International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 4 (May 2014) http://ijirae.com

Simulation and Implementation of FC-TCR

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Abstract- This paper deals with hardware implementation of fixed capacitor thyristor controlled reactor (FC-TCR) system as well as simulation of FC-TCR in various environments using PsCAD/EMTDC and Matlab/Simulink. The simulation results are presented in open loop and closed loop environment. Laboratory model for FC-TCR is implemented using low cost microcontroller techniques and successfully tested on transmission line model with various load conditions. The current drawn by SVC is varied by changing firing angle. The experimental results are compared with simulation results.

Index Terms— FACTS, Static VAR Compensator (SVC), Power Electronics, PsCAD/EMTDC, Matlab/Simulink.

I. INTRODUCTION

There is a continuous rise in demand of electrical power. To meet this rise, the growth in generation is essential, which is not always possible due to various limitations like environmental, financial, resources, land, etc. Expansion of transmission network is always not easy. Due to these problems, the entire power system is operated at its highest capacity which may generate problems of stability, voltage collapse and grid failure. To provide stable, secure and quality power supply to end users and to utilize available transfer capacities in better way, Flexible AC transmission systems (FACTS) controllers are used to enhance power system stability along with their main application of power flow control [1].

The Power electronic based FACTS devices are employed to power systems to improve system performance. FACTS are devices that can be used into power grids in series, shunt and both in shunt and series combination. With FACTS devices, the following merits can be achieved in power systems:

- Enhanced power transfer capability
- Improved system stability and power quality
- Reduced environmental impact
- Reduced transmission losses

Following types of FACTS devices are used to enhance the performance of transmission system:

(A) Shunt Devices
  i) Static Var Compensator (SVC)
  ii) Static Synchronous Compensator (STATCOM)
(B) Series Devices
  i) Thyristor Controlled Series Capacitor (TCSC)
  ii) Static Synchronous Series Compensator (SSSC)

Two types of SVCs are used frequently.

(i) Fixed Capacitor-Thyristor Controlled Reactor (FC-TCR)
(ii) Thyristor Switched Capacitor-Thyristor Controlled Reactor (TSC-TCR)

II. STATIC VAR COMPENSATOR (SVC)

Static VAR systems are employed in transmission systems for number of applications. The primary function is the fast control of voltage in a transmission network. The device may be installed at the midpoint of transmission lines or at the ends. SVCs are shunt connected static generators / absorbers whose outputs can be changed to control the voltage of the systems [2].

An SVC can improve the performance of transmission and distribution in a number of ways. Providing an SVC at one or more locations in the network, can increase power transfer capability and minimize the losses and maintain a smooth voltage profile under different operating situations. The dynamic stability of the system can also be improved, and active power oscillations mitigated. The use of SVC gives the following advantages:

- Voltage stability in the system
- Less transmission losses
- Enhanced transmission capacity, so more power can be transferred
- Higher transient stability limit
- Damping of small disturbances
- Reduced voltage fluctuations and light flicker

In its simplest form, SVC is used as Fixed Capacitor-Thyristor Controlled Reactor (FC-TCR) configuration as shown in Fig. 1.

The TCR branch provides continuously controllable reactive power only in the lagging power-factor region. To extend the controllable range to the leading power-factor region, a fixed-capacitor bank is connected in shunt with the TCR. The TCR MVAr is rated larger than the fixed capacitor to compensate the capacitive MVAr and provide net inductive-reactive power should a lagging power-factor operation be desired [3].

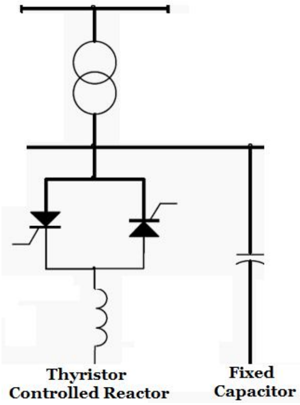


Fig.1: Configuration of FC-TCR

The fixed-capacitor banks, generally connected in a star configuration, are split into 3-phase group. Each capacitor consists of a small tuning inductor which is connected in series and tunes the branch to work as a filter for a specific harmonic order [4].

III. SIMULATION OF FC-TCR

For simulating SVC and to observe the effectiveness of SVC system chosen for study is shown in Fig. 2. The source is connected by transmission line with fixed capacitor in parallel with thyristor controlled reactor (TCR) branch with parallel load-1 and load-2. Load-1 is fixed while load-2 is operated by breaker after specified time duration to affect the system voltage and reactive power requirement. Normally loads are RL in nature so here parallel RL load is considered[5].

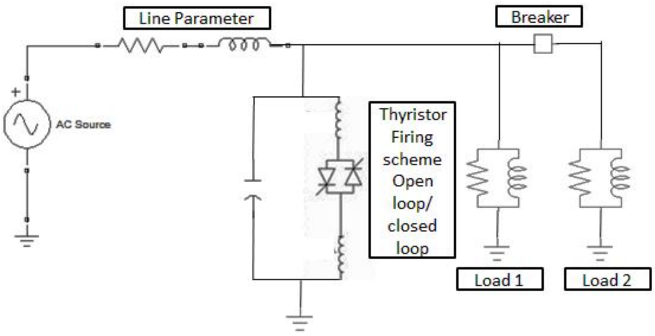


Fig. 2: System Considered for Simulation

To implement FC-TCR in system first and foremost thing is the sizing of capacitor and inductor. If breaker is open there is no need to put SVC in operatiion. Inital firing angle α must be such that under condition that SVC does not exchange any power with AC system. To illustrate SVC's ability for providing voltage regulation at the point of connection control scheme has been implemented in closed loop as well in open loop environment in two different software simulations PsCAD/EMTDC and Matlab/Simulink[6]. SVC voltage and current waveforms for different firing angles are shown in figure 3.

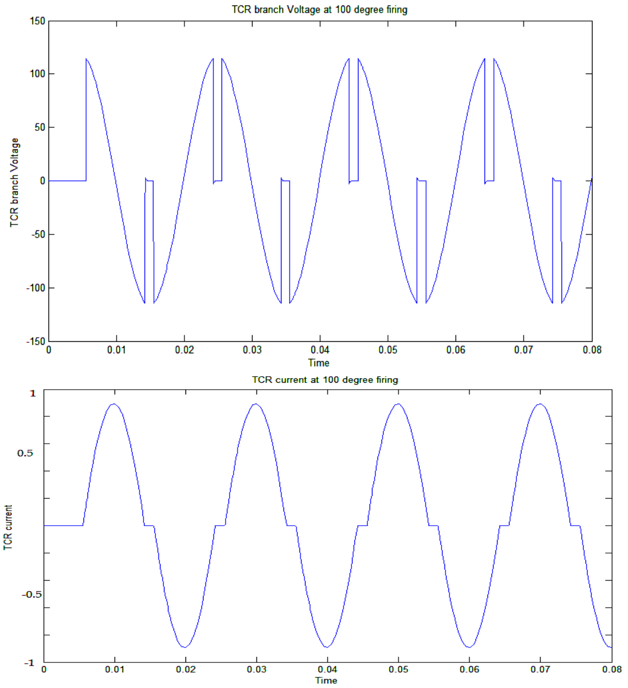


Fig. 3 SVC Voltage and Current at $\alpha = 100^o$

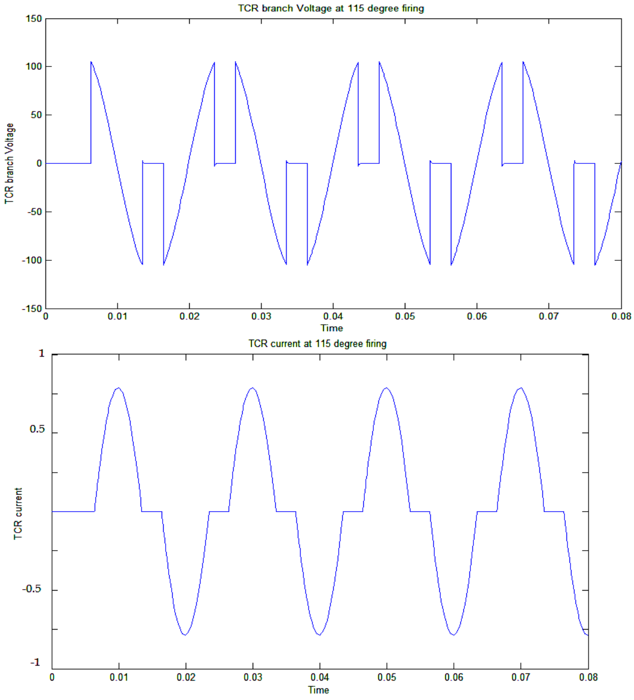
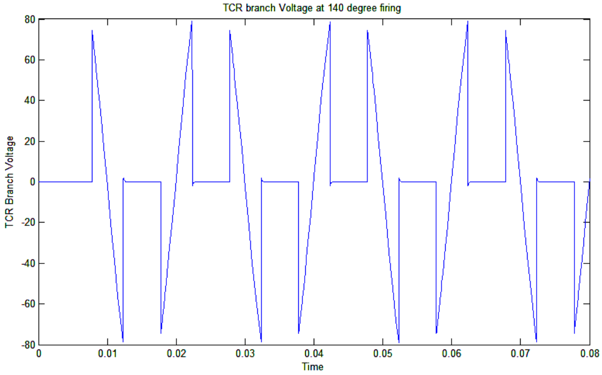


Fig. 4 SVC Voltage and Current at α = 115°



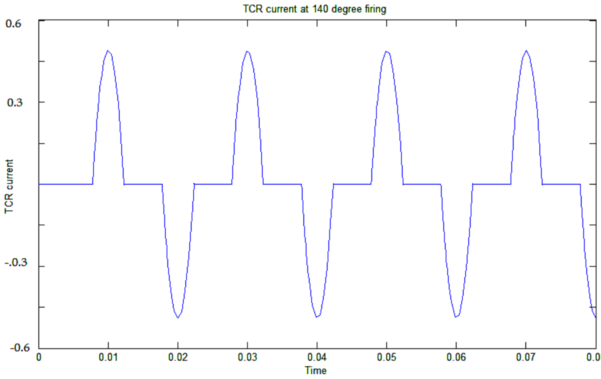


Fig. 5 SVC Voltage and Current at α = 140°

Fig. 6 shows PsCAD/EMTDC results for load change at 0.3second for the duration of 0.15second again break opens the load at 0.45 seconds.

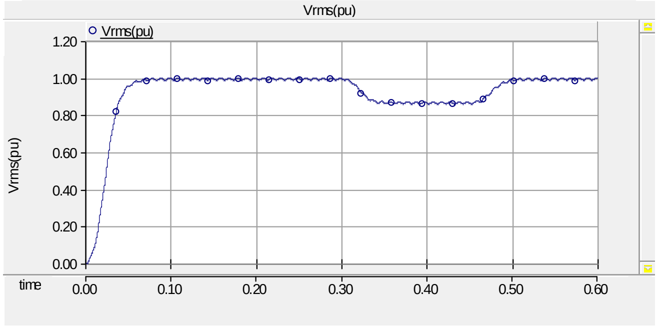


Fig. 6: Open loop voltage at load point in pu

Incase X_C and X_L cancel out each other, in that case SVC reactance is infinite and there is no current leaving or entering the SVC so power exchange between SVC and the source or load system is zero.

TCR equivalent reactance is given by[4]

$$X_{\mathrm{TCR}} = \frac{\pi X_L}{\sigma - \sin\sigma}$$

and

$$\sigma = 2(\pi - \alpha)$$

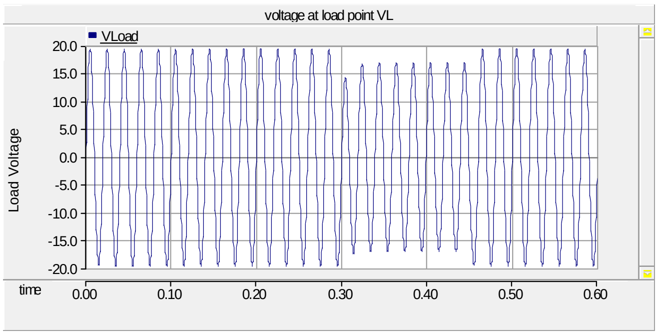


Fig. 7: Open Loop Load Voltage in kV

where XL is the reactance of the linear inductor and σ & α are the thyrisotr conduction and firing angles respectively At α =90° TCR conducts fully and the equivalent reactance X_{TCR} becomes X_L. At α =180° TCR blocked and its equivalent reactance becomes extremely large i.e infinite[5].

Total SVC reactance including capacitor branch is given by

$$X_{SVC} = \frac{X_C X_{TCR}}{X_C + X_{TCR}}$$

And as function of conduction angle σ

$$X_{SVC} = \frac{\pi X_C X_L}{X_C(\sigma - \sin\sigma) - \pi X_L}$$

And as a function of firing angle α

$$X_{SVC} = \frac{\pi X_C X_L}{X_C[2(\pi - \alpha) + \sin 2\alpha] - \pi X_L}$$

So we can say that effective reactance of SVC branch is function of firing angle α.

In closed loop scheme amplitude of bus voltage is measured and converted to pu system and filtered. then it is compared against voltage reference[9]. difference of two voltage reading is processed by PI controller which causes a corresponding change in firing anlge α. the value provided by PI controller is used as input to TCR firing angle control unit.

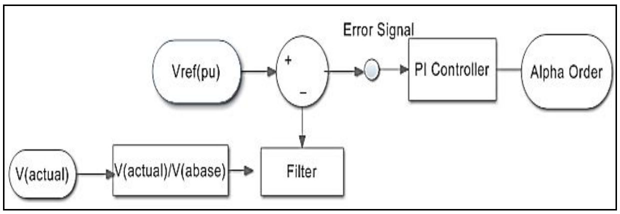


Fig 8: Close loop control scheme

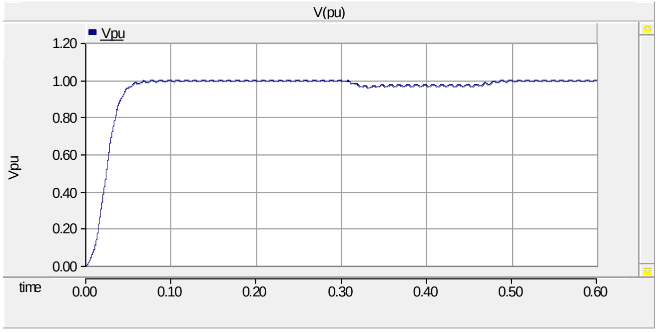


Fig. 9: Close loop voltage at load point in pu

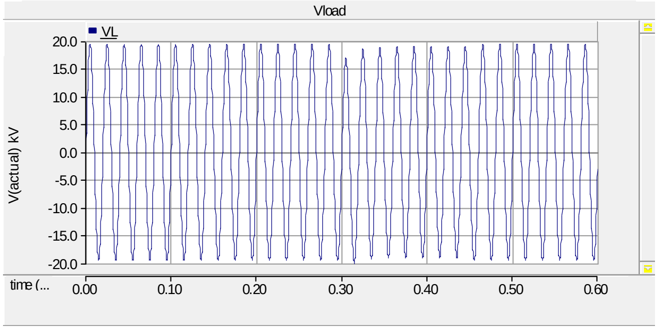


Fig. 10: Close loop voltage at load point in kV

IV. HARDWARE IMPLEMENTATION

Here the hardware setup is done on medium transmission line model and under variable RL load condition firing angle is set to change the requirement of reactive power injection into the system. The firing angle is generated using microcontroller 89C51 (8051). The pulses are generated based on Zero crossing detector circuit input of ZCD is given to controller based on ZCD output microcontroller generates pulses and that is given to antiparallel connected thyristor with isolation using coupler ICs. In actual single pulse is generated that is inverted and given to second thyristor of same leg with assurance of avoiding short circuit of the thyristor pair leg.

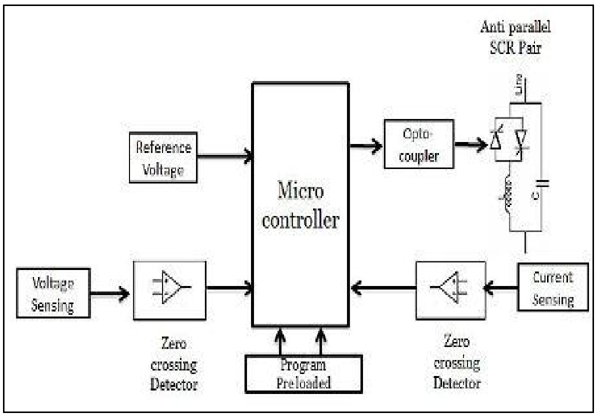


Fig. 11: Controlling scheme for TCR branch

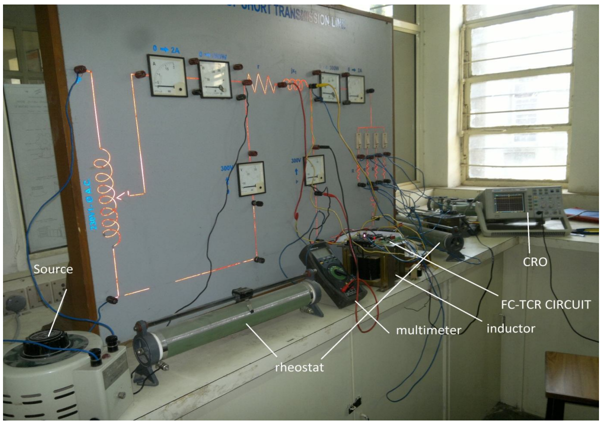


Fig.12: Hardware implementation of TCR

Experimental setup of the hardware is shown in Fig. 12, is very similar to system that is simulated in Matlab and PsCAD. Load in laboratory setup is chosen as RL load and value of Fixed Capacitor is 125 µf and inductor of 100mH. Sending end voltage is set to 110Volt and receiving end voltage is measured for various load condition.

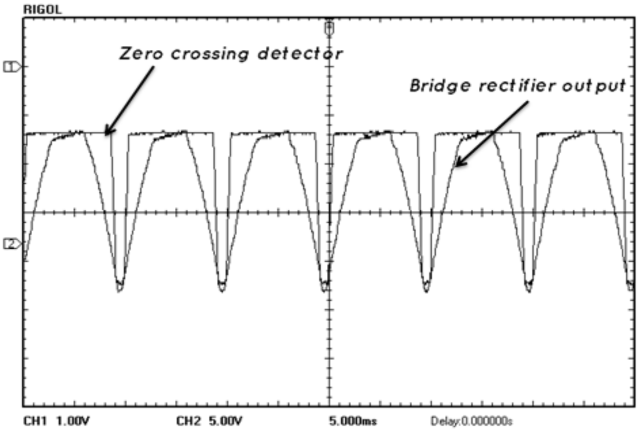


Fig. 13: Comparison of rectifier output with ZCD pulses

After implementing hardware circuit with full wave bridge rectifier and zero crossing detector using dual operational amplifier output signals are obtained as shown in figure 13 at each zero crossing pulses are generated from operational amplifier the same pulses are given to microcontroller unit and then processed for delay operation for firing of thyristor.

V. RESULTS

With alpha α =126^{o} pulse and waveform is shown in figure 17. Ultimately with increase in firing angle current decreases. So the system reactive power can be varied by varying the firing angle α. Readings are taken for various load condition tabulated in table1 and table2 withour SVC and with SVC(variable firing angle α). Table 3 shows variation of SVC current with variable anlge α.

TABLE I. BUS VOLTAGE VARIATION WITHOUT SVC

Bus Voltage Variation Without SVC						
Sr. No	Sending voltage Vs (v)	Current-Sending Is(amp)	Power-Sending Ws (Watt)	Power-Receiving Wr (Watt)	Current-Receiving Ir (Amp)	Receiving Voltage Vr (V)
1	110	0.3	39	38	0.3	106
2	110	0.42	42	41	0.42	104.7
3	110	0.61	53	52	0.61	102

TABLE II. BUS VOLTAGE VARIATION WITH SVC

Bus Voltage Variation With SVC							
Sr No	Sending end Volt Vs	Current Is (amp)	Sending end Power Ws (watt)	Power Wr (Watt)	Current Ir (Amp)	Receiving end Voltage Vr	Firing angle in degree
1	110	0.6	41	39.5	0.27	116	100^{o}
2	110	0.63	50	48	0.39	114	115^{o}
3	110	0.71	53	52	0.51	110	140^{o}

TABLE III. FIRING ANGLE AND TCR CURRENT

Sr. No	Sending end Voltage (volt)	Alpha(α Degree)	Itcr
1	110	100^{o}	0.9
2	110	115^{o}	0.3
3	110	140^{o}	0.3

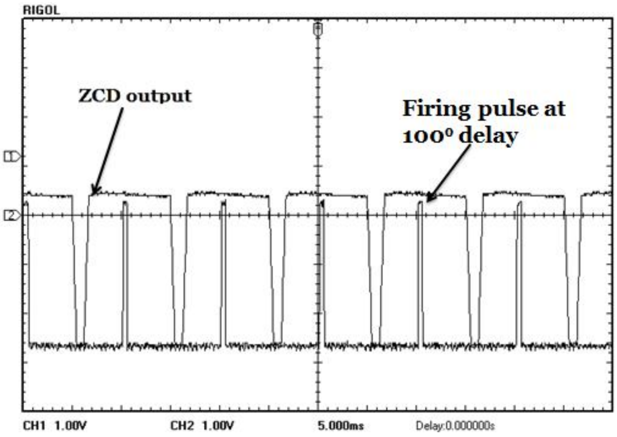


Fig.14: Firing pulses at 100^{o} comparison with ZCD signal

Results are obtained for open loop control of TCR branch by firing pulses generated from microcontroller for various delay angles and result is tabulated in table I, II, and III. Waveform obtained for firing angle at 100, 115 and 140 are shown in figure 14, 15 and 16.

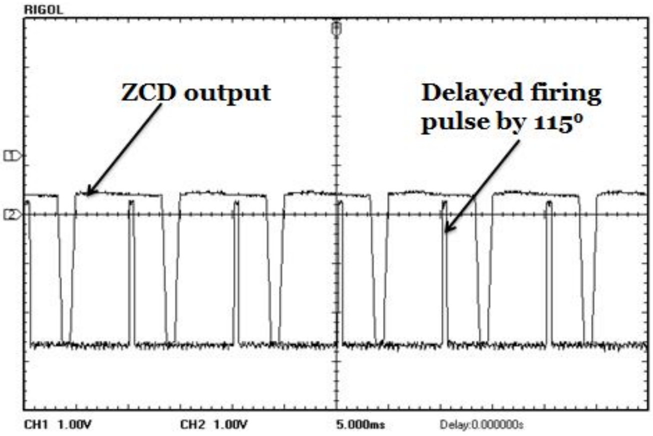


Fig. 15: Firing pulses at 115^{o} comparison with ZCD signal

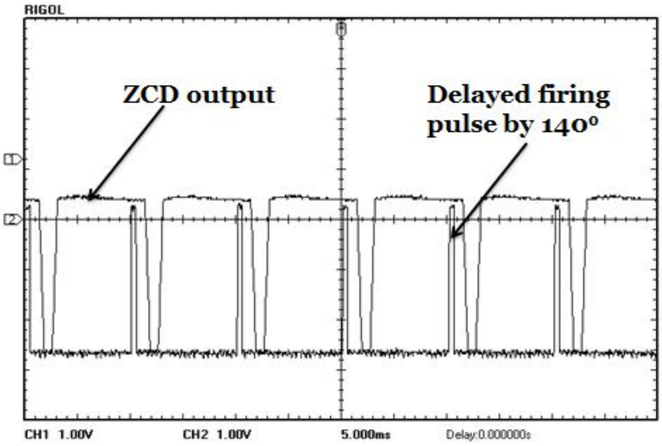


Fig. 16: Firing pulses at 140^o comparison with ZCD signal

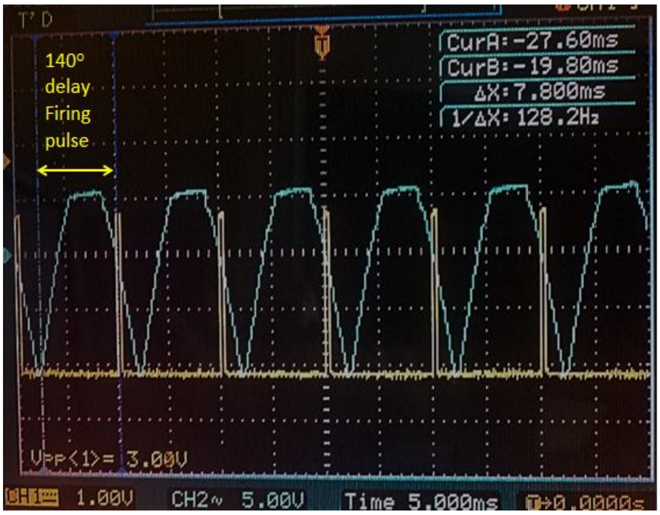


Fig. 17: Firing pulse for α=140˚

VI. CONCLUSION

From the simulation results for FC-TCR using Matlab-Simulink and PsCAD it is found that suggested scheme can effectively use to control voltage and reactive power profile. Simulation results are verified using hardware implementation and it is found that FC-TCR is effective compensation technique compare to mechanical operated or other dynamic power flow controllers. Also it is observed that in closed loop system the performance of system improved as well response time of system is very fast.

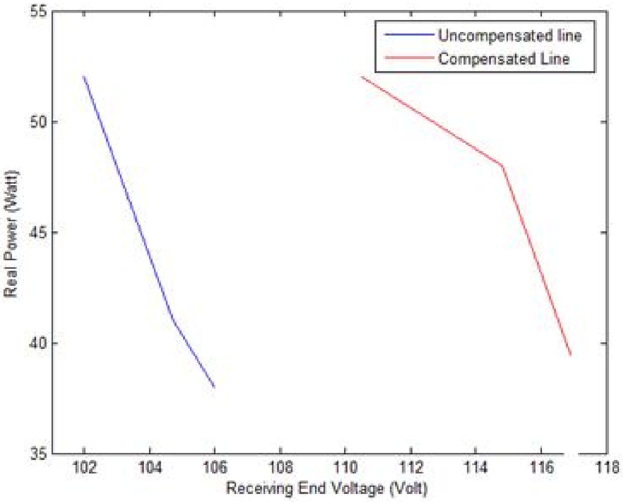


Fig. 18: Real power v/s receiving end voltage

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