Experimental Results of Microcontroller Based FC-TSR-TCR Systems

T.Vijayakumar and A.Nirmalkumar

***Abstract*—** This paper deals with the simulation and experimental results of Fixed Capacitor Thyristor switched Reactor Thyristor controlled reactor (FC-TSR-TCR) system. The FC-TSR-TCR system is simulated using MATLAB and the simulation results are presented. The power and control circuits are simulated. Laboratory model for the FC-TSR-TCR system is implemented using Atmel microcontroller and it is tested. The current drawn by the FC-TSR-TCR varies with the variation in the firing angle. Stepped variation of current is obtained using thyristor switched reactor. The experimental results are compared with the simulation results.

***Index Terms*—** FACTS, FC-TSR-TCR, MATLAB, SIMULINK, Reactive POWER.

NOMENCLATURE

α - Delay Angle

i_L (t) - Current in the Reactor

σ - Conduction Angle

$i_{LF}(\alpha)$ - Fundamental Reactor Current

V - Amplitude of the applied AC Voltage

L - Inductance of the Thyristor Controlled Reactor

ω - Angular Frequency of the Applied Voltage

$i_{LF\ max}$ - Maximum Current

X_c - Equivalent series reactance of the capacitor

X_L - Equivalent series reactance of the Inductance

V_c - Capacitor Voltage

I_{FL} - fundamental reactor current

I_T - Current Drawn by the Thyristor

f - Frequency

T - Time Period of the Applied AC Voltage

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I. NTRODUCTION

In the control of Electric Power Systems, systems and procedures are used to compensate dynamically the detrimental effects of non-linear loads. The compensation process should be carried out without important alteration of source signal quality. Some benefits are expected using compensation reduction of losses in distribution lines, harmonic content minoration, and power factor improvement. The dynamic behavior of industrial loads requires the use of compensator that can be adapted to load changes. Unfortunately, the techniques frequently used for compensation are based on circuit controllers that alter the waveform of the signal subjected to control. Such is the case of the *static compensator* [1-2], which must perform harmonic cancellation, reactive power compensation, power factor correction, and energy saving. Although the static compensator is commonly used and studied under sinusoidal voltage conditions, waveforms corresponding to the controlled current present high harmonic content.

This paper focuses on the fixed capacitor Thyristor switched Reactor Thyristor controlled reactor [3]. as shown in Fig 1. Compensation with FC-TSR-TCR consists of controlling the current in the reactor L from a maximum (thyristor valve closed) to zero (thyristor valve open) by the method of firing delay angle control. The fixed capacitor (FC) and TCR constitute a basic VAR-generator arrangement (FC-TCR). The constant capacitive VAR generation of C is opposed by the variable VAR absorption of the TCR. The Simulink circuit model of FC-TSR-TCR system is shown in Fig 2.

Calculation of the firing angle can be made in the time domain [4] or in the frequency domain[5]-[6], using different approaches. Assuming the supply voltage to be sinusoidal, calculation of the firing angle is obtained with minimum complexity [1],[7].,The variation of firing angle α from 90^0 to 180^0 produces increasing distortion of the current in the FC-TSR-TCR branch, and consequently that of line current. It increases the RMS value of the line current and the THD, and deteriorates the power factor.

The literature [1] to [20] does not deal with the implementation of FC-TSR-TCR system. An attempt is made in the present work to implement FC-TSR-TCR system using Atmel microcontroller.

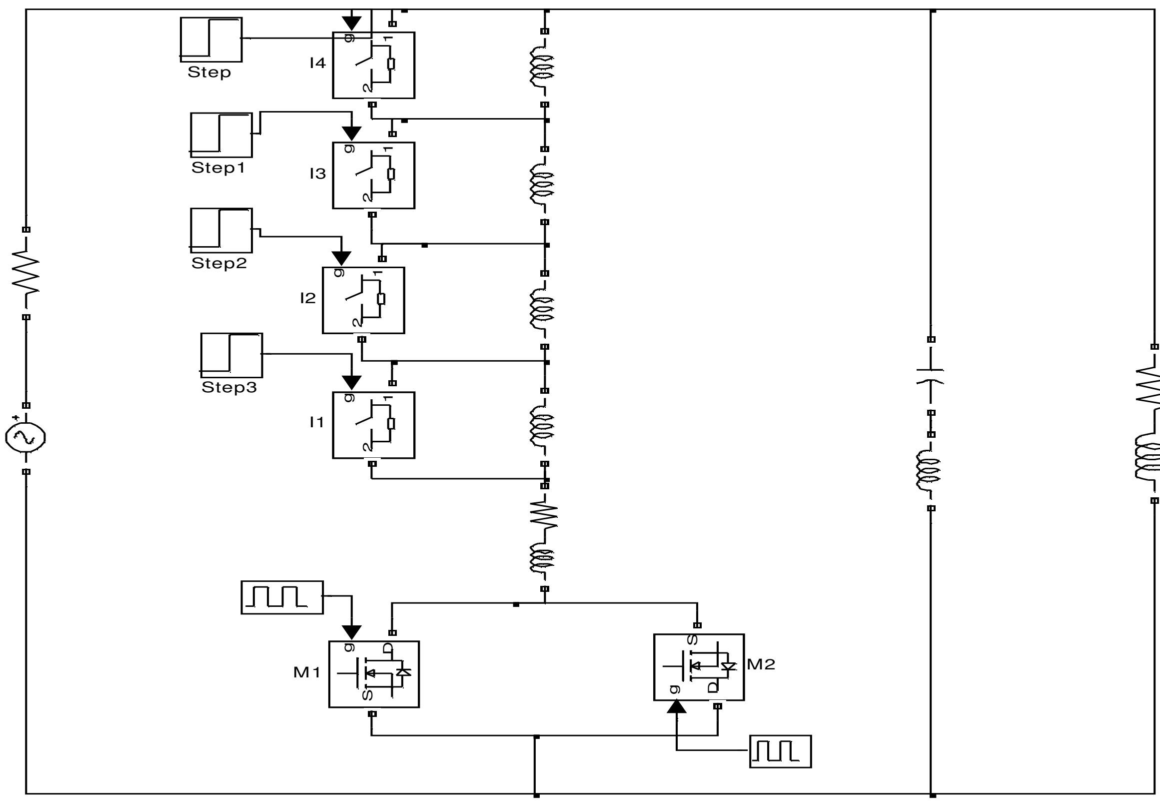

Fig1.Basic Circuit Diagram of FC-TSR-TCR

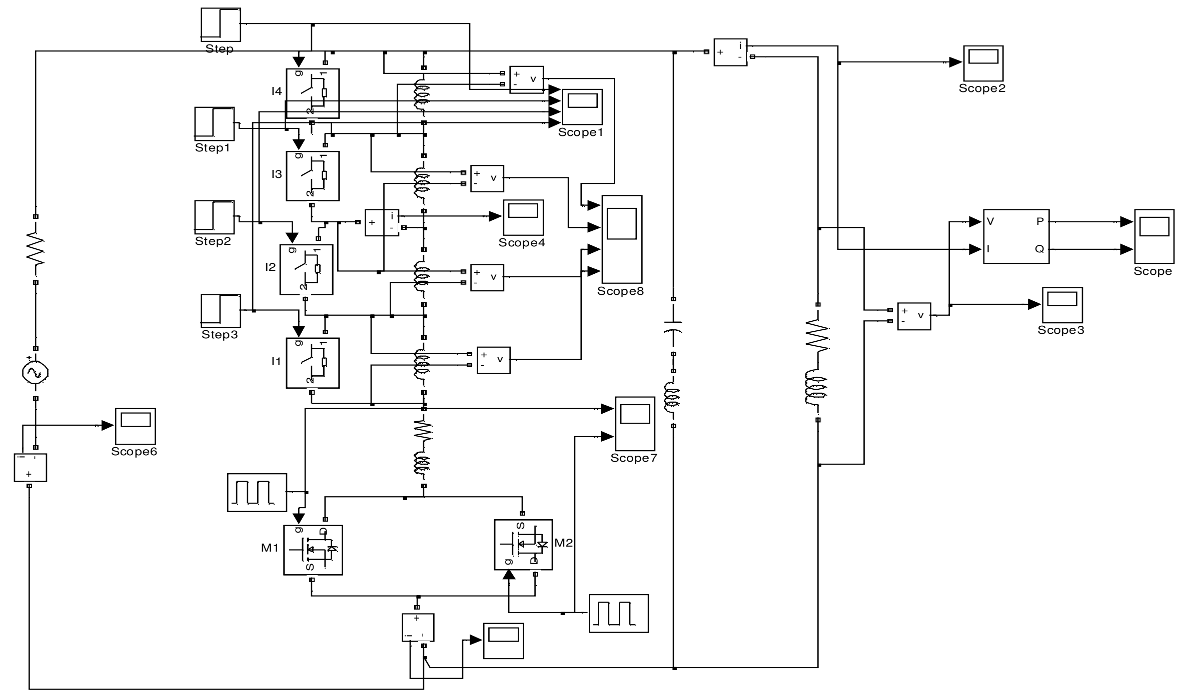

Fig2 Simulink Circuit Diagram

Anomalous phenomena of conduction angle in TCR-SVC and its control is given in [8]. A sub harmonic oscillation related to Switching nonlinearity in TCR-SVC is given in [9]. Optimal Placement of SVC for static and Dynamic Voltage Security Enhancement is given in [10]. Modelling and Simulation of Static VAR Compensator with Matlab is given in [11]. Power analysis of static VAR compensators is given in [12]. Mathematical Modelling and Simulation of SVC and STATCOM into a Power System is given in [13]. A Compact Control Algorithm for Reactive Power Compensation and Load Balancing with Static VAR Compensator is given in [14]. Modeling and Application Studies for a Modern Static VAR System Installation is given in [15]. Optimal Network Placement of SVC Devices is given in [16]. Optimal Placement of Facts Controllers in Power Systems via Evolution Strategies is given in [17]. An Approach for Optimal Placement of Static VAR Compensators Based on Reactive Power Spot Price is given in [18]. Comparison of shunt capacitor, SVC and STATCOM in static voltage stability margin enhancement is given in [19]. Optimal PI Controller Design and Simulation of a Static VAR Compensator Using Matlab's Simulink is given in [20].

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II. FC-TSR-TCR SYSTEM

The FC-TSR-TCR system is modified by introducing TCRs. The TSR system gives stepped variation of current and TCR gives smooth variation of current. Thus the range of control of reactive power can be increased by using TSR. The TSR system consists of three reactors and three IGBTs. Three different amplitudes of currents can be obtained by using three switches. The FC-TSR-TCR system is best suitable for dynamic loads. The RMS value for the current is as follows

$$I_{RMS} = \frac{I_M}{\sqrt{2}}(\pi - \alpha + Sin2\alpha/2)^{1/2} \quad (1)$$

The average thyristor current is

$$I_T = \frac{I_M}{\pi}(1 + Cos\alpha) \quad (2)$$

The current in the reactor can be expressed with v (t) = V Cos ωt as follows:

$$i_L(t) = \frac{1}{L}\int_{\alpha}^{\omega t} v(t)dt = \frac{V}{\omega L}(\sin\omega t - \sin\alpha) \quad (3)$$

The fundamental reactor current $I_{LF}(\alpha)$, can be expressed as a function of angle α:

$$I_{LF}(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right) \quad (4)$$

The amplitudes of these are a function of angle *α*, as expressed by the following equation:

$$I_{Ln}(\alpha) = \frac{V}{\omega L}\frac{4}{\pi}\left\{\frac{Sin\alpha Cos(n\alpha) - nCos\alpha Sin(n\alpha)}{n(n^2-1)}\right\} \quad (5)$$

Under steady-state conditions, when the thyristor valve is closed and the TSC branch is connected to a sinusoidal ac voltage source, v = V sin wt, the current in the branch is given by

$$i(\omega t) = V\frac{n^2}{n^2-1}\omega C\cos\omega t \quad (6)$$

Where

$$n = \frac{1}{\sqrt{\omega^2 LC}} = \sqrt{Xc}/\sqrt{X\,L} \quad (7)$$

III. SIMULATION RESULTS

The simulation circuit of FC-TSR-TCR system is shown in Fig2.The scope-1 is used for indicating the switching pulses for the controlled reactors. The scope-2 represents the current through the load.Scope-3 indicates the voltage across the load. Scope-4 is used to indicate the real and reactive powers.Scope-5 represents the source current. The input current is shown in Fig 3a. The pulses given to the gates of S_1 and S_2 are shown in Fig 3b. The voltage across the tapped reactor is shown in Fig 3c. The pulses given to the IGBT's across the reactors are shown in Fig 3d. Four different switching combinations are used as shown in Fig 3d. The load current is shown in Fig 3e. The voltage across the load is shown in Fig 3f. The active and reactive powers are shown in Fig 3g.Current through the reactor with L = 10mH is shown in Fig 3h. Current with L = 40mH is shown in Fig 3i. Current through the reactor with L = 70mH is shown in Fig 3j. The variation of current with the inductance is given in the curve shown in Fig 3 k. It can be seen that the TCR current decreases with the increase in the value of inductance.L

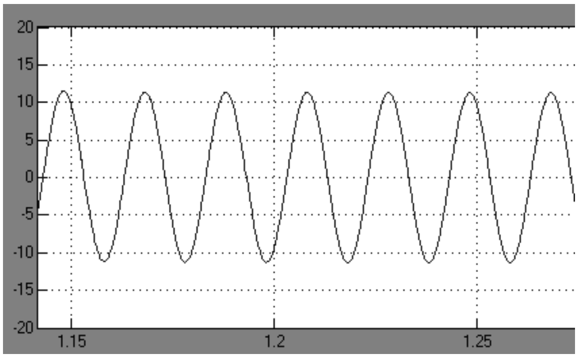

Fig 3a Source Current

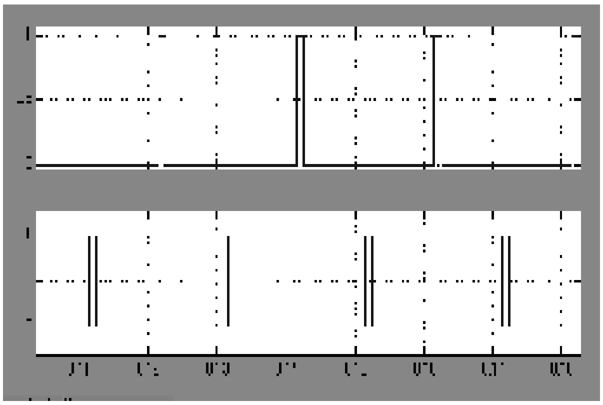

Fig 3b Switching Pulses for S_1 & S_2

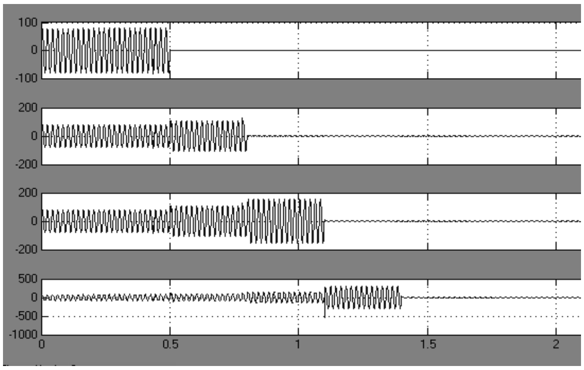

Fig 3c Voltage across Tapped Reactors

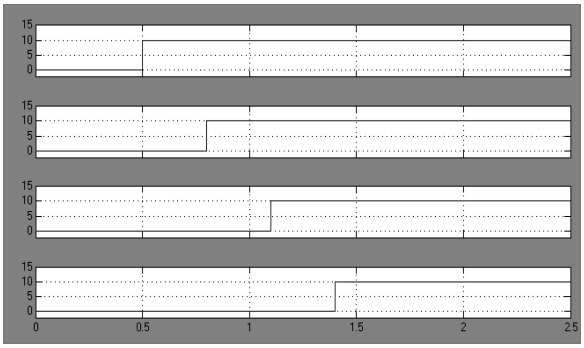

Fig 3d Switching Pulses for Shunt Switches

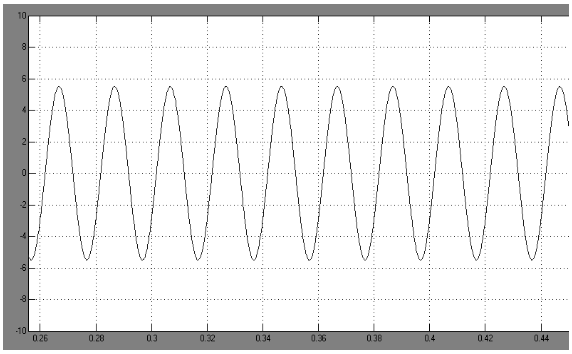

Fig 3e Output Current

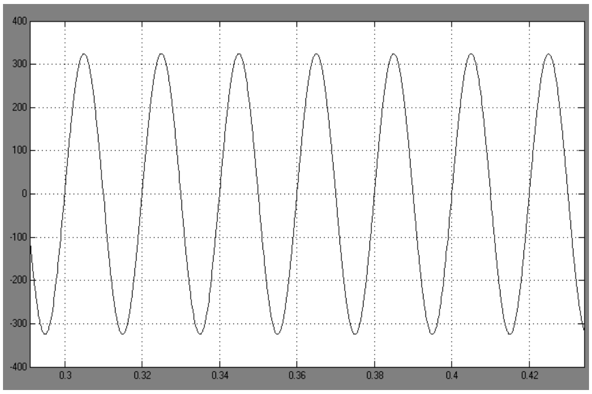

Fig 3f Output Voltage

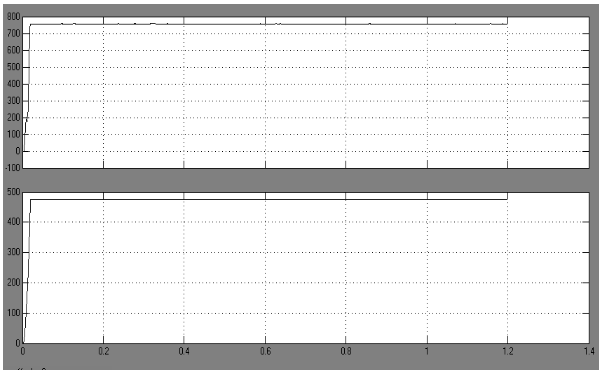

Fig 3g Active & Reactive Powers in the Load

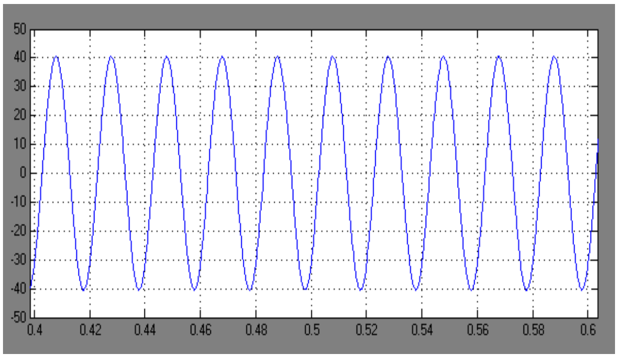

Fig 3h Current through TCR with L=10mH

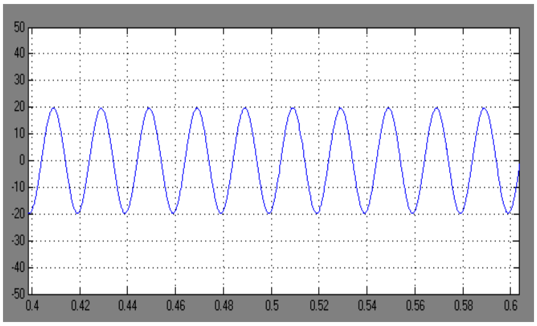

Fig 3i Current through TCR with L=40mH

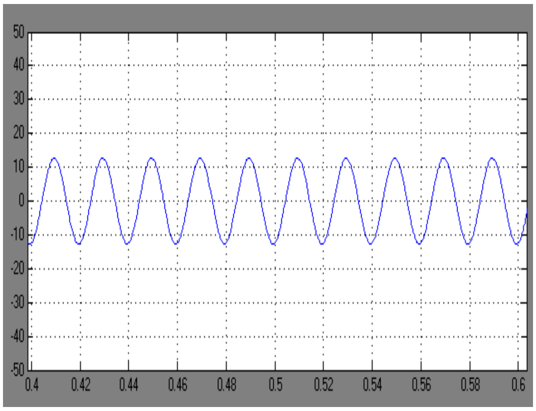

Fig 3j Current through TCR with L=70mH

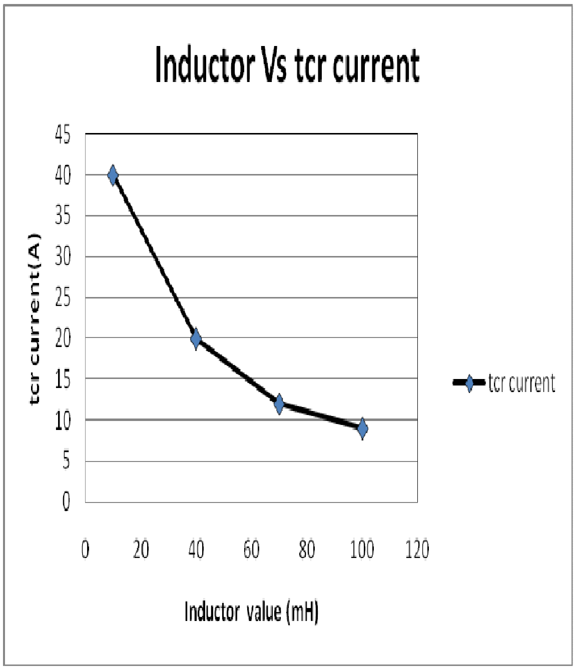

Fig 3k Variation of TCR current

IV. EXPERIMENTAL RESULTS

The hardware is implemented using Atmel microcontroller. The hardware layout is shown in Fig 4a. The hardware consists of driver board and power circuit board. Driving pulses to the MOSFET are shown in Fig 4b.Current through the reactor with L = 70mH is shown in Fig 4c.Current with L = 40mH is shown in Fig 4d. Current through the reactor with L = 10mH is shown in Fig 4e. From the figures 3 and 4, it can be seen that the experimental results coincide with the simulation results.

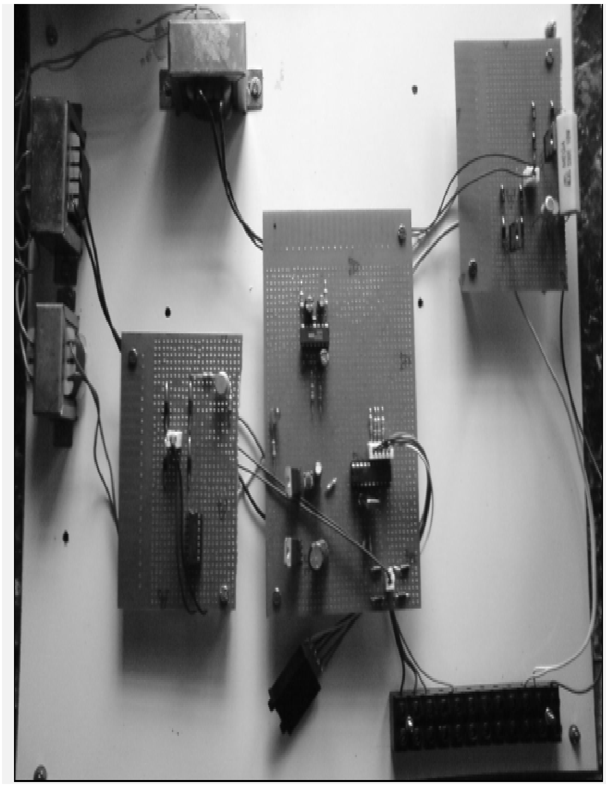

Fig 4a Hardware Layout

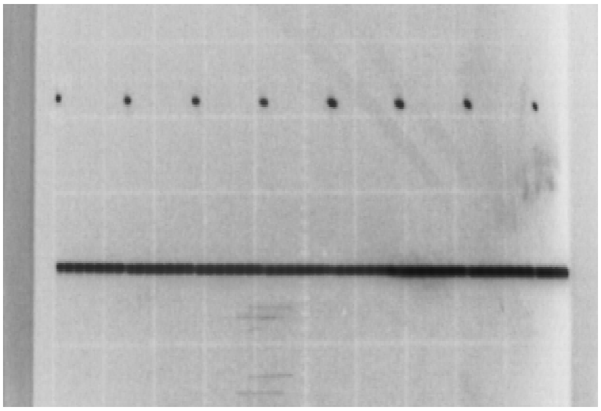

Fig 4b Driving Pulses

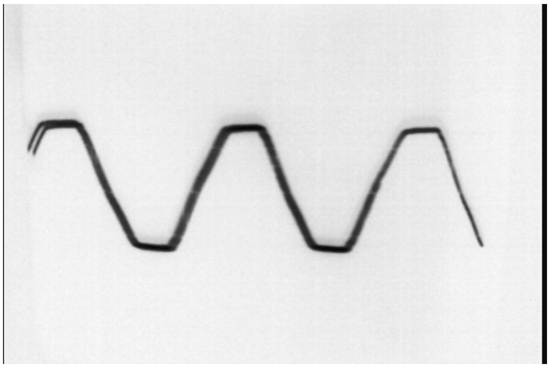

Fig 4c. Current through reactor with L=10mH

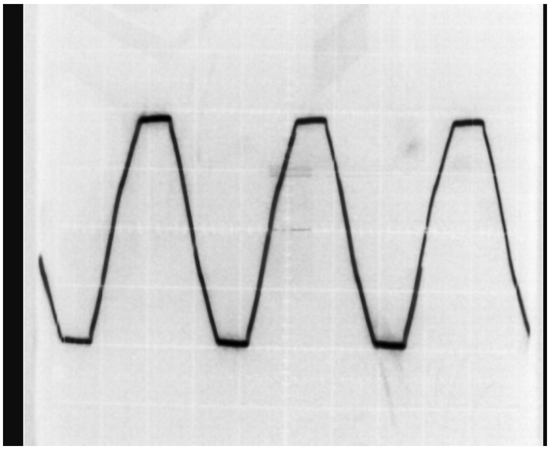

Fig 4d. Current through reactor with L=40mH

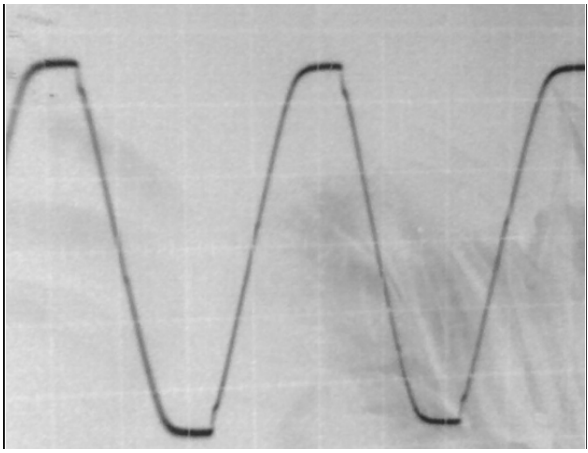

Fig 4e. Current through reactor with L=70mH

V CONCLUSION

The variation of reactive power using tapped inductor FC-TSR-TCR is analyzed. The variation of reactive power with the variation in the firing angle is studied. The range of reactive power control can be increased by using the combination of thyristor controlled reactor and fixed capacitor system. The circuit model for FC-TSR-TCR is obtained and the same is used for simulation using Matlab Simulink. From the simulation studies, it is observed that reactive power variation is smoother by using FC-TSR- TCR system. The experimental results are almost similar to the simulation results.

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