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Use of Thyristor Controlled Series Capacitor for Reactive Power Compensation

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ABSTRACT:- Reactive Power Compensation (RPC) plays a vital role in decreasing the power loss of transmission lines and reducing the voltage deviation. The system load keeps on changing continuously and so results into system parameters changes. Tap changing transformers, capacitor banks and synchronous condensers were conventionally used for the compensation. Flexible AC Transmission System (FACTS) devices are found to be more efficient in this regard. In this paper modeling of Thyristor Controlled Series Capacitor (TCSC) as one of the FACTS devices is considered for solving the RPC problem.

Keyword*: FACTS, TCSC, reactive power control, loss*

I. INTRODUCTION

The Reactive Power Compensation (RPC) is very important for keeping the voltage profile constant at all the buses in power system for secure and economic operation of power systems. The reactive power generation by itself has no cost but however it affects the total generation cost by decreasing the transmission loss. By the reactive power compensation the transmission loss will be minimized because RPC mainly deals with power factor improvement. So, its consequence is to lower the production cost by satisfying the constraints. Environmental, cost problem are major hurdles for power transmission network expansion. Pattern of generation that results in heavy flows tends to incur greater losses and reducing the stability and security of the power system[1].

The increasing Industrialization, urbanization of life style has lead to increasing dependency on the electrical energy, resulted into rapid growth of power systems which resulted into few uncertainties. Power disruptions and individual power outages are one of the major problems and affect the economy of any country. In contrast to the rapid changes in technologies and the power required by these technologies, transmission systems are being pushed to operate closer to their stability limits and at the same time reaching their thermal limits due to the fact that the delivery of power have been increasing. [4,9]The major problems faced by power industries in establishing the match between supply and demand is:

1. Transmission & Distribution; supply the electric demand without exceeding the thermal limit.
2. In large power system, stability problems causing power disruptions and black-outs leading to huge losses.

These constraints affect the quality of power delivered. [2,3] However, these constraints can be suppressed by enhancing the power system control. One of the best methods for reducing these constraints is FACTS devices. Hence there is an interest in better utilization of available capacity by installing Flexible AC Transmission System (FACTS) devices such as Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Phase Angel Regulator (TCPAR) , Unified Power Flow Controller (UPFC), Static Synchronous Compensator(STATCOM) and SVC which help in controlling the flow in heavily loaded lines and enhance system stability.

Recently with the advent in power electronics technology , many FACTS devices have been evolved .These new devices are more efficient in controlling present transmission and distribution systems of electricity . In this study, Power flow model of TCSC as one of the FACTS devices have been considered . In this investigate first the Optimal Power Flow (OPF) analysis is done using Power Simulator software. The reactance of the TCSC is made either inductive or capacitive and its effect is investigated in the 3 Bus System for its insertion in one of the line and the results of OPF have been compared.

II. MATHEMATICAL MODELLING OF TCSC AS ONE OF THE FACTS DEVICE FOR OPF

Series compensation is nothing but the control of transmission line impedance which can be either inductive or capacitive in nature. Series compensation aims at controlling active and reactive power flow through the transmission lines[5, 6, 9]. Thyristor Controlled Series Capacitor (TCSC) is a basically variable impedance type series compensator. It is connected in series with the transmission line to damp the system oscillations, minimize the transmission network loss and thus simultaneously increases the power transfer capability along with improvement in transient stability of the system. Here in the analysis, steady state operation of TCSC is considered.. The effect of a TCSC on the network can be seen as a controllable reactance inserted in series in the related transmission line for compensating transmission line reactance in which it is connected. It may have capacitive or inductive characteristics to decrease or increase the reactance of the line X_L respectively. Their values are functions of reactance of the line where the device is located [5]. Moreover, to avoid over compensation of the line, the working range of the TCSC is considered to be [-0.39X_L, 0.39X_L]. It increases the maximum power transfer in that line along with voltage profile improvement. A simple transmission line represented by its lumped Л equivalent parameters connected between bus i and bus j is shown in Fig. 1. Where G_{ij} is the series conductance and B_{ij} is the series susceptance of a transmission line. B_{sh} is the shunt susceptance of a transmission line. The model of a transmission line with a TCSC connected between bus – i and bus- j is shown in Fig. 2.

The power injection model is a desirable one for the RPC analysis in this study as it is capable of handling the FACTS devices while performing the computations of power flows. The bus admittance matrix of Y_BUS matrix and the bus impedance matrix ,Z_BUS matrix of the power system is unaffected by using this model. In fact, the power injection model is the most convenient and appropriate for power systems with FACTS devices [7]. For a transmission line connected between bus i and bus j, the voltages and angles at bus i and j are $V_i, \delta_i \text{ and } V_j, \delta_j$respectively. Therefore, complex power flow from bus i to bus j and vice versa are defined by the following equations:

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

where

$$\delta_{ij} = \delta_i - \delta_j$$

Similarly the active and reactive power from bus j to bus i is given by

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

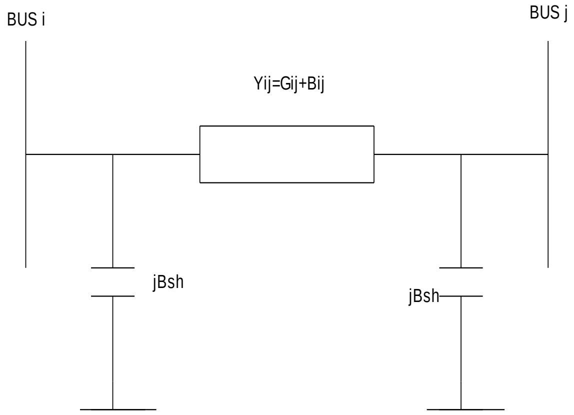

Fig.1 Transmission line model

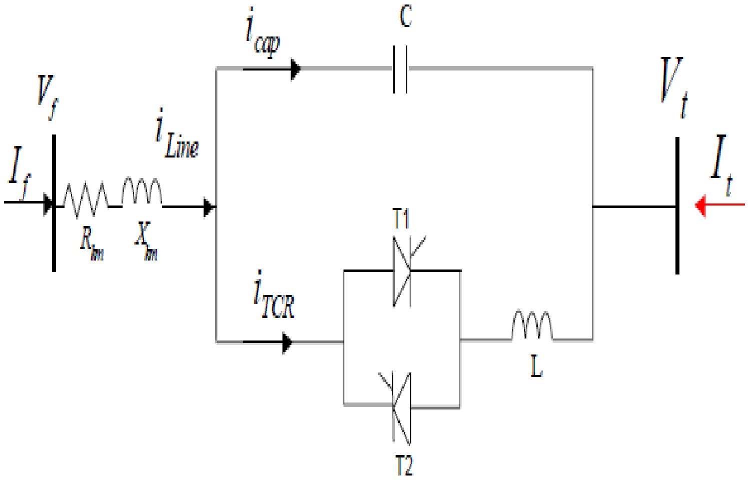

Fig. 2. Model of TCSC

According to the operating principle of the TCSC[5], it can control the active power flow for the line *l* (between bus- *i* and bus- *t* where the TCSC is installed).The fundamental frequency of TCSC equivalent reactance as a function of the TCSC firing angle α is

$$X_{TCSC} = X_C + K_1(2\sigma + sin^2_{\sigma}) - K_2 cos^2_{\sigma\omega r}(\tan(\sigma\omega r) - tan\sigma)) \tag{3}$$

where

$\sigma = \pi - \alpha$

$X_{TCSC} = X_C X_L/(X_L - X_C)$

$K_1 = (X_{LC} + X_C)/\pi$

$K_2 = 4X_{LC}^2 X_L/\pi$

$\omega_r = \dfrac{1}{2\pi\sqrt{LC}}$

There exists a relation between the firing angle α and X_{TCSC}. The complex power injected by TCSC at bus i is given as follows

$$P_{TCSCfinj} = G'_{ij}V_i^2 + V_i V_t(G'_{ij}cos\delta_{it} + B'_{ij}sin\delta_{it})$$

$$Q_{TCSCfinj} = -B'_{ij}V_i^2 + V_i V_t(G'_{ij}sin\delta_{it} - B'_{ij}cos\delta_{it}) \tag{4}$$

III. SIMULATION RESULTS AND DISCUSSION

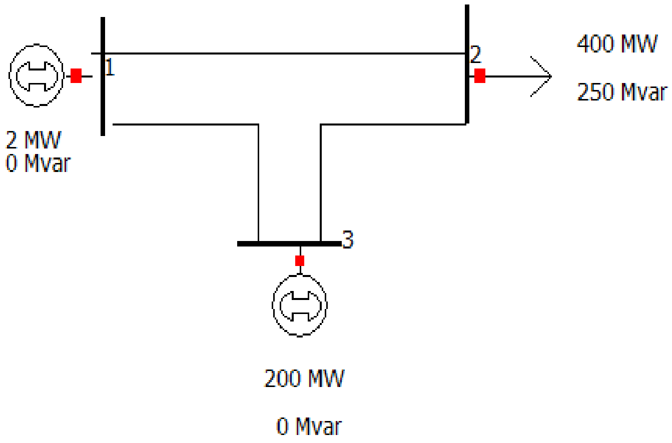

Fig. 3 Sample power system

The details of the sample power system chosen for analysis is 3 bus system as shown in Fig. 3 consisting of slack bus ,load bus and generator bus and three interconnected transmission lines . The details of the various parameters at buses is given by the Table 1. The transmission line data is depicted in Table 2 where the resistance (R) , reactance(X) and admittance(Y_{ij}) of the line is given on per unit basis ,base MVA being 100MVA.

Table 1 Bus data of 3 Bus System

Bus No	type	V pu	∂	P	Q
1	Slack bus	1.05	0.0	--	--
2	PQ bus	1.00	0.0	-4	-2.5
3	PV bus	1.04	0.0	2.0	0

Table 2 Transmission Line Data for the 3 Bus Power system

Line no	From Bus i	To Bus j	R+jX (pu)	Shunt Susceptance jBsh (pu)	Admittance of the line y_{ij} (pu)
1	1	2	0.02+j0.04	0.0	10-j20
2	1	3	0.01+j0.03	0.0	10-j30
3	2	3	0.0125+j0.025	0.0	16-j32

For the power system shown in Fig.3 above the simulation is carried out using Power World simulator software for Optimal Power flow using Newton Raphson Algorithm for normal load condition before TCSC being inserted in the system. Table 3 shows the simulation results for the Transmission Loss through various lines without TCSC. Now, the same system is tested for Optimal Power Flow analysis with the TCSC inserted in line between buses 2 and 3 for being inductive and capacitive in nature respectively. The values of the reactance have been changed and the simulation is done using Power World Simulator software.

The results for voltage magnitude and phase angle, generated real and reactive power Pg and Qg for different TCSC conditions is shown in Table 4. And the power flows through various lines have been depicted in Table 5. The comparative results obtained for the complex power loss are given in the Table 6. The results show that the real power loss without using TCSC for the system is found to be 20.7MW .Whereas the same have been found using inductive reactance of TCSC to be 21.5MW. And for the same system loading conditions the results have been found to be optimistic using capacitive reactance of TCSC. Thus, the power loss using capacitive reactance is found to be 20.5 MW.

Table 3 Simulation Results for the Transmission Loss through various lines without TCSC for Optimal Power Flow

Line no	From bus	To bus	P_{ij} (MW)	Q_{ij} (MVAR)	P_{Lij} (MW)	Q_{Lij} (MVAR)
1	1	3	40.1	20.3	0.21	0.62
2	1	2	180.6	120.2	9.42	18.83
3	2	3	-228.8	-148.6	11.06	22.13
Total Loss					20.07	41.6

Table 4 Results of 3 Bus System with the insertion of TCSC in line between buses 2-3 for Optimal Power Flow

Bus no	Without TCSC				With TCSC(inductive)				With TCSC(capacitive)			
	V (pu)	$\square^0$	P_g (MW)	Q_g (MVAR)	V (pu)	$\square^0$	P_g (MW)	Q_g (MVAR)	V (pu)	$\square^0$	P_g (MW)	Q_g (MVAR)
1	1.00	0.0	220.68	141.58	1.00	0.0	221.52	150.5	1.00	0.0	220.51	131.4
2	0.9171	-3.01	-	-	0.9085	-3.56	-	-	0.9267	-2.35	-	-
3	0.9898	-0.57	200	150	0.9927	-0.15	200	150	0.9868	-1.1	200	150

Table 5 Results for the Transmission Loss in lines with TCSC connected in line between buses 2-3

Line no	From bus	To bus	With TCSC(inductive)				With TCSC(capacitive)			
			P_{ij} (MW)	Q_{ij} (MVAR)	P_{Lij} (MW)	Q_{Lij} (MVAR)	P_{ij} (MW)	Q_{ij} (MVAR)	P_{Lij} (MW)	Q_{Lij} (MVAR)
1	**1**	**3**	**15.1**	**19.3**	**0.06**	**0.18**	**70.3**	**21.3**	**0.54**	**1.62**
2	**1**	**2**	**206.4**	**131.2**	**11.96**	**23.93**	**150.2**	**110.2**	**6.94**	**13.88**
3	**2**	**3**	**-205.5**	**-142.8**	**9.5**	**26.4**	**-256.7**	**-153.6**	**13.03**	**15.9**
			Total Loss		**21.5**	**50.5**	**Total Loss**		**20.5**	**31.4**

Table 6 Comparison of the Total Loss

	P_L (MW)	Q_L (MVAR)
Without X_{TCSC}	**20.7**	**41.6**
With $+X_{TCSC}$	**21.5**	**50.5**
With $-X_{TCSC}$	**20.5**	**31.4**

IV. CONCLUSION

Thus the mathematical modeling TCSC as one of the FACTS devices has been done and the simulation of the 3 Bus power system for optimal power flow using TCSC as variable inductive reactance or capacitive reactance is performed using Power world Simulator software. From the simulation results obtained, it can be concluded that the TCSC being capacitive in nature reduces the power loss substantially and hence gives optimistic results.

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