Simulation and Comparison of Various FACTS Devices in Power System

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Abstract - The Power electronic based FACTS devices can be added to power transmission and distribution systems at strategic locations to improve system performance. This paper deals with the simulation of various FACTS controllers using simulation program with Integrated circuits Emphasis (PSPICE) .The FACTS controllers will control series impedance, shunt impedance, current, voltage and phase angle. In this paper, simple circuit model of Thyristor Controlled Reactor, Thyristor Controlled voltage regulator and UPFC systems were simulated. The simulation results coincide with the theoretical results.

Index Terms: FACTS controllers, FACTS, power electronic equipment, PSPICE

I. 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 [1, 2]. The increasing complexity and interconnectedness of existing power systems present new challenges for their secure operation. Therefore, they call new and efficient forms of power control. 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. In the evolving utility environment, financial and market forces are, and will continue to, demand a more optimal and profitable operation of the power system with respect to generation, transmission, and distribution. Now, more than ever, advanced technologies are paramount for the reliable and secure operation of power systems [3, 4]. To achieve both operational reliability and financial profitability, it has become clear that more efficient utilization and control of the existing transmission system infrastructure is required.

Improved utilization of the existing power system is provided through the application of advanced control technologies. Power electronics based equipment, or Flexible AC Transmission Systems (FACTS), provide proven technical solutions to address these new operating challenges being presented today [5]. FACTS technologies allow for improved transmission system operation with minimal infrastructure investment, environmental impact, and implementation time compared to the construction of new transmission lines. When discussing the creation, movement, and utilization of electrical power, it can be separated into three areas, which traditionally determined the way in which electric utility companies had been organized. These are illustrated in Fig.1.

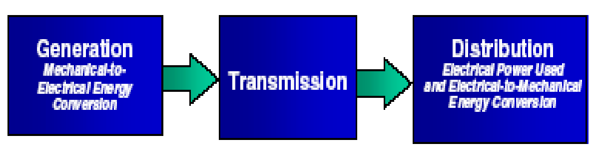

Fig.1. Illustration of the creation, movement and utilization of electrical power

Although power electronic based equipment is prevalent in each of these three areas, such as with static excitation systems for generators and Custom Power equipment in distribution systems, the focus of this paper and accompanying presentation is on transmission that is, moving the power from where it is generated to where it is utilized [6,7].

A. Basic Transmission Line

The current measurement block is used to measure the instantaneous current flowing in the transmission line. The voltage measurement block is used to measure the source voltage. R1, L1 represents the source impedance. The line impedance of (5+j0.023) Ω is represented by R2, R3, L2and L3. The load impedance of (1+j0.02) Ω is represented by R4 and L4. Scope displays the signals generated during a simulation. In Fig.2, 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 & Reactive Power measurement block.

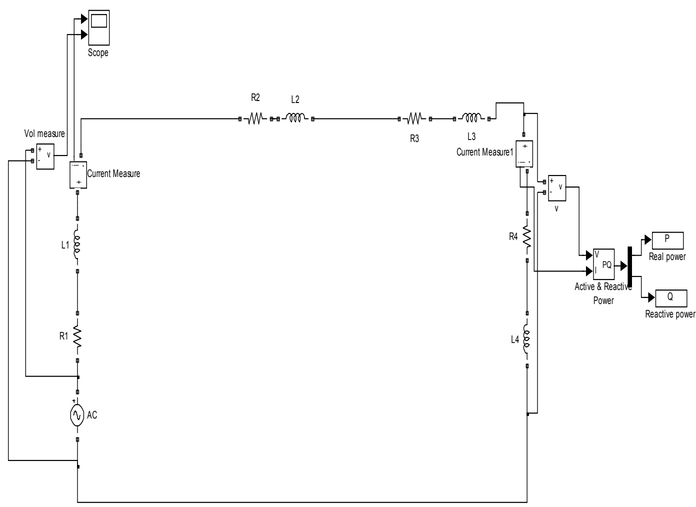

Fig.2. The basic transmission line model for 11KV

B .Results of Simulation

The Real power and the Reactive Powers measured in the load are 0.23MW and 1.12MVAR as shown in Fig.3. This power flow is obtained without any compensation. By introducing FACTS Controllers in the transmission line, the power flow can be increased.

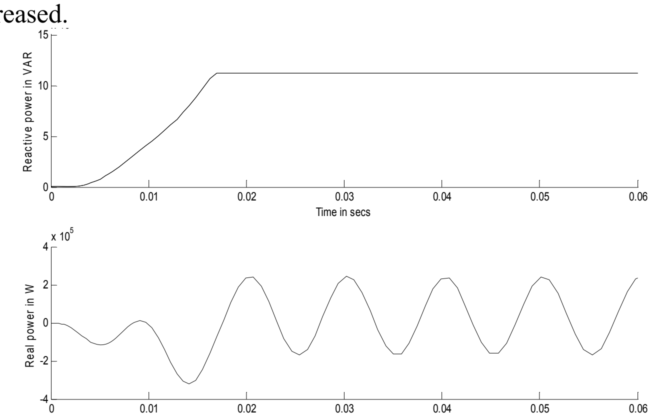

Fig.3 Real and Reactive Powers

II. PERFORMANCE AND SIMULATION OF CONTROLLERS

The various compensators like Fixed Capacitor Thyristor Controlled Reactor, Thyristor Controlled Voltage Regulator and Static Tap Changer Systems are designed the different operating voltage levels and the simulations were analyzed.

A. 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 as shown in Fig.4

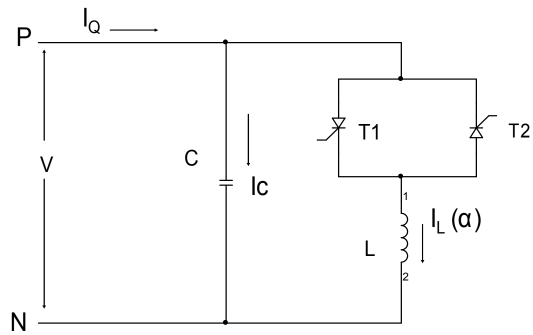

Fig.4 Fixed Capacitor Thyristor Controlled Reactor

The current in the reactor is varied by the method of firing delay angle control method. The constant capacitive var generation (Qc) of the fixed capacitor is opposed by the variable var absorption (Q_L) of the thyristor controlled reactor, to yield the total var output (Q) required. At the maximum capacitive var output, the thyristor-controlled reactor is off. To decrease the capacitive output, the current in the reactor is increased by decreasing delay angle α.

At zero var output, the capacitive and inductive currents become equal and thus both the vars cancels out. With further decrease of angle α, the inductive current becomes larger than the capacitive current, resulting in a net inductive output [8, 9]. The model of FC-TCR with the line voltage of 11KV is shown in Fig.5. The current through the TCR is measured using the current measurement block. The line impedance of (5+j0.023) Ω is represented by R2 and L2.

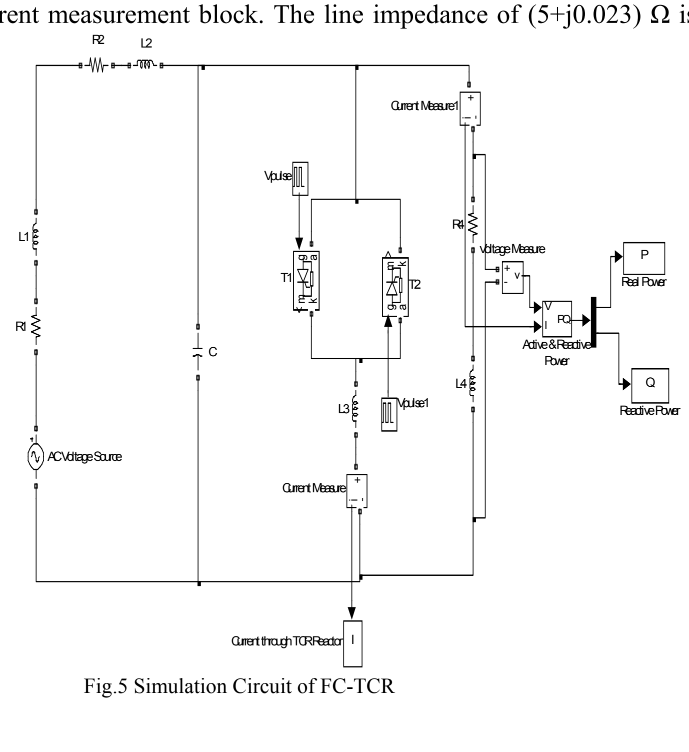

Fig.5 Simulation Circuit of FC-TCR

Capacitor C is the fixed capacitor of 200µF and the value of TC Reactor represented by L3 is 100mH. T1 and T2 together represent the thyristor switch whose triggering pulses are provided by the two Voltage pulse blocks. The load impedance of (1+j0.1) Ω is represented by R4 and L4. 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.

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

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.2 Variation of TCR Current and Power for different firing angles

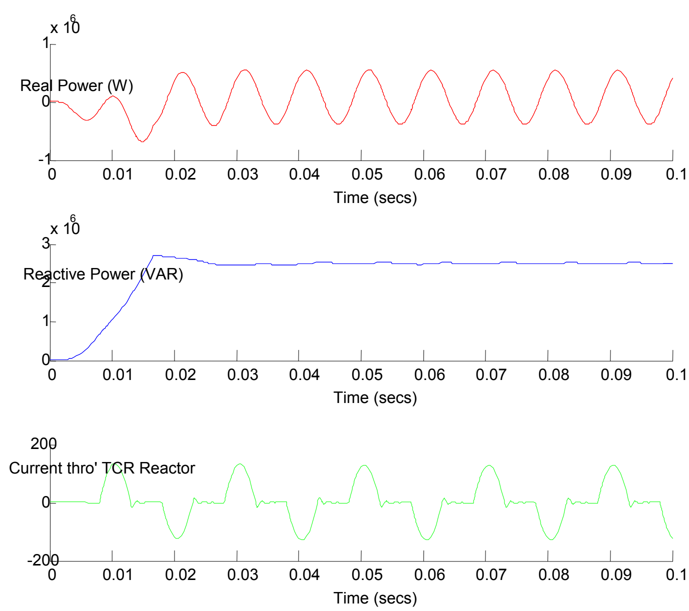

Fig.6 Current through TCR, Real and Reactive Powers

The current through the TCR is shown in Fig.6. The Real and Reactive Powers measured in the load for a typical value of firing angle $\alpha = 144^o$ and Capacitance, C =200μF is also shown in the same Fig.6.

B. Thyristor Controlled Voltage Regulator

The basic concept of voltage regulation is the addition of an appropriate in-phase or a quadrature component to the prevailing terminal voltage in order to change (increase or decrease) its magnitude to a desired value. In thyristor based approach of voltage regulation, the insertion of voltage is obtained by selection of appropriate tap of a regulating transformer (insertion transformer), in series with the line.

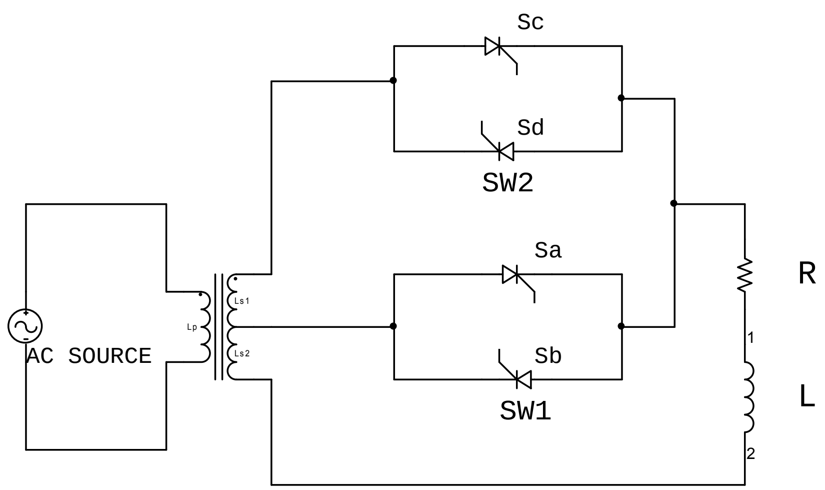

Fig.7 Thyristor Controlled Voltage Regulator

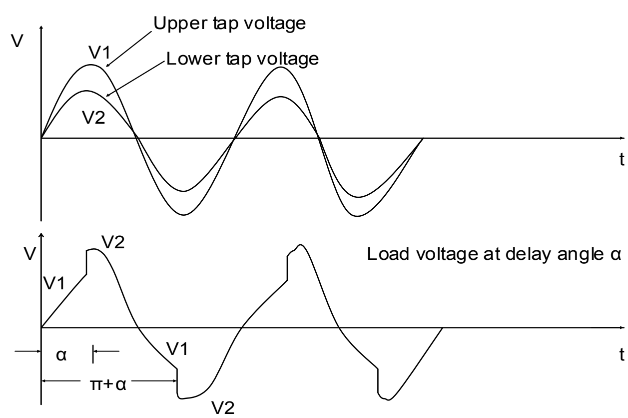

Fig.8 Upper Tap, Lower Tap and Load Voltage

The power circuit scheme of a thyristor tap changer with a RL load is shown in Fig.7. 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. At $\alpha = \alpha_1$, valve sw_2 is gated on, which commutates the current from the conducting thyristor valve sw_1 by forcing a negative anode to cathode voltage across it and connecting the output to the upper tap with voltage V_2. Valve sw_2 continues conducting until the next current zero is reached. Thus, by delaying the turn-on of sw_2 from zero to π, any output voltage between V_2 and V_1 can be attained, as shown in Fig.8 the load voltage.

The circuit used for simulation is shown in Fig.9. Simulation was carried out using a 6.35KV / 132KV three phase transformer which is modeled using voltage dependent voltage sources.

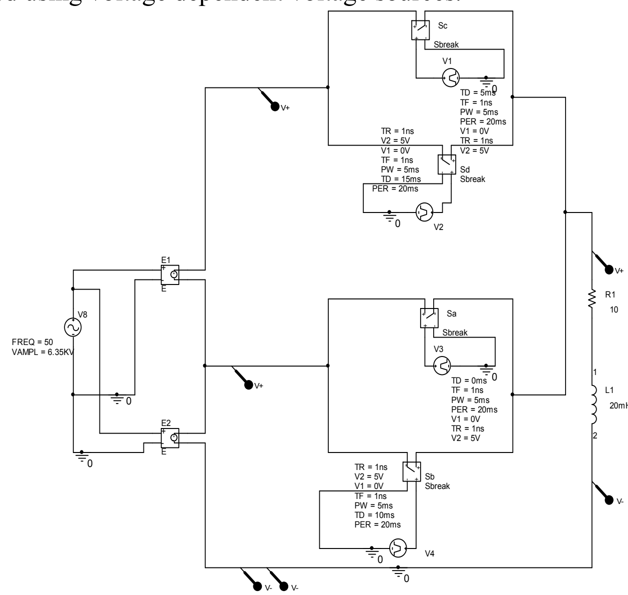

Fig.9 Simulation Circuit of TCVR

Table.3 shows the Reactive power variation for different sets of firing angle. Table 4.4 shows the Reactive 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.

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

Table.3 Variation of Reactive Power for different firing angles.

S.No	**% Of Upper Tap Voltage (V)**	**% Of Lower Tap Voltage (V)**	**Reactive Power (MVAR)**
1	10	90	1130
2	20	80	1000
3	40	60	950

Table.4 Variation of Reactive Power for different Upper and Lower Tap Voltages as percentage of secondary voltage

Fig.10 shows the upper tap and lower tap voltages of the three phase transformer. Fig.11 shows the resultant voltage measured in the RL load. By delaying the turn-on of SW_2 from 0 to 2π, any output voltage between V_1 and V_2 can be attained.

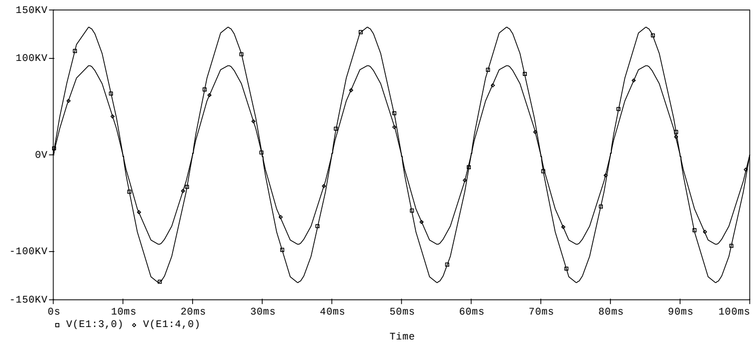

Fig.10 Upper and Lower Tap Voltages

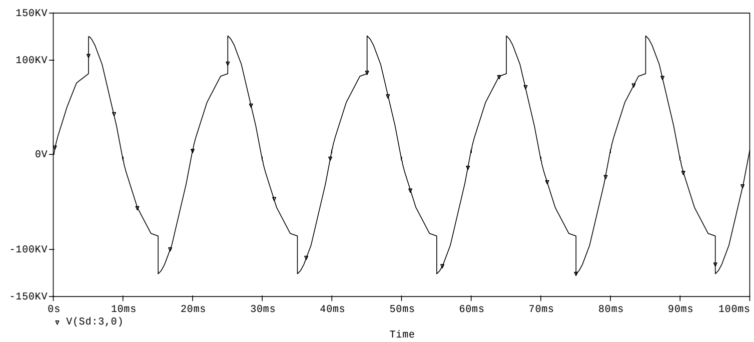

Fig.11 Load Voltage

C. ***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. The UPFC primarily injects a voltage in series with the line whose phase angle can vary between 0 to 2π with respect to the terminal voltage and whose magnitude can be varied from 0 to a defined maximum value (depending on the rating of the device). Hence, the device must be capable of generating and absorbing both real and reactive power. This controller can be realized by using two Voltage Source Converters (VSCs) employing GTOs as shown in the Fig.12.

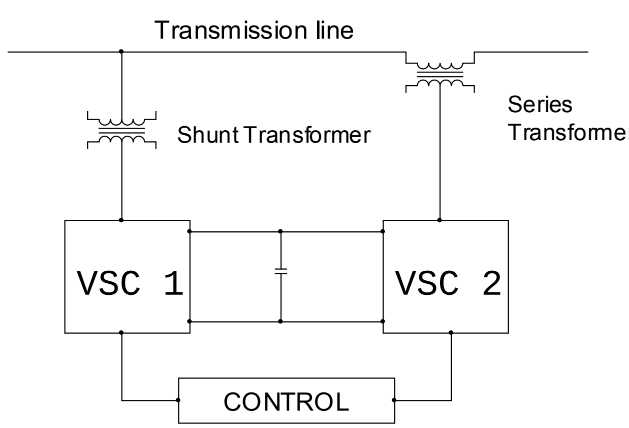

Fig.12 Basic Unified Power Flow Controller

The circuit model of UPFC system is shown in Fig.13. The current measurement block2 and block3 is used to measure the shunt reactive current and the effective current respectively. The voltage measurement block is used to measure the source voltage. R1, L1 represents the source impedance. The line impedance of (5+j0.023) Ω is represented by R2, R3, L2and L3. The load impedance of (1+j0.02) Ω is represented by R4 and L4. Scope displays the signals generated during a simulation. Scope1 is used to view the shunt reactive current. The real power and reactive power in the load is measured using the Active & Reactive Power measurement block. These powers are viewed as shown in the Fig.14.

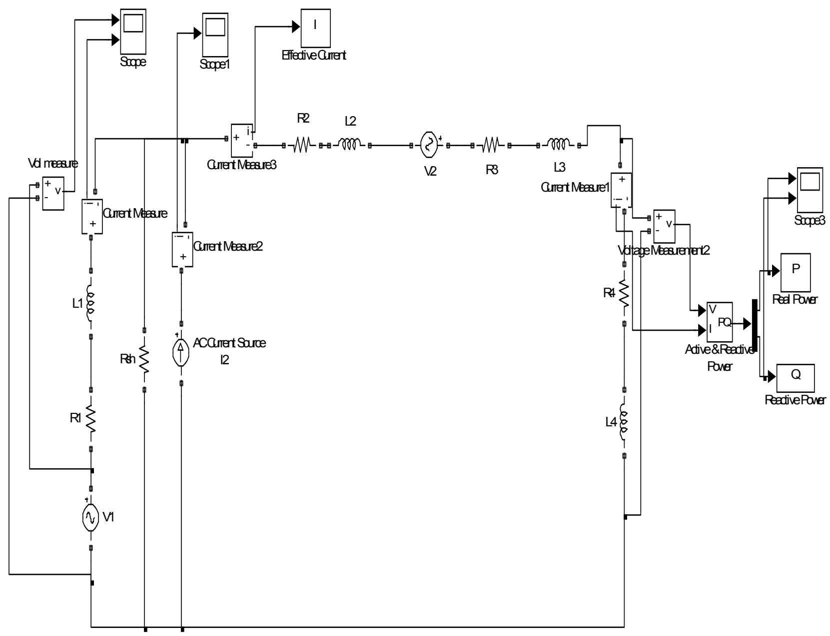

Fig.13 Simulation Circuit of UPFC

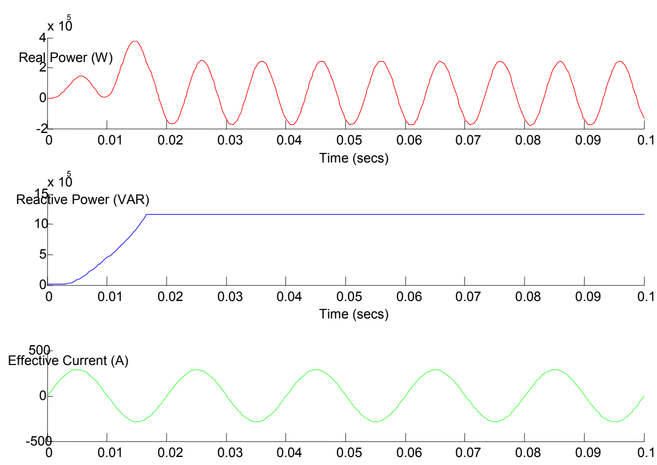

Fig.14 Effective Current, Real and Reactive Powers

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^o to 360^o. Table.6 shows the improvement in power factor obtained by injecting a series voltage of magnitude 2kV at three different angles of injection- 0^o, 50^o and 90^o for different magnitude of shunt reactive current injection.

Table.5 Variation of Real and Reactive Powers with variation in the angle of injected voltage

Angle of Injected Voltage V2 (deg)	Source Current (A)	Effective Current (A)	Real Power (MW)	Reactive Power (MVAR)
0	220	286	0.245	1.15
50	255	320	0.310	1.47
90	266	332	0.330	1.56
120	262	327	0.318	1.51
150	250	310	0.285	1.36
180	224	286	0.245	1.16
240	174	238	0.168	0.80
270	164	230	0.159	0.75
300	171	238	0.175	0.80
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^o		Voltage V2 injected at 50^o		Voltage V2 injected at 90^o	
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

III. CONCLUSION

This paper describes the control strategy for Real and Reactive powers of the transmission line using FC-TCR and the voltage regulation using TCVR and UPFC. 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 using UPFC voltage boosting in the transmission line, the power flow in the line is increased.

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