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An Improved Method for Starting of Induction Motor with Reduced Transient Torque Pulsations

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Abstract: Three phase induction motor produces severe starting torque pulsations. This causes shocks to the driven equipment and damage to the mechanical system components. In this method a novel method for starting of induction motor is proposed. The scheme depends on initial switching instances at which each phases of motor terminals are connected to the supply. A mathematical model for a three phase induction motor is developed in matlab/simulink and observed the effectiveness of the system in the elimination of torque pulsations. Hardware is implemented with an AC voltage controller using skt 24/12e thyristors. The gate control is provided with 89C51 microcontroller and the simulation results are verified through the hardware.

Keywords: Induction motor, motor starter, torque pulsations, modelling.

NOMENCLATURE

J	Moment of inertia in Kg-m2
i_{ds}, i_{qs}	2-phase stator currents in Ampere
i_{dr}, i_{qr}	Transformed two phase rotor currents in Ampere
r_s, L_s	2-phase stator resistance in ohms and inductance in Henry
r_r, L_r	2-phase stator resistance in ohms and inductance in Henry referred to stator in ohms
Te	Electromagnetic Torque in N-m
T_L	Load Torque in N-m
V_{ds}, V_{qs}	2-phasee stator voltage in Volts
L_m	mutual inductance in Henry
w_r	rotor speed in rad/sec
P_o	Number of poles

I. INTRODUCTION

Induction motors have wide range of applications in many industrial as well as manufacturing processes. They are highly efficient motors when operated near to its rated torque and speed. Three phase induction motor produces severe starting torque pulsations [1] due to the interaction between slip frequency current and transient asymmetrical flux. These torque pulsations cause shocks to the driven equipment and damage to the mechanical system components such as gear, shafts, couplings etc. Also high inrush current is drawn by the motor which may reduce the efficiency and cause insulation failure. A perfect starter can avoid these problems and provide smooth running for the machine. The

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starting methods of three phase induction motors are generally classified into four[2][3][4]: Direct online starting (DOL), electromechanical reduced voltage starting, solid state reduced voltage starting and variable frequency drives (VFD). Among these DOL starting is the cheapest way but it may present difficulties for the motor itself and the loads supplied from the common coupling point due to the voltage dip in the power supply during starting. Electromechanical reduced voltage starters consist of star delta starting, rotor resistance starting, autotransformer starting etc. But all these conventional methods have their own draw backs such as non simultaneous switching of all the three phases to the supply, need for frequent inspection and maintenance, failure in the moving parts due to large number of switching etc. Soft starters or solid state reduced voltage starters are simple, reliable and economically viable and are increasingly used in industries. Variable frequency drives are more expensive due to its converter and inverter sections.

The mechanical subsystem determines the amount of torque pulsations in shaft at the starting instant. In this paper a new control strategy is proposed for eliminating the torque pulsations and provides a smooth acceleration for the motor. The method is based on the initial switching instants of each motor terminal given to the supply. A mathematical model is developed in matlab/simulink for a 415 V, 4.7 A, 1435 rpm and 50 Hz three phase induction motor. Hardware is implemented using a three phase voltage controller with a gate control circuit and the simulation results are verified.

II. MATHEMATICAL MODEL

The mathematical model is developed in terms of abc axes coordinates. Reference frames are just like an observer platforms where the unique equation of the system can be developed. The coefficients of the differential equations depend on the rotor angle and time. The time varying inductances are eliminated by performing suitable transformation from abc to d-q axes reference frame fixed to the stator[5][6]. The dynamic equations for the induction motor are given below.

$$\begin{bmatrix} \frac{di_{ds}}{dt} \\ \frac{di_{qs}}{dt} \\ \frac{di_{dr}}{dt} \\ \frac{di_{qr}}{dt} \end{bmatrix} = \frac{1}{\sigma} \begin{bmatrix} \frac{-r_s}{L_s} & \frac{\omega_r L_m^2}{L_s L_s} & \frac{r_s L_m}{L_s L_r} & \frac{\omega_r L_m}{L_s} \\ \frac{\omega_r L_m^2}{L_s L_s} & \frac{-r_s}{L_s} & \frac{\omega_r L_m}{L_s} & \frac{r_r L_m}{L_s L_r} \\ \frac{r_s L_m}{L_s L_r} & \frac{\omega_r L_m}{L_s} & \frac{r_r}{L_r} & \frac{\omega_r L_m}{L_s} \\ \frac{\omega_r L_m}{L_s} & \frac{r_s L_m}{L_s L_r} & \frac{\omega_r L_m}{L_s} & \frac{r_r}{L_r} \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} + \frac{1}{\sigma} \begin{bmatrix} \frac{1}{L_s} & 0 & 0 & 0 \\ 0 & \frac{1}{L_s} & 0 & 0 \\ 0 & 0 & \frac{1}{L_r} & 0 \\ 0 & 0 & 0 & \frac{1}{L_r} \end{bmatrix} \begin{bmatrix} V_{ds} \\ V_{qr} \\ 0 \\ 0 \end{bmatrix} \quad (1)$$

Where $\sigma = 1-(L_m^2/L_rL_s)$, V_{ds} and V_{qs} are given by

$$\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} V_{rs} \\ V_{ys} \\ V_{bs} \end{bmatrix} \quad \text{.......... (2)}$$

and

$$\begin{bmatrix} V_r \\ V_y \\ V_b \end{bmatrix} = V_m \begin{bmatrix} \sin(\omega t) \\ \sin(\omega t - 2\pi/3) \\ \sin(\omega t + 2\pi/3 \end{bmatrix} \quad \text{.......... (3)}$$

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The matrix equation (1) is derived by the proper transformations of the quantities for which the rotor reference frame is fixed to the stator. These differential equations are used to develop a suitable system matrix for the entire model. Equation (2) shows voltage equations in abc axes quantities and equation (3) shows the corresponding transformations to d-q axes quantities.

The electromagnetic torque is given by

$$Te = \sqrt{\frac{3}{2}\frac{P_0}{2}} L_m(i_{dr} i_{qs} - i_{qr} i_{ds}) \quad \text{.......... (4)}$$

And the speed is given by

$$\frac{d\omega_r}{dt} = \frac{T_e - T_L}{J} \quad \text{.......... (5)}$$

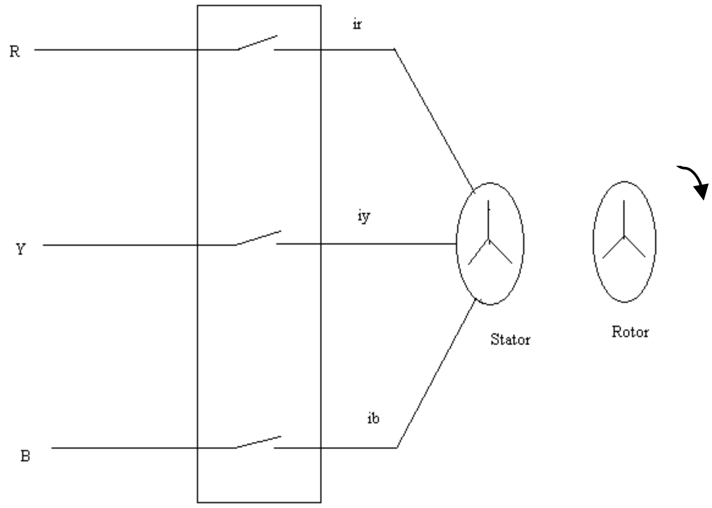

Fig. 1 Schematic diagram for starter of induction motor

After adding the torque balance equation for dynamic operation, the model is brought into the state space form for simulation. Matlab function for measuring the torque, speed in radians and rpm is developed. Equation (4) and (5) shows the torque and speed equations respectively.

III. PROPOSED CONTROL SCHEME

In the proposed control technique the initial switching instants of motor terminals to the three phase supply is controlled. Fig.1 shows the schematic of the starting circuit for induction motor. In this three switches are connected to each phases of the supply. The switching instants determine the current variation and the transient torque pulsations at the starting of induction motor. Interaction between current and flux causes the starting torque pulsations. So by providing a gradual variation in flux the torque can be control within the acceptable limit. Initially the motor is started with only two phases of supply. So at starting the effective flux will be varying with the rotor angle. By proper switching of the third phase the flux jump is avoided and thus provides a smooth acceleration for the motor.

Extensive simulations were done with different combinations of initial switching instants. It is found that improved torque pulsations is obtained by giving Y and B phases at starting, i.e. t = 0 and R phase with a time delay of t_1 seconds.

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This results a reduced voltage at starting hence the current is controlled. This is found to be a better technique and the motor gets a smooth acceleration with high starting torque and minimized torque pulsations.

IV. SIMULATION RESULTS

The proposed scheme is implemented in the mathematical model developed. Three switching instances of power supply are given below and the three input voltages are shown in Fig. 2.

Switching instants Y, B phases at t = 0

R phase at t_1 = 0.013333 sec

The simulation is started with a time delay of 2 sec for better understanding. So all the waveforms in the figures are started at 2 sec. Torque profile for normal starting scheme is shown in the Fig. 3 and that for the proposed scheme is shown in Fig. 4. It is observed that for small firing angles the starting torque pulsations are very much large while the settling time is small. But for increased firing angles the starting torque pulsations are less but the settling time is large. In the new scheme an improved torque profile is obtained as shown in Fig. 4. The positive as well as negative torque pulsations are almost eliminated and a waveform without many transients is obtained. Due to reduced voltage at the starting instant the current drowns is also much less compared to any other method. The transient time is very less and the steady state torque is obtained within 1.5 seconds.

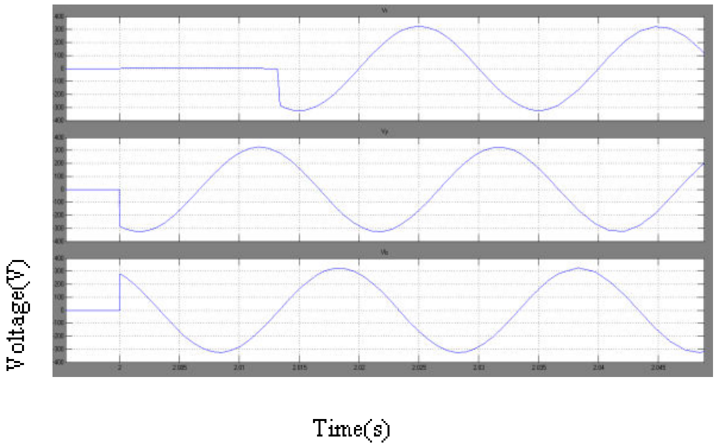

Fig. 2 Three phase input voltages given to the motor terminals

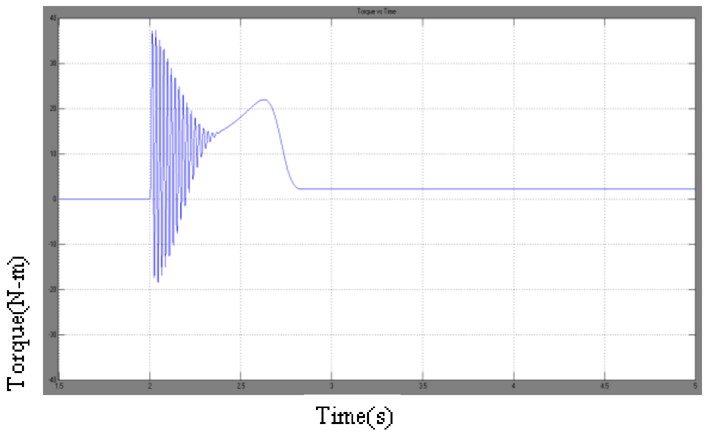

Fig. 3 Torque profile for 0^0 firing angle

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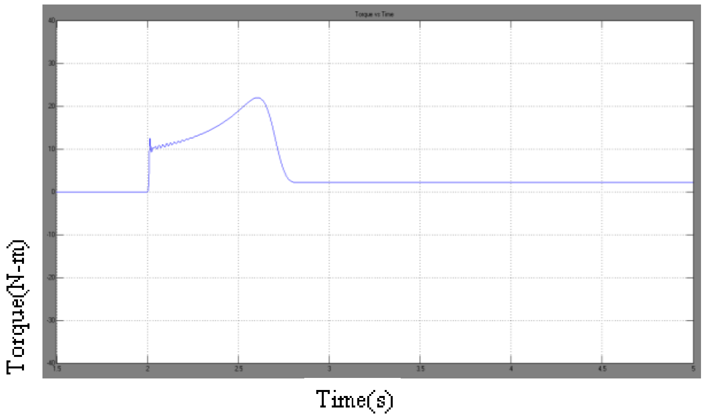

Fig. 4 Torque waveform for the proposed scheme

V. EXPERIMENTAL SETUP

The experiment is carried out with an AC voltage controller developed with two anti parallel thyristors connected in each phases of the power supply as shown in Fig. 5. Thyristor is of type skt 24/12e with ratings 1200 V, 50 A. The switching instants are determined by the firing circuit. Firing circuit consists of zero crossing detectors, microcontroller and pulse transformers. The programming is done in 89C51 microcontroller and the program is tested with softwares like KEIL µvision 4 and proteus 7 professional. The proteus model and corresponding switching waveforms are shown in Fig. 6 and Fig. 7.

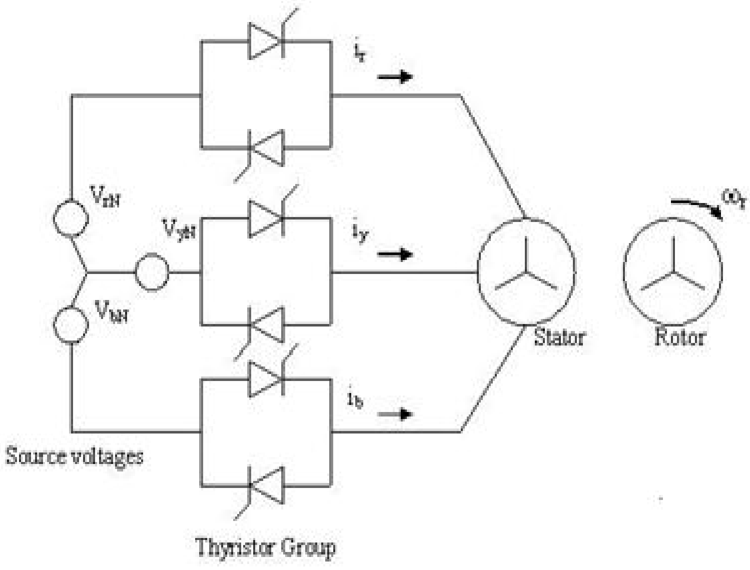

Fig. 5 AC voltage controller

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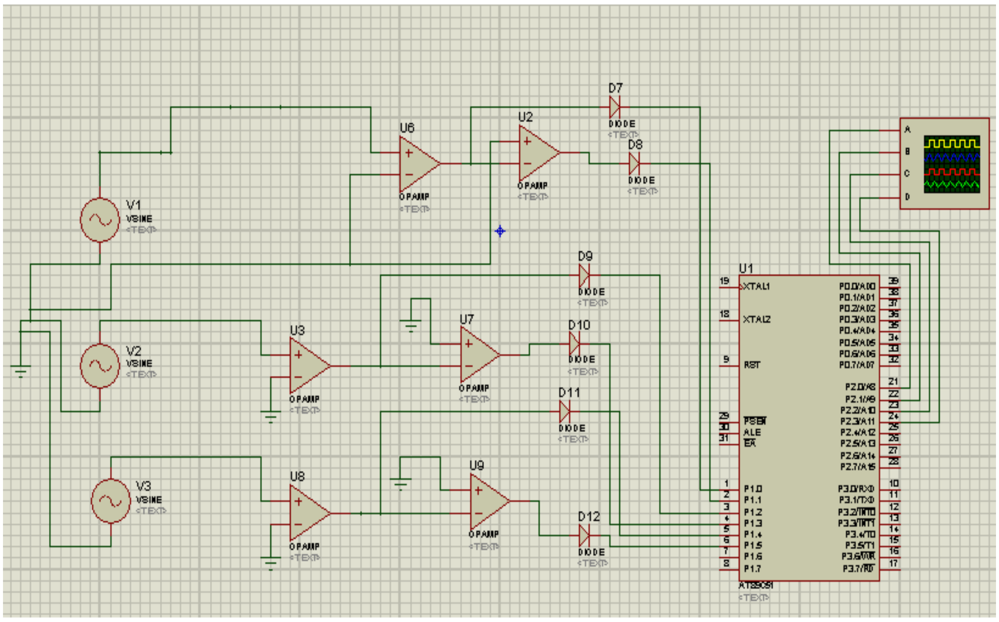
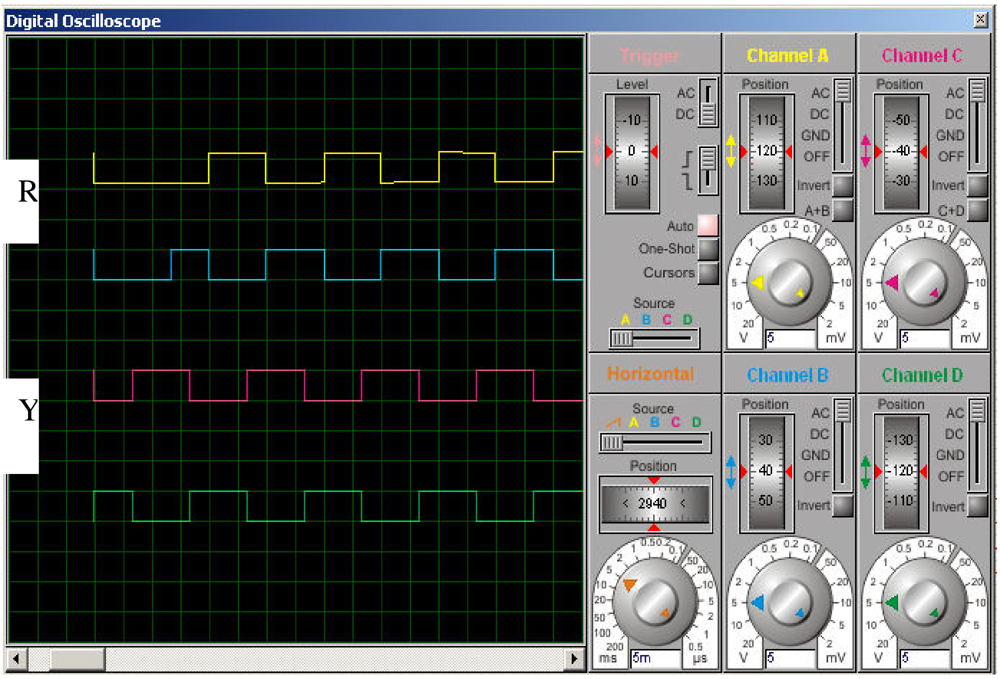


Fig. 6 Proteus model for generating switching pulses



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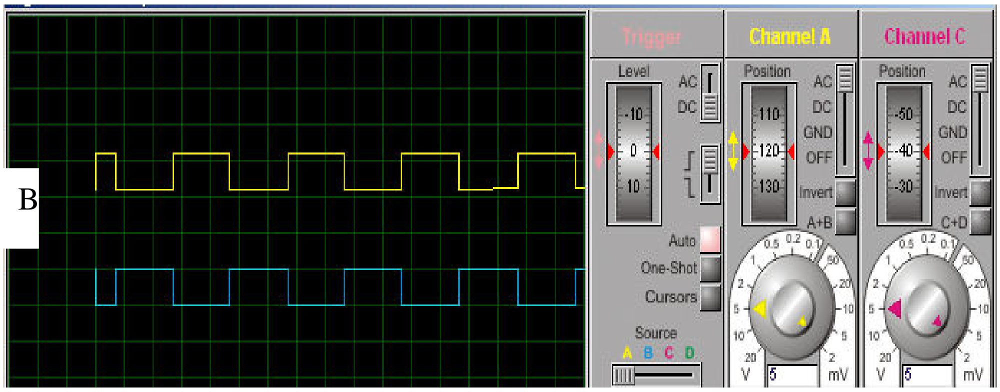

Fig. 7 Output of microcontroller for each phase with corresponding phase shift

According to the program the switching pulses for the R phase are generated after a delay of .013333 sec as shown in the Fig. 7. After testing, the hardware is implemented. The zero crossings of all the three phases are determined by the zero crossing detectors which use MCT 2E opto-coupler as shown in the Fig. 8 and are given to the microcontroller and the output is processed to a triggering circuit where the pulse transformer generates triggering signals (fig. 9). The triggering pulses generated for anti parallel thyristors connected in R phase is shown in Fig. 10(a). And that for Y and B phases are shown in Fig. 10(b).

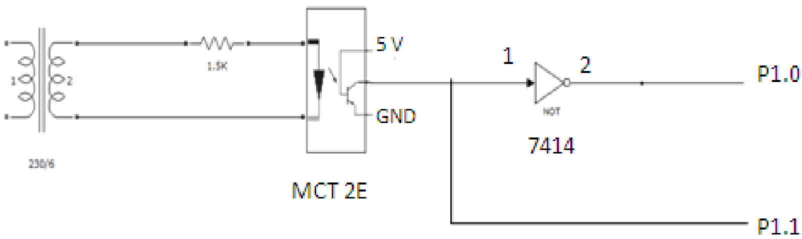

Fig. 8 Zero crossing detector using MCT 2E

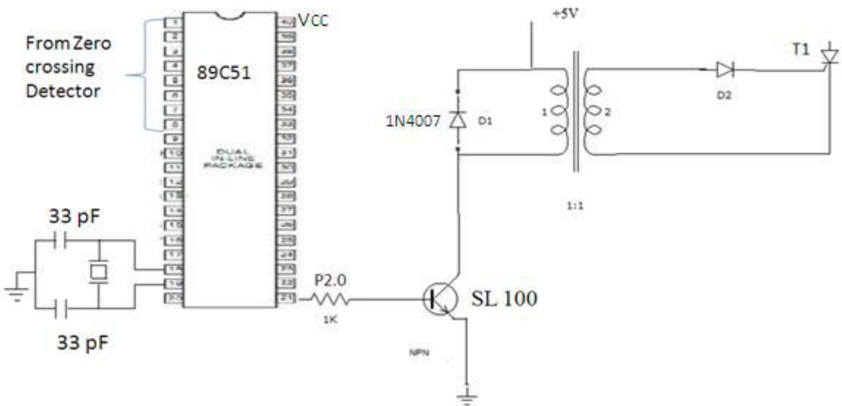

Fig. 9 Triggering circuit for SCR

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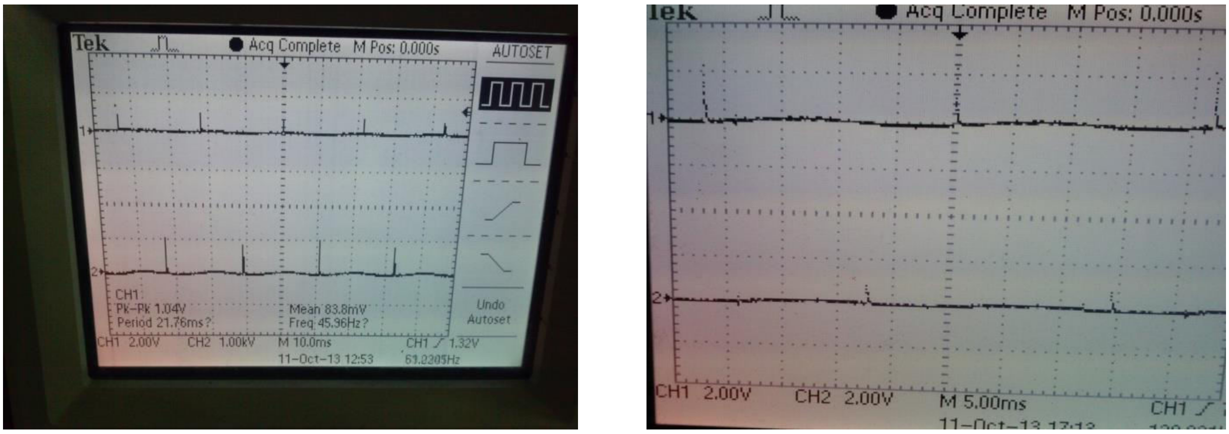

Fig. 10(a) Triggering pulses for R phase (b) for Y and B phases.

Fig. 11 Gate drive circuit

The gate signals with amplitude of 5V is generated. The minimum gate voltage required to trigger the skt 24/12e thyristor is only 3V. The entire gate drive circuit is shown in the Fig. 11. Induction motor is supplied through the AC voltage controller; motor is accelerated smoothly and run satisfactarily.

VI. Conclusion

In this paper a new control strategy is presented to improve the electromagnetic torque pulsations at starting. The initial switching instants of the motor terminals to the supply are controlled. Only two phases are given at the starting instant and the third phase is given after a short time delay. Torque profile is seemed to be improved with minimized torque pulsations. AC voltage controller is developed. Gate drive circuit using 89C51 microcontroller is tested in Proteus 7 professional. Required switching sequence is obtained. This method efficiently minimized torque pulsations at starting, hence avoid shocks to the driven equipment and reduce damage in mechanical system components such as gears, couplings and shafts. So this technique can be implement in industries for large induction motors.

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BIOGRAPHY

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