International Journal of Advanced Scientific Research and Management, Volume 3 Issue 9, Sept 2018
www.ijasrm.com
ISSN 2455-6378

Analysis and Effect of a FACT Device - Static VAR Compensator on a Long transmission Line Using Simulation

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Abstract

Static VAR compensator is a FACT device used in a transmission system , which is composition of Flexible power electronic devices, used for enhancing the prevailing transmission system capabilities to make it more effective with its flexible , fast and independent operation. The Power system complete deregulation of Generation, Transmission and Distribution as individual units can be achieved by using this FACTS device. The necessary loading capability of a prevailing transmission system can also be increased nearer to the thermal limits without affecting the stability of the system. Complete smooth control of reactive power variation using a close-loop can be achieved using shunt connected FACTS devices such as Static VAR Compensator (SVC) which can be utilized for the purpose of reactive power compensation. FACTS devices with proper Intelligence make them adaptable to the System requirements and hence it is emerging in the present state versatile transmission system. Here in this paper an attempt is made with simulation to design the Fuzzy logic control of firing angle for SVC device to achieve smooth, better, easy and adaptive control of reactive power. The aspect of design, modeling and simulations are carried out for long Transmission line of 750 km and the necessary and required compensation is placed at the load end (i.e receiving side).

Keywords- *Fuzzy logic, FACTS and SVC.*

1. Introduction

The necessary reactive power generation and absorption in power system is very much required since the reactive power is used in maintaining the voltage profile of power system stable. The main and required elements for generation and absorption of reactive power in a transmission line are transformers and alternators. The transmission line is distributed with parameters all along the line, on light loads or at no loads the system becomes predominant and further the line supplies charging VAR (i.e generates reactive power) w.r.t the load connected. To maintain the terminal voltage at the rear end i.e at load bus with adequate, the required reactive reserves are needed. So to fulfill this FACTS devices like SVC can generate or supply the reactive power to the load end side in transmission system, which helps in achieving better economy in power transfer capability.

In this paper the long Transmission line is simulated using 4π line segments by keeping the sending end voltage constant. The receiving end voltage fluctuations were observed for different loads. In order to maintain the receiving end voltage constant, shunt inductor and capacitor is added for different loading conditions. So a FACT device - SVC is simulated by means of fixed capacitor and thyristor controlled reactor (FC-TCR) which is placed at the load side. The firing angles are varied in steps for different loading conditions to see that the sending end voltage equals the receiving end voltage. Fuzzy logic controller (FLC) is trained and designed to get the required firing angles to trigger SVC so that a flat profile voltage is maintained. The results that obtained, were verified and were utilized in making fuzzy rule base to achieve required reactive power compensation for the long transmission line. Based on the results acquired for load voltage variations for different values of load capacitance, inductance and resistance a rule based fuzzy controller is designed to have a control in the firing angle for SVC in order to maintain the receiving end voltage constant automatically.

2. Operating principles and modeling of SVC

A basic single phase thyristor controlled reactor [Narain. G. Hingorani] (TCR) shown in Fig.1 has a fixed (usually air core) reactor with inductance L and a two anti parallel SCRs connected. The device is made into conduction by application of gate pulses to

International Journal of Advanced Scientific Research and Management, Volume 3 Issue 9, Sept 2018
www.ijasrm.com
ISSN 2455-6378

SCRs simultaneously without having a change in polarity. In addition to, it will automatically block the ac current whenever it crosses zero, until and unless the gate signal is reapplied again. The current value in the reactor can be controlled from maximum value (SCR closed) to zero (SCR open) by the method of firing delay angle control. That is, the if the SCR conduction is delayed with respect to the maximum of the applied voltage in each half-cycle, and the duration of the current conduction interval is controlled. This method of current control is illustrated separately for the positive and negative current cycles in Fig.2 where the applied voltage V and the reactor current $i_L(\alpha)$ at zero delay angle (switch fully closed) and at an arbitrary α delay angle are shown. When α =0, the SCR closes at the crest of the applied voltage and evidently the resulting current in the reactor will be the same as that obtained in steady state with a permanently closed switch. When the gating of the SCR is delayed by an angle α ($0 \le \alpha \le \pi/2$) with respect to the crest of the voltage, the current in the reactor can be expressed [1] as follows

$$V(t) = V \cos \omega t. \quad (1)$$

$$i_L = (1/L) \int_{\alpha}^{\omega t} V(t)dt = (V/\omega L)(\sin \omega t - \sin \alpha) \quad (2)$$

Since the SCR, by definition, opens whenever the current reaches zero, and it is also valid for the interval $\alpha \le \omega t \le \pi-\alpha$. Similarly for the subsequent negative half-cycle intervals, the sign of the terms in equation (1) becomes opposite.

From equation (1) the term $(V/\omega L) \sin \alpha = 0$ is offset which is shifted down for positive and up for negative current half-cycles obtained at α = 0, as illustrated in Fig.2. Since the SCRs automatically turns off at the instant of current zero crossing of SCR this process actually controls the conduction intervals (or angle) of the SCR. That is, the delay angle α defines the prevailing conduction angle σ ($\sigma = \pi-2\alpha$). Thus, as the delay angle α increases, the corresponding increasing offset results in the reduction of the conduction angle σ of the SCR, and the consequent reduction of the reactor current. At the maximum delay of $\alpha = \pi/2$, the offset also reaches its maximum of $V/\omega L$, at which both the conduction angle and the reactor current becomes zero. The two parameters, delay angle α and conduction angle σ are equivalent and therefore TCR can be characterized by either of them; their use is simply a matter of preference. For this reason, expression related to the TCR can be found in the literature both in terms of α and σ [Narain. G. Hingorani].

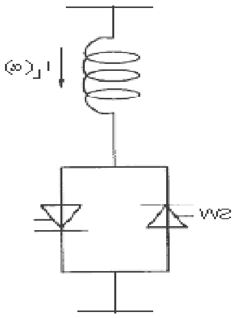

Fig. 1. Basic Thyristor Controlled Reactor

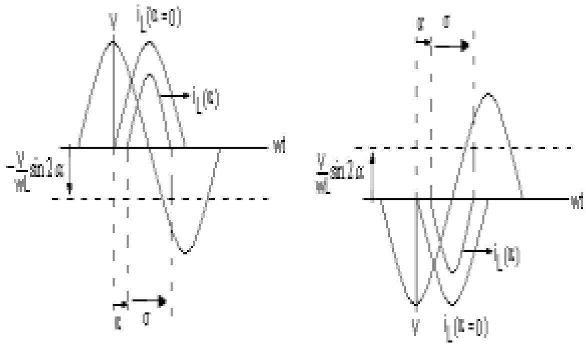

Fig.2. firing delay angle

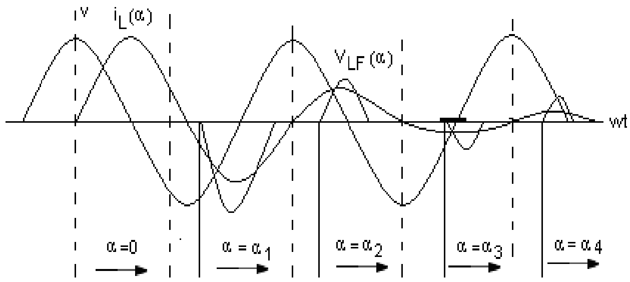

Fig. 3. Operating waveforms

It is evident that the magnitude of the current in the reactor varied continuously by delay angle control from maximum (α=0) to zero (α=π/2) shown in Fig.3, where the reactor current $i_L(\alpha)$ together with its fundamental component $i_{LF}(\alpha)$ are shown at various delay angles α [Narain. G. Hingorani]. However the adjustment of the current in reactor can take place only once in each-half cycle, in the zero to π/2 interval [Narain. G. Hingorani]. This restriction result in a delay of the attainable current control. The worst-case delay, when changing the current from maximum to zero (or vice versa), is a half-cycle of the applied ac voltage. The amplitude $I_{LF}(\alpha)$ of the fundamental reactor current $i_{LF}(\alpha)$ can be expressed as a function of angle α [Narain. G. Hingorani].

$$I_{LF}(\alpha) = V/\omega L \, (1 - (2/\pi)\, \alpha - (1/\pi) \sin(2\alpha)) \quad (3)$$

Where V is the amplitude of the applied voltage, L is the inductance of the thyristor-controlled reactor and ω is the angular frequency of the applied voltage. The variation of the amplitude I_{LF} (α), normalized to the maximum current I_{LFmax}, (I_{LFmax}= V/ωL), is shown plotted against delay angle α shown in Fig.4.

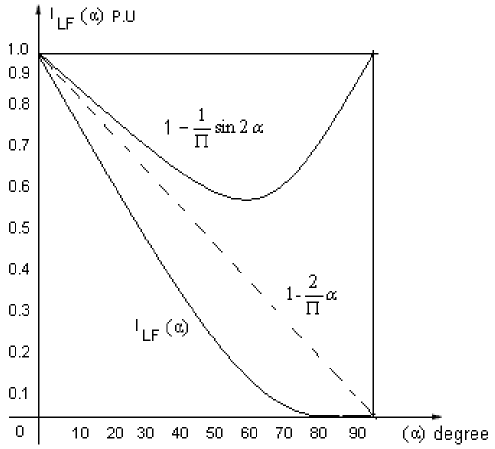

Fig.4. Amplitude variation of the fundamental TCR current with the delay angle (α)

It is clear from Fig.4 the TCR can control the fundamental current continuously from zero (SCR open) to a maximum (SCR closed) as if it was a variable reactive admittance. Thus, an effective reactance admittance, B_L(α), for the TCR can be defined. This admittance, as a function of angle α is obtained as:

$$B_L(\alpha)=1/\omega L(1-(2/\pi)\alpha-(1/\pi)\sin(2\alpha)) \quad (4)$$

Evidently, the admittance B_L(α) varies with α in the same manner as the fundamental current I_{LF}(α).The meaning of equation (4) is that at each delay angle α an effective admittance B_L(α) can be defined which determines the magnitude of the fundamental current, I_{LF}(α), in the TCR at a given applied voltage V. In practice, the maximal magnitude of the applied voltage and that of the corresponding current limited by the ratings of the power components (reactor and SCRs) used. Thus, a practical TCR can be operated anywhere in a defined V-I area, the boundaries of which are determined by its maximum attainable admittance, voltage and current ratings as illustrated in the Fig.5a. The TCR limits are established by design from actual operating requirements. If the TCR switching is restricted to a fixed delay angle, usually α = 0, then it becomes a thyristor switched reactor (TSR). The TSR provide a fixed inductive admittance and thus, when connected to the ac system, the reactive current in it will be proportion to the applied voltage as the V - I plot in the Fig.5b.

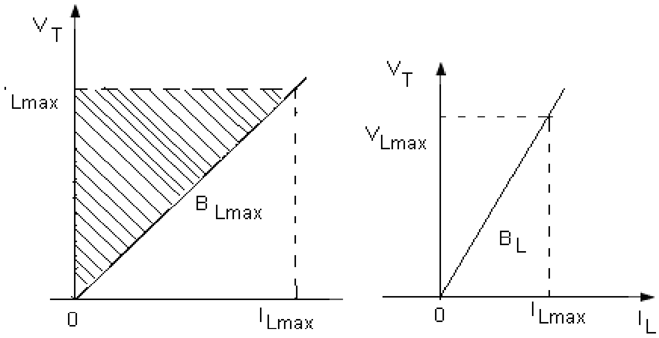

Fig.5. Operating V-I area of (a) For TCR and (b) For TSR

V_{Lmax} = voltage limit, I_{Lmax} = current limit
B_{Lmax} = max admittance of TCR,
B_L = admittance of reactor

A basic VAR generator arrangement using a fixed capacitor with a thyristor-controlled reactor (FC-TCR) shown in Fig.6 [Narain. G. Hingorani].The current in the reactor is varied by the previously discussed method of firing delay angle control. A filter network that has the necessary capacitive impedance at the fundamental frequency to generate the reactive power required usually substitutes the fixed capacitor in practice, fully or partially, but it provides low impedance at selected frequencies to shunt the dominant harmonics produced by the TCR.

The fixed capacitor thyristor-controlled reactor type VAR generator may be considered essentially to consist of a variable reactor (controlled by a delay angle α) and a fixed capacitor. With an overall VAR demand versus VAR output characteristic as shown in Fig.7 in constant capacitive VAR generator (Q_c) 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 (α= 90^0). To decrease the capacitive output, decreasing delay angle α. At zero VAR output increases the current in the reactor, the capacitive and inductive current becomes equal and thus the capacitive and inductive VARs cancel out. With a further decrease of angle α, the inductive current becomes larger than the capacitive current, resulting in a net inductive VAR output. At zero delay angle, the thyristor-controlled reactor conducts current over the full 180^o interval, resulting in maximum inductive VAR output that is equal to the difference between the VARs generated by the capacitor and those absorbed by the fully conducting reactor.

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International Journal of Advanced Scientific Research and Management, Volume 3 Issue 9, Sept 2018
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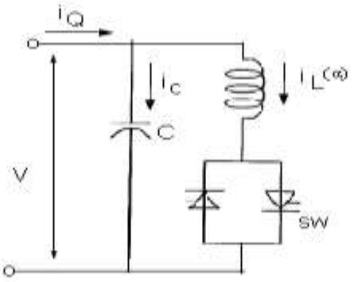

Fig.6. basic FC-TCR type static generator

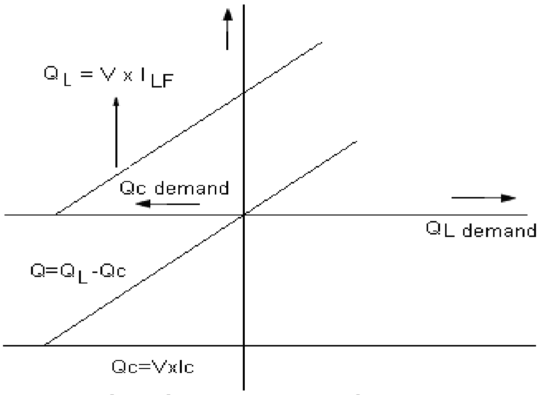

Fig.7. VAR demand versus VAR output characteristic

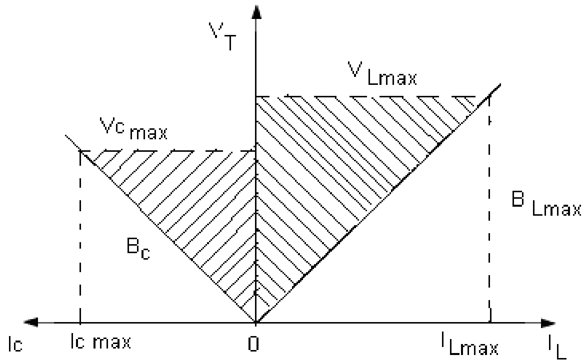

Fig.8. V-I characteristics of the FC-TCR type VAR Generator

In Fig.8 the [1] voltage defines the V-I operating area of the FC-TCR VAR generator and current rating of the major power components. In the dynamic V-I Characteristics of SVC along with the Load lines showed in the Fig.9[1] the load characteristics assumed straight lines for Dynamic studies as easily seen that the voltage improved with compensation when compared without compensation.

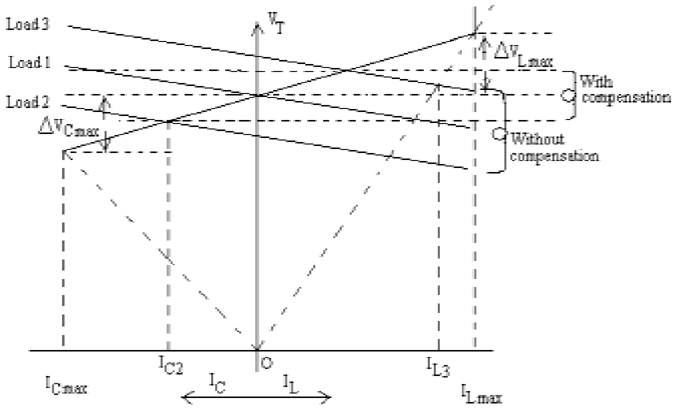

Fig.9. Dynamic V-I Characteristics of SVC with Load lines

V_{Cmax} = voltage limit of capacitor
B_C = admittance of capacitor
V_{Lmax} = voltage limit of TCR
I_{Cmax} = capacitive current limit
I_{Lmax} = inductive current limit
B_{Lmax} = max inductive admittance

3. Fuzzy logic controller

Fuzzy logic is a new control approach with great potential for real time applications [Bart Kosko,1994] [T J Ross,1997]. Fig.10 shows the structure of the fuzzy logic controller (FIS-Fuzzy inference system) in MATLAB Fuzzy logic toolbox. [MATLAB Manual][S.M.Sadeghzadeh, M. Ehsan, 1998].Load voltage and load current taken as input to fuzzy system. For a closed loop control, error input can be selected as current, voltage or impedance, according to control type [C C Lee,1990]. To get the linearity triangular membership function is taken with 50% overlap. The output of fuzzy controller taken as the control signal and the pulse generator provides synchronous firing pulses to thyristors as shown in fig.11. The Fuzzy Logic is a rule based controller, where a set of rules represents a control decision mechanism to correct the effect of certain causes coming from power system [A.M. Kulkarni,2003] . In fuzzy logic, the five linguistic variables expressed by fuzzy sets defined on their respective universes of discourse. Table-I shows the suggested membership function rules of FC-TCR controller. The rule of this table can be chosen based on practical experience and simulation results observed from the behavior of the system around its stable equilibrium points.

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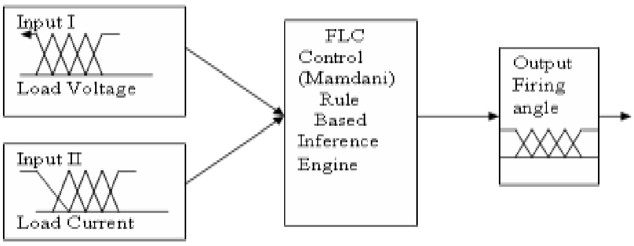

Fig.10. Structure of fuzzy logic controller

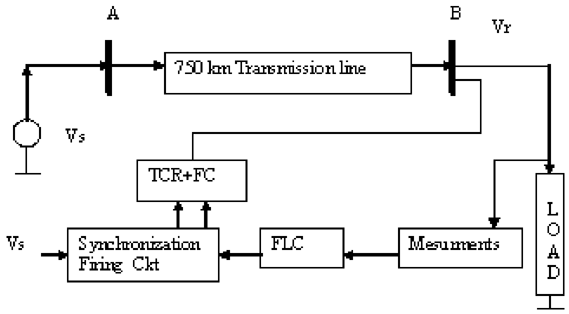

Fig.11. Single Phase equivalent circuit and fuzzy logic control structure of SVC

Table I. Membership function rules

	Load voltage					
		NL	NM	P	PM	PB
Load current	NL	PB	PB	NM	NM	NL
	NM	PB	PB	NM	P	NL
	P	P	PM	NM	NM	P
	PM	NM	P	NM	NM	PM
	PB	NL	NM	NM	NL	NL

4. Hardware implementation

An available simple two-bus artificial transmission (λ/8) line model of 4π line segments with 750 km, distributed parameters were used in this study. The line inductance 0.1mH /km, capacitance 0.01µf/km and the line resistance 0.001Ω were used. Each π section is of 187km, 187km, 188km and 188 km. Supply voltage is 230V - 50 Hz having source internal resistance of 1 Ω connected to node A. Static load is connected at receiving end B .The load resistance was varied to obtain the voltage variations at the receiving end. A shunt branch consisting of inductor and capacitor is added to compensate the reactive power of transmission line. With the change of load and due to Ferranti effect, the variations in voltages are observed at receiving end B of transmission line [A.M. Kulkarni,2003]. The practical values of shunt elements are varied for different loading conditions to get both sending and receiving end voltages equal. As shown in Table II.

Table II compensated practical values of inductor and capacitor

S.NO	Load Resistance	Compensating Inductance	Compensating Capacitance
	Ω		(µf)
1	600	0.9 H	1
2	500	0.9H	1
3	400	0.19H	2
4	300	0.18 H	5
5	150	0.19H	5
6	75	0.22H	8
7	50	0.14	8.5
8	40	0.14	9
9	30	0.14	10
10	20	0.14	12

A. *FIRING CIRCUIT DESIGN*

IC TCA 785 a 16 pin IC shown in Fig.12 is used in this study for firing the SCRs. This IC having output current of 250 mA and a fuzzy logic trainer kit with two input variables and having 5 linguistic sets is used. This can generate 5 X 5 rules. The output of fuzzy logic which varies from DC -10V to +10V is given to IC 785 controller pin11, which controls the comparator voltage VC ,and the firing angle α for one cycle and (180 +α) during negative cycle shown in fig.13

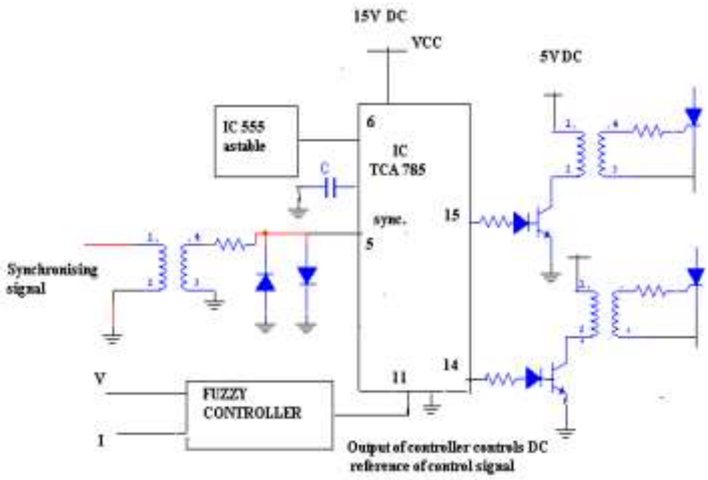

Fig.12. Firing Scheme with TCA 785 IC

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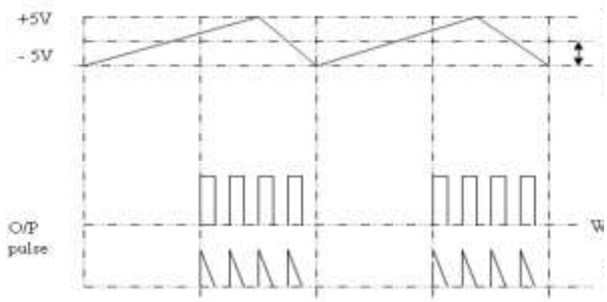

Fig.13.Generation of wave forms of TCA 785 IC

5. Test Results

Without any compensation the transmission line was not maintaining the voltage within the reasonable limits which is an essential condition. With the increase of load, the voltage level at the load end gets reduced. At light loading condition, the load voltage ie the receiving end voltage is greater than the sending end voltage, as the reactive power generated is greater than absorbed. At higher loads the load voltage drops, as the reactive power absorbed is greater than generated, as shown in Table III. Fig.14 and Fig.15 indicates unequal voltage profiles. Fig.16 clearly shows the firing angle and inductor current control.

Table III Load voltage before and after compensation

Tr Line Parameters for Lt=.10mh/km Ct =0.1µf/km R.= 0.001Ω		Before compensation For Vs= 230V (p-p)		After Compensation For L= 0.19H C= 8µ f For Vs= 230 (P-P)		
R Ω	V_S (rms) Volts	V_R (rms) Volts	I_R rms Amp	V_R (rms) Volts	I_R (rms) Amp	α.
600	163.2	271.7	0.55	163.1	2.03	90
500	163.2	269.2	0.68	163.4	2.03	95
400	163.2	269	0.91	162.8	2.09	100
300	163.2	262.2	1.33	162.5	2.18	102
180	163.2	259.2	1.46	162.4	2.19	104
160	163.2	258.1	1.6	162.3	2.23	106
140	163.2	251.4	1.79	162.9	2.29	108
120	163.2	244.9	2.04	161.9	2.35	110
100	163.2	235.3	2.39	162.6	2.45	112
80	163.2	221.7	2.78	162.9	2.65	115
60	163.2	197.2	3.33	163.3	3.07	130
50	163.2	158.7	3.97	163.5	4.12	160

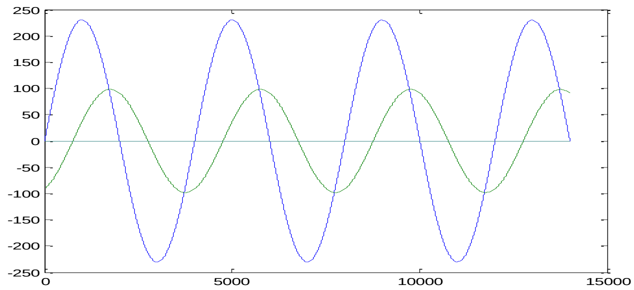
Fig.14. Uncompensated voltages for heavy loads

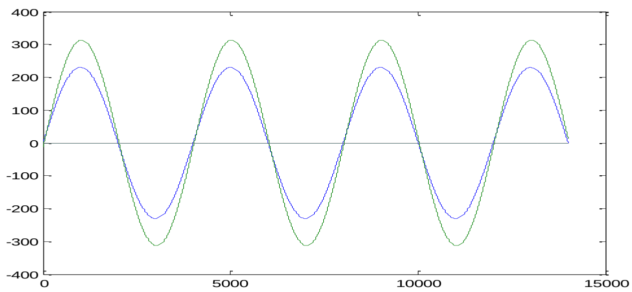
Fig.15. Uncompensated voltage for light load

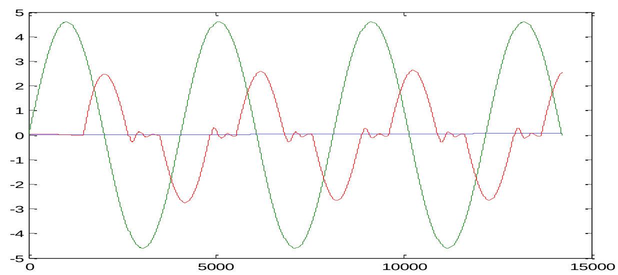
Fig.16. Inductor Current for firing angle 165 deg

6. Conclusion

This paper presents the Fuzzy logic control of firing angle for SVC in order to achieve better, smooth and adaptive control of reactive power , and it can be concluded that the use of fuzzy controlled SVC (FC-TCR) the compensating device with the firing angle control is continuous, effective and it is a simplest way of controlling the reactive power of transmission line.

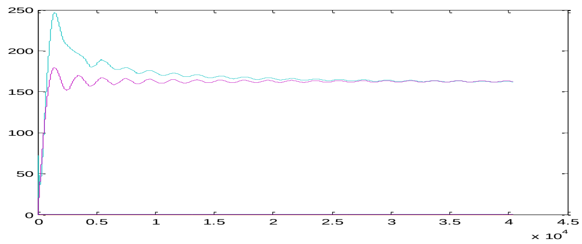
Fig.17. Compensated $V_R = V_S$ (RMS voltage) for R=200Ω

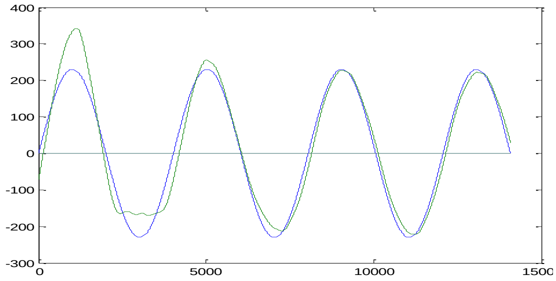

Fig.18. Compensated $V_R = V_S$ (instantaneous voltage) For R=200 Ω

It is observed that SVC device was able to compensate both over and under voltages. Compensating voltages are shown in Fig.17 and Fig.18. The use of fuzzy logic has facilitated the closed loop control of system, by designing a set of rules, which decides the firing angle given to SVC to attain the required voltage. With MATLAB simulations [4] [5] and actual testing it is observed that SVC (FC-TCR) provides an effective reactive power control irrespective of load variations.

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