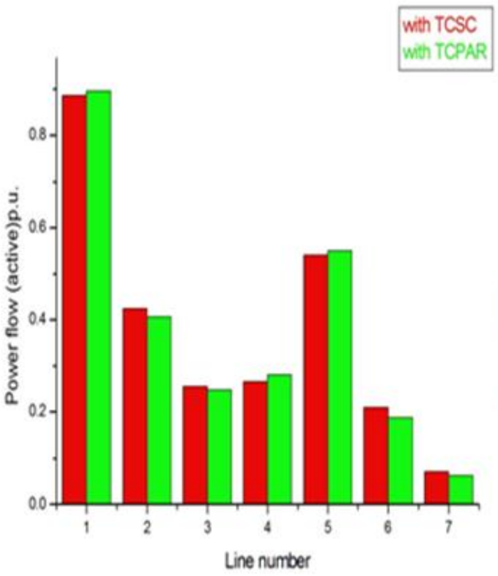
Line (pu)	1-2	1-3	2-3	2-4	2-5	3-4	4-5
R	0.0200	0.0800	0.0600	0.0600	0.0400	0.0100	0.0800
X	0.0600	0.2400	0.1800	0.1800	0.1200	0.0300	0.2400
B	0.0600	0.0500	0.0400	0.0400	0.0300	0.0200	0.0500

Table 4. Generator and load data for TCSC

Bus	*V* (pu)	δ (°)	Generation		Load	
			P (pu)	*Q* (pu)	*P* (pu)	*Q* (pu)
1	1.060	0.000	0.000	0.000	0.000	0.000
2	1.000	0.000	0.400	0.000	0.200	0.100
3	1.000	0.000	0.000	0.000	0.450	0.150
4	1.000	0.000	0.000	0.000	0.400	0.050
5	1.000	0.000	0.000	0.000	0.600	0.100

Table 5. Power flow data

Line	Power flow with TCSC		Power flow with TCPAR	
	p	Q	P	Q
Line 1-2	0.8868	0.7419	0.8968	- 0.2997
Line 1-3	0.4245	0.1675	0.4064	- 0.0199
Line 2-3	0.2550	- 0.0269	0.2482	0.0622
Line 2-4	0.2661	- 0.0157	0.2808	0.0527
Line 2-5	0.5411	0.0561	0.5503	0.0908
Line 3-4	0.2100	0.0251	0.1873	- 0.0722
Line 4-5	0.0713	0.0041	0.0626	- 0.0281



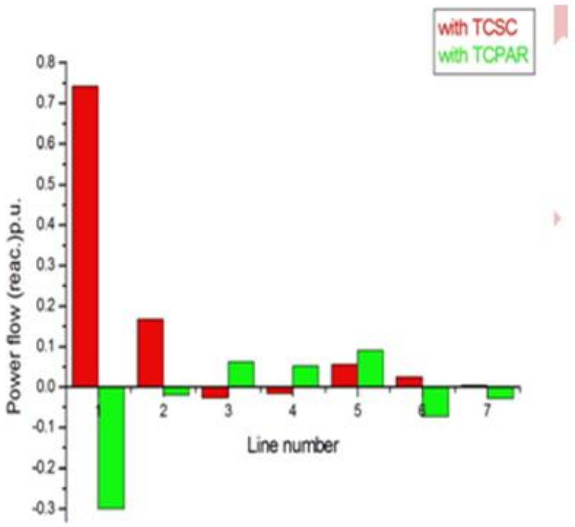


Figure 4. Power flow (active) with TCSC & TCPAR **Figure 5. Power flow (react.) with TCSC & TCPAR**

The approach has been examined on a 5 bus test system in this paper, where the buses are numbered from 1 to 5 and the lines from 1 to 7. The bus-1 is slack bus, bus-2 is PV bus and buses-3 to 5 are PQ or load buses. The Newton Raphson algorithm is applied in power flow calculation for both TCPAR and TCSC [10]. The 5 node network is used to quantify the TCSC and TCPAR behaviour in an interconnected network. The transmission lines were modified to incorporate one TCSC & one TCPAR separately one by one. As TCSC is injected, the node bus-TCSC is added to the network which is named as bus-6. The reactance value is selected by OPF algorithm are X = -0.015, Xlo = -0.05 and Xhi = 0.05,with respect to a base voltage of 400kv. When TCSC is inserted in line-3 to 4 the power flow increases from 0.1939 (without TCSC) to 0.21 p.u. and line losses decrease. In case of line-4 to 5, the power increases but losses also increases. In other lines with TCSC insertion, the line reactance increases to its highest or lowest value and voltage magnitude & phase angle increases rapidly to infinity.

To see the effect of TCPAR on the power flow in the lines, it is inserted in two locations. Its basic function is to inject reactive power, according to the thyristor firing angle, into the network, which help the system to support voltage profile. When TCPAR is inserted in line-1which is overloaded before introduction to TCPAR, the variation in power transited on the lines according to the angle of transformation factor of TCPAR. The angle ranging from 0 degree to 8 degree, the TCPAR reduced 85% of active power transported by line-1 and this reduction is accompanied by increased power in other lines. Power in line-2 & 6 show lower powers and in rest of lines, power increased with increase of angle θ. The TCPAR is now inserted in line-7 to increase the transmitted power by this line, which is often charged. This increase reached 150% for an angle θ of 24 degree. This proves the effectiveness of TCPAR to control the power flow through the lines. As angle increased the voltage magnitude at buses fall. To remedy this, an SVC is inserted in the line which has virtually no effect.

V. CONCLUSION

The TCPAR allows increasing or decreasing the power flowing in the line where it is inserted. It does not inject any active power in the network whereas in case of TCSC, the node bus-TCSC injects active power. A disadvantage of TCPAR is the voltage drop, that causes in the network. To compensate, this voltage drop, SVC is inserted in the network which enhance the cost of entire system whereas the TCSC is cheap device comparatively. TCSC can control the dynamic power flow of the network. So, it is concluded that TCSC as nodal bus inject power in the network and can control the power flow with small cost comparatively TCPAR because SVC unit is additional device in later technique. Hence TCSC is more useful than TCPAR and other FACTS devices.

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