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Performance Analysis of FACTS Controllers

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Abstract: The characteristics of FACTS controllers such as Fixed Capacitor- Thyristor Controlled Reactor (FC-TCR) Thyristor Controlled Voltage Regulator (TCVR) and Unified Power Flow Controller (UPFC) used for reactive power compensation in a transmission network are analyzed and the operation and simulation results are presented in this stduy. The control strategy for Real and Reactive powers of the transmission line using FC-TCR and UPFC and the voltage regulation using TCVR are described. In case of FC-TCR, the control is achieved by controlling the current through the TC reactor by varying the phase of the thyristor switch. In TCVR system, the power flow in the line is controlled by voltage regulation method. Thus, by voltage boosting in the transmission line, the power flow in the line is increased. This method uses thyristor based control and thus overcomes the difficulties of a conventional type on-load tap changer. The control in case of UPFC is obtained by replacing the traditional UPFC consisting of shunt converter and series converter with a current source and a voltage source model. The reactive power supplied to the load can be increased by increasing the magnitude of shunt current. The power factor can be increased by increasing the angle of injected voltage. The circuit models of FC-TCR, TCVR and UPFC systems are developed and the respective systems are simulated successfully using these models. The simulation results are presented to demonstrate the performance of the controllers

Key words: FACTS controllers, FC-TCR, TCVR, UPFC

INTRODUCTION

Rising energy costs and greater sensitivity to environmental impact of new transmission lines necessitated new controllers to minimize losses and maximize the stable power-transmission capacity of existing lines. FACTS technology opens up new opportunities for controlling power and enhancing usable capacity of the existing lines. FACTS technology is one that incorporates power-electronics based and other static controllers to enhance controllability and increase power transfer capability. In most of the AC systems the load sharing while transmitting power is entirely governed by the line impedance. In this context, the high power switching devices applied at the transmission level is bringing utilities new opportunities as well as new challenges for controlling the main parameters related to power flow and voltage control. Relative importances of controllable parameters are:

- Control of the line impedance X can provide powerful means of current control.
- When the angle is not large, which is often the case, control of X or angle substantially provides the control of active power.
- Control of angle, which in turn controls the driving voltage, provides a powerful means of controlling the current flow and hence active power flow when the angle is not large.
- Injecting a voltage in series with the line and with any phase angle with respect to the driving voltage can control the magnitude and the phase of the line current.
- When the angle is not large, controlling the magnitude of one or the other line voltages can be a very cost-effective means for the control of reactive power flow through the interconnection.
- Combination of the line impedance control with a series controller and voltage regulation with a shunt controller can provide a cost-effective means to control both the active and reactive power flow between the two systems.

An alternative approach to the conventional on load tap change voltage control was described by Arrillaga and Duke (1980). The UPFC control and analysis was described by Fugit and Watanaba (1999). Gutierrez *et al.* (2002) has explained the power-quality improvement by control of reactive power using FC-TCR Circuits. The

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basic concept of Unified Power Flow Controller for Flexible AC Transmission Systems was proposed by Gyungyi (1992).

Fixed Capacitor Thyristor Controlled Reactor (FC-TCR) is a type of Static Var Compensator (SVC) as explained by Jen *et al.* (1996) presents a mathematical model for computer simulation and control of SVC to achieve system balance. UPFC which consists of a series and a shunt converter connected by a common dc link capacitor can simultaneously perform the function of transmission line real/reactive power flow control. A new type of real and reactive power flow controller for a UPFC was proposed by Kannan *et al.* (2004). The development of a control scheme for the series injected voltage of the UPFC to damp the power oscillations and improve transient stability in a power system was presented by padiyar and Uma (1999). A new kind of FC-TCR Controller based on multiprocessor and digital phase shifters is designed and implemented by Renjie *et al.* (2004).

The objective of this work is to simulate the FACTS controllers using PSPICE and MATLAB and study its characteristics.

MODELING AND SIMULATION OF BASIC TRANSMISSION LINE

The basic transmission line model for 11KV is shown in Fig. 1.

In Fig.1, scope is used to view both the line current and source voltage. The real power and reactive power in the load is measured using the Active and Reactive Power measurement block. The Real power and the Reactive Powers measured in the load are 0.23MW and 1.12MVAR

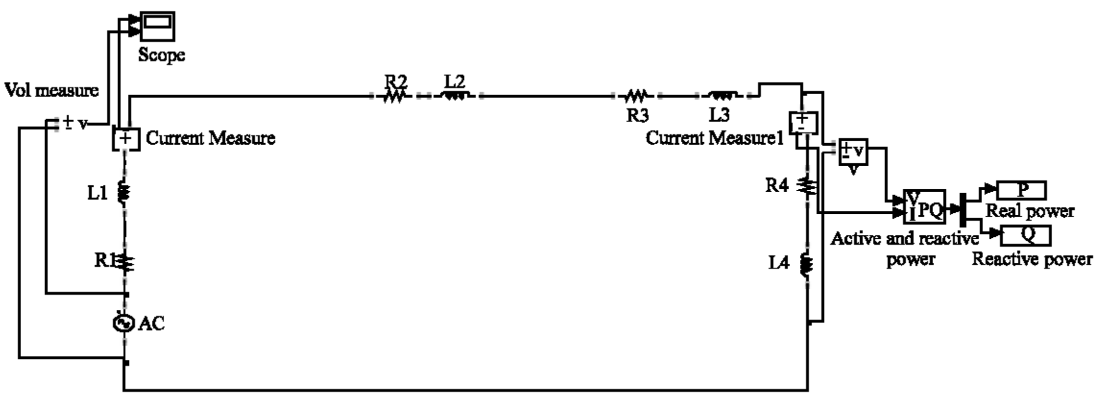

Fig. 1: Simulation circuit of basic transmission line

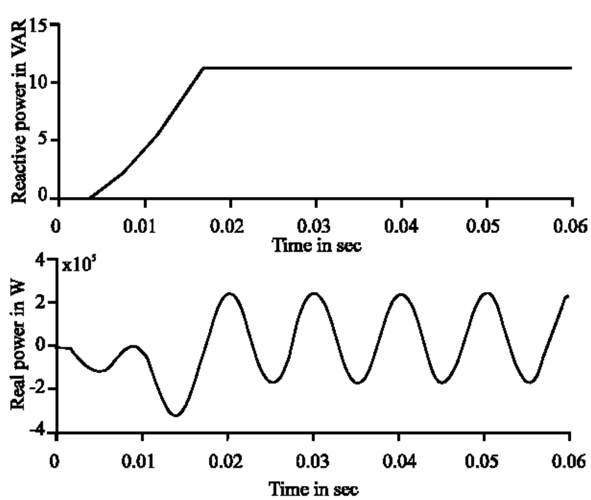

Fig. 2: Real and reactive powers

as shown in Fig. 2. This power flow is obtained without any compensation. By introducing FACTS Controllers in the transmission line, the power flow can be increased.

FIXED CAPACITOR THYRISTOR CONTROLLED REACTOR

The Fixed Capacitor Thyristor-Controlled Reactor (FC-TCR) is a var generator arrangement using a fixed (permanently connected) capacitance with a thyristor controlled reactor. The model of FC-TCR with the line voltage of 11KV is shown in Fig. 3. From the Table 1, it can be inferred that for increase in the value of capacitance, there is increase in the real as well as reactive power. From the Table 2, it is seen that, the current through the TCR varies from maximum to zero as the firing angle is increased. Also, the real power and reactive power increases for increase in the firing angle.

The current through the TCR is shown in Fig. 4. The real and reactive powers measured in the load for a typical value of firing angle $\alpha = 144°$ and Capacitance, C = 200 μF is also shown in the same figure.

THYRISTOR CONTROLLED VOLTAGE REGULATOR

This arrangement can give continuous voltage magnitude control by initiating the onset of thyristor valve conduction. The voltage obtainable at the upper tap and lower tap are V_2 and V_1, respectively. The gating of the thyristor valves is controlled by the delay angle α, with respect to the voltage zero crossing of these voltages.

Table 1: Variation in Real Power and Reactive Power for different values of Capacitance with α =108°

S. No	Capacitance (μF)	Real power (MW)	Reactive power (MVAR)
1	200	0.42	2.0
2	300	0.60	2.8
3	400	1.00	4.6
4	500	1.20	5.0

Table 2: Variation of TCR current and power for different firing angles

S. No	Firing angle (deg)	Current through TCR (A)	Real power (MW)	Reactive power (MVAR)
1	108	284	0.42	2.00
2	126	210	0.49	2.30
3	144	130	0.54	2.50
4	162	55	0.58	2.65
5	176	10	0.59	2.70
6	180	0	0.6	2.74

Table 3: Variation of reactive power for different firing angles

	Firing angle (deg)				
	Lower tap		Upper tap		
	S_a	S_b	S_c	S_d	
S. No	α_1	α_2	α_3	α_4	Reactive power (MVAR)
1	0	180	90	270	1100
2	0	180	126	306	1000
3	0	180	162	342	950

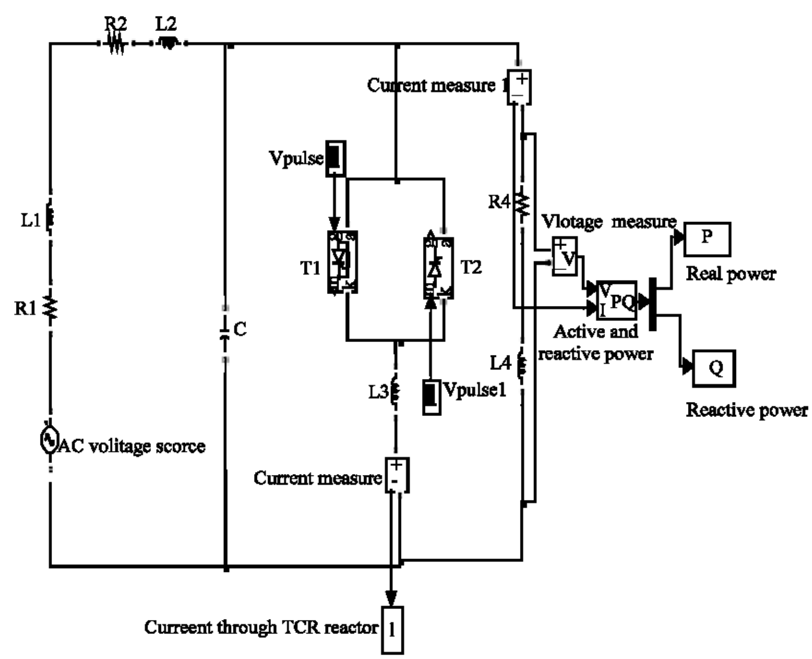

Fig. 3: Simulation circuit of FC-TCR

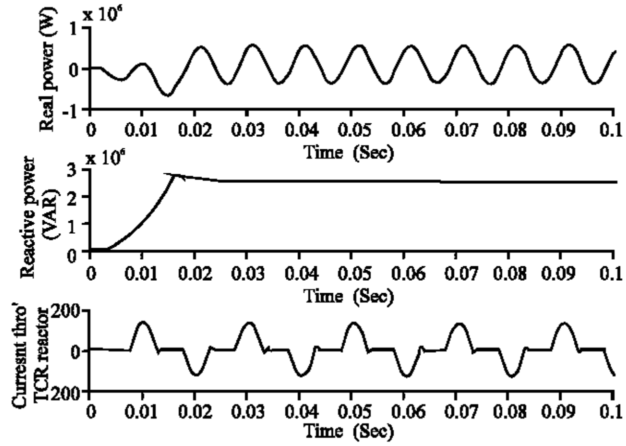

Fig. 4: Current through tcr, real and reactive powers

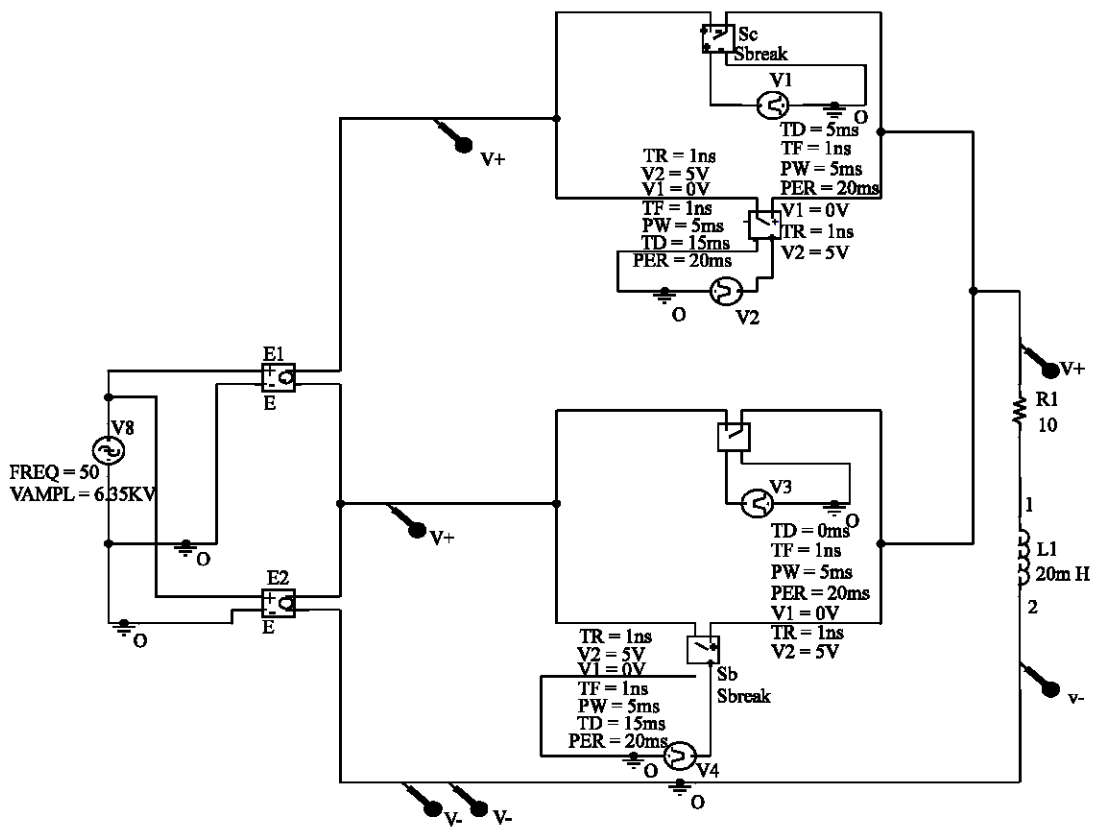

Fig. 5: Simulation circuit of TCVR

The circuit used for simulation is shown in Fig. 5. Simulation was carried out using a 6.35 kV/132 kV three phase transformer which is modeled using voltage dependent voltage sources.

Table 3 shows the Reactive power variation for different sets of firing angle. Table 4 shows the Reactive

Table 4: Variation of Reactive Power for different upper and lower tap voltages as percentage of secondary voltage

S. No	Upper tap voltage (V) (as percentage of secondary voltage)	Lower tap voltage (V) (as percentage of secondary voltage)	Reactive power (MVAR)
1	10	90	1130
2	20	80	1000
3	40	60	950

power variation for different upper tap and lower tap voltages expressed as percentage of secondary voltages. The ideal switches S_a, S_b, S_c and S_d are triggered at α_1, α_2, α_3 and α_4, respectively.

UNIFIED POWER FLOW CONTROLLER (UPFC)

The unified power flow controller is a second generation FACTS device, which enables independent control of active and reactive power. It is a multifunction power flow controller with capabilities of terminal voltage regulation, series line compensation and phase angle regulation. This controller can be realized by using two Voltage Source Converters (VSCs) employing GTOs. The circuit model of UPFC system is shown in Fig. 7. Table 5 shows the variation of Real and Reactive powers by injecting a series voltage of fixed magnitude 2kV at different angles of injection from 0 to 360°. Table 6 shows the improvement in power factor obtained by injecting a series voltage of magnitude 2kV at three different angles of injection- 0°, 50° and 90° for different magnitude of shunt reactive current injection. Fig. 8 shows the Real Power, Reactive Power and the effective current for a typical value of shunt reactive current injection of 66.67A (20% of the total current). Series voltage of magnitude 2kV is injected at 0° with respect to the line current.

Table 5: Variation of power with variation in the angle of injected voltage

Sl.no	Angle of V2 (deg)	Source current (A)	Effective current (A)	Real power (MW)	Real power(MVAR)
1	0	220	286	0.245	1.15
2	50	255	320	0.310	1.47
3	90	266	332	0.330	1.56
4	120	262	327	0.318	1.51
5	150	250	310	0.285	1.36
6	180	224	286	0.245	1.16
7	240	174	238	0.168	0.80
8	270	164	230	0.159	0.75
9	300	171	238	0.175	0.80
10	360	218	285	0.246	1.15

Table 6: Variation of power factor with variation in the angle of injected voltage

Voltage V2 injected at 0°		Voltage V2 injected at 50°		Voltage V2 injected at 90°	
I2 (A)	Power factor	I2 (A)	Power factor	I2 (A)	Power factor
66.67	0.200	66.67	0.28	66.67	0.587
150	0.402	280	0.406	280	0.669
280	0.743	290	0.587	290	0.743
290	0.95	310	0.866	310	0.95

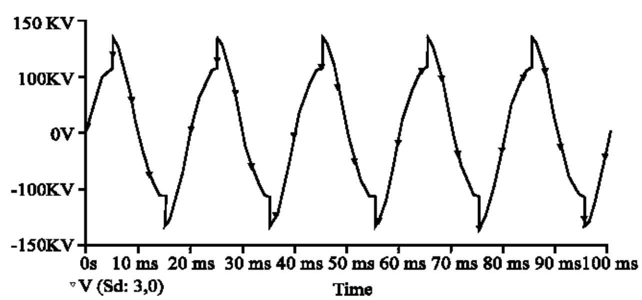

Fig. 6: Load voltage

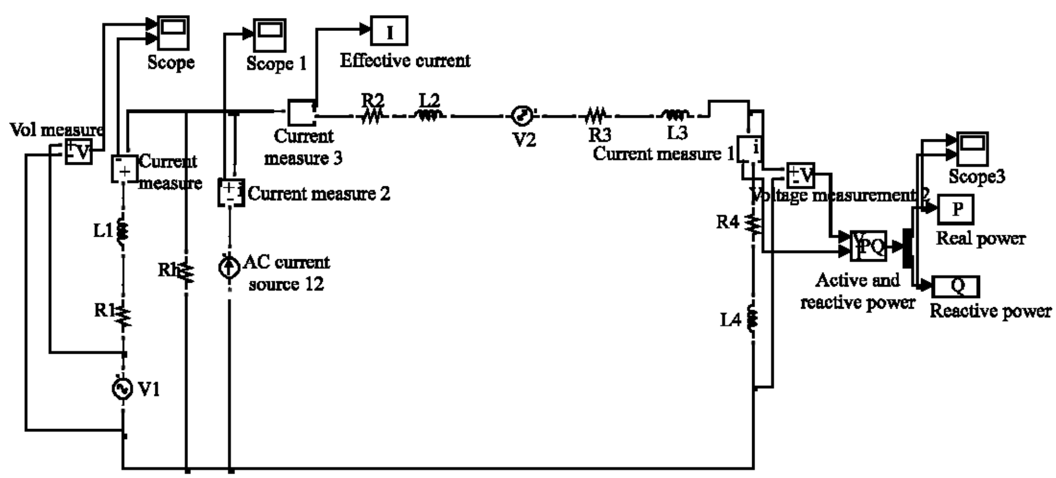

Fig. 7: Simulation circuit of UPFC

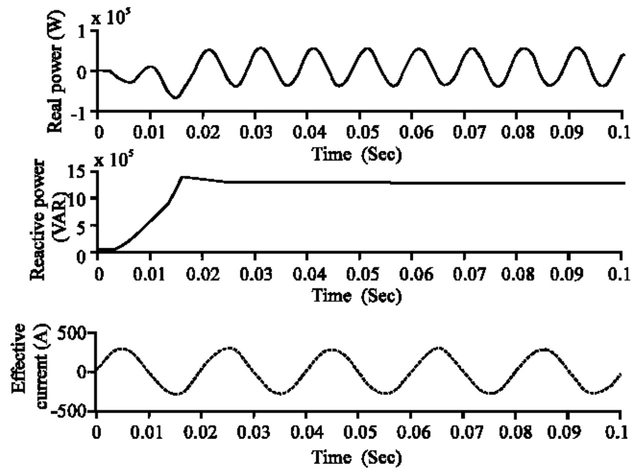

Fig. 8: Effective current, real and reactive powers

CONCLUSION

This research describes the control strategy for Real and Reactive powers of the transmission line using FC-TCR and UPFC and the voltage regulation using TCVR. The FC-TCR Compensator has the ability to change its reactive power by controlling the current flow through the reactor for various firing angles.The TCVR is a modern voltage regulator that regulates the voltage, replaces the traditional mechanical on-load tap changer. The alternative approach to the conventional on load tap changing is the Static Tap Changer System, involves boosting transformer and phase angle controlled thyristor switching. The UPFC controls the transmission line real/reactive power flow and the power factor can be improved by controlling the respective parameters used in the circuit. The circuit models of FC-TCR, TCVR and UPFC systems are developed and the simulation results coincide with theoretical results.

REFERENCES

Arrillaga, J. and R.M. Duke, 1980. A Static alternative to the transformer on load tap change, IEEE. Trans. Power Apparatus Sys., pp: 99.

Fugita and Watanaba, 1999. Control and Analysis of UPFC', IEEE. Trans. Power Elec., 14: 1021-1027.

Gutierrez, J., J.C. Montano, M. Castilla and A. Lopez, 2002. Power-quality improvement in reactive power control using FC-TCR circuits IECON 02, Industrial Electronics Society, IEEE. Annu. Conf., 2: 880-885.

Gyungui, L., FIEE. 1992. Unified Power Flow Control concept for Flexible AC Transmission System' IEEE Proceedings- C, Vol. 139.

Jen-Hung Chen, Wei-Jen Lee and Mo-Shing Chen, 1996. Using a static var compensator to balance a distribution system Industry Application Conference, 1996. Thirty-First IAS Annual Meeting, IAS, Conf. Rec. IEEE., 4: 2321-2326.

Kannan, S., Shesha Jayaram and M.M.A. Salama, 2004. 'Real and Reactive Power Coordination for a Unified Power Flow Controller' IEEE. Trans. Power Sys., 19: 1454-1461.

Padiyar, K.R. and K. Uma Rao, 1999. 'Modeling and control of Unified Power Flow Controller for transient stability' Elec. Power Energy Sys., pp: 1-11.

Renjie Ding, Jun Zhang, Yong Min, Zhiqiang Shi, Haitao Song and Yuwei Zhao, 2004. Design and implementation of a new kind of FC-TCR controller based on multiprocessor and digital phase shift triggers Power Electronics, Machines and drives, PEMD. Second International Conference on (Conf. Publ. No. 498) 1: 181-185.