Techniques of Controlling Dynamic Performance of Induction Motor using Soft Starter

[1]Mr.Yogesh Likhar

[1]Assistant Professor
[1]Electrical Engineering Department,
[1]Laxmi Devi Institute of Engineering &Technology, Alwar, Rajsthan India

Abstract— **This paper presents different techniques for controlling of dynamic starting performance of three phase induction motor using voltage controller based soft starter. Controlling of torque is based on firing angle control of voltage controller and hence voltage input to induction motor. Different open loop and close loop strategies are presented. Finally a comparison among different controlling strategies is presented. MATLAB SIMULINK software is used to develop models and simulation results are used to comparing.**

Index Terms— **Induction motor (IM); thyristor; starting torque.**

I. INTRODUCTION

At present most of the industrial loads (about 60%) are induction motors, so uncontrolled starting or direct online starting is not only affects the motor its self but it can disturb the power system as well. The power electronics devices based soft starting of three phase induction motor is efficient among all conventional starting methods of three phase induction motor like stator resistor or mechanical switch based starters due to the fact that power electronics based switches have higher efficiency and reliability.[1]

Variable speed drives such as pump need inverter fed dc link induction motor, in which AC-DC and DC-AC conversion takes place are costly, bulky and complex. However, speed control in wider range is possible. Voltage controller based starters are cheap, compact and simple, and can be used in applications where high starting torque requirement and speed controlling is not required.[2] Applications where frequency control is not required voltage controller can be used efficiently and it not only solve the starting issues but save energy as well.

An induction machine (IM) may some pulsations in electromechanical torque, which may be severe in nature at the time of starting which depend upon the initial switching instants of the first cycle of all three-phases to the supply, regardless of the starting method. These electromagnetic torque pulsations are reflected to the shaft and its amount depends on the parameters of the mechanical sub system. These pulsations of torque may damages in the mechanical system components, such as couplings and gears, in the long term and cause shocks to the driven equipment.

A voltage controller based soft starter in various controlling schemes can provide a solution for starting torque pulsation control. In [4] confirm that the transient torques are due to interaction between transient asymmetrical flux and alternating current.[2] provide a constant current control technique to control starting torque pulsation and limit starting current.[1]provide performance optimization of [2].[3]provide a scheme to control   starting torque . In this method torque is taken as a feed-back instead of current.

In this paper comparison of various open and close loop dynamic performance controlling methods is provided. Simulation models of different torque controlling techniques with the help MATLAB SIMULINK are developed and simulation results are obtained for different schemes.

II. CONTROLLING OF DYNAMIC PERFORMANCE

A three phase voltage controller is used for controlling purpose. A three phase voltage controller consists of three pairs of back to back connected thyristors. Each thyristor conduct for 180° and conducting sequence is T_1,T_2,T_3,T_4,T_5 and T_6. In every 60° new thyristor conducts. Fig shows the connection and sequence of thyristors. The input voltage is controlled by controlling the firing angle of thyristors and as the electromagnetic torque is very sensitive to the applied voltage dynamic torque can be control without changing the frequency. When the motor starting is completed starter is bypassed and full voltage is applied to the motor.
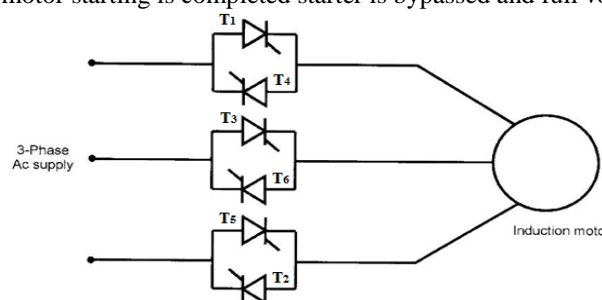

Fig 1 Three phase ac voltage controller fed IM

In three phase induction motor torque of motor is very sensitive to input voltage variation.
Torque is given by,

$$T = 3\ P\ R_r V^2 / [2\ \omega_s\ S\ \{(R_S + R_r/S)^2 + (X_S + X_R)^2\}]$$

So, torque can be controlled by controlling supply voltage with the help of voltage controller based soft starter using open loop or close loop controlling given below.

2.1 Open loop controlling

In open loop controlling methods of controlling torque reduced voltage is applied at the time of staring and voltage is keep increasing until steady state. This reduces start-up current but also reduces start-up motor torque. When motor reaches its steady state speed full supply voltage is applied to induction motor. Using open loop controlling methods starting torque pulsation can be eliminated to considerable amount. This is a simple and economical solution for starting torque pulsation for low rating motors.

Below figure shows gradual increment of supply voltage at the time of starting in open loop control.
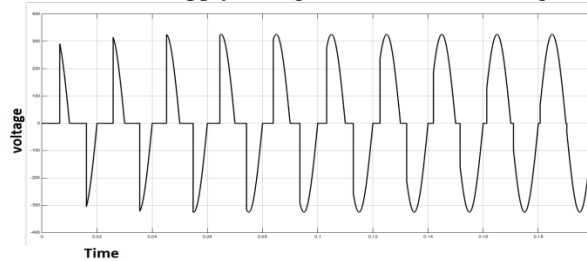

Fig 2 Controlled phase voltage of soft starter

2.2 Close loop controlling

In close loop controlling methods one of the output quantities is taken as feedback signal to generate control input signals for firing angle of input of the voltage controller.

[1] And [2] describes a constant current control scheme which uses stator current as a feedback signal, according to which control signals are generated. In this scheme controlling of starting torque pulsations is achieved by initial instant control method discussed later in this paper.

[3] Gives a scheme of controlling torque of three phase induction motor. In this scheme the starting torque of motor is controlled using torque signals as feedback signal. This torque signal is compared with a reference torque and error signal is fed to a controller block which generates firing angle signal for voltage controller and hence torque is controlled.

III. CONTROLLING TECHNIQUES

In controlling of starting torque using voltage controller based soft starter different controlling techniques are used for open and close loop controlling methods these controlling techniques and basic principle along with their simulation model is presented in section.

Different techniques used are as follows:

3.1 Open loop with continuous falling firing angle

In this technique firing angle triggering function follows a curve in which it decreases with the time. This decrement in firing angle can be linear or co-sinusoidal.

At the instant of starting the firing angle is kept very high approximately 120° and it the patterns shown in figure 3 and figure 4. As the angle decreases the supply voltage to induction motor fed by voltage controller increases accordingly.
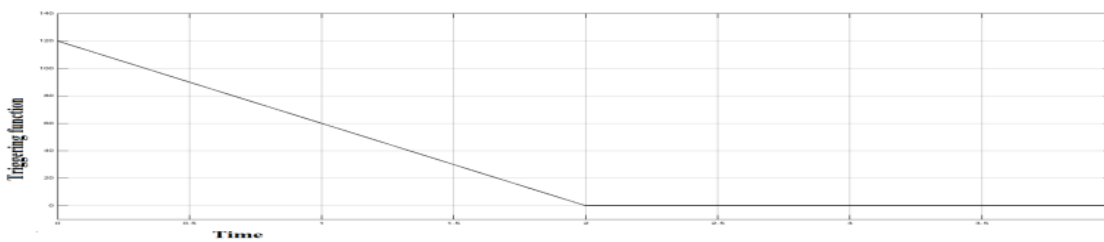

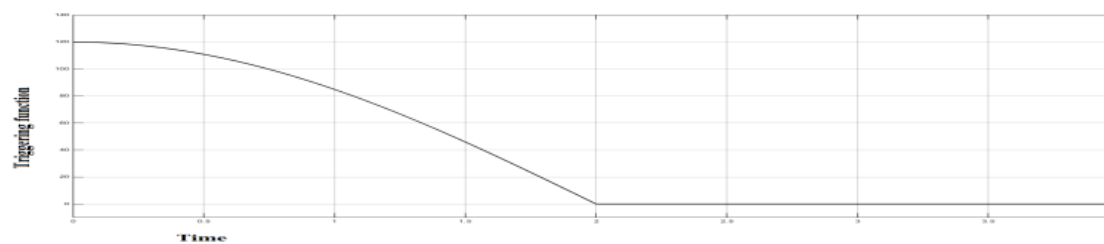Fig 3 Three phase ac voltage controller linear triggering function

Fig 4 Three phase ac voltage controller cosinusoidal triggering function

In this technique peak value of starting torque and current depends on the time for which this dynamic function of firing angle is applied i.e. if the dynamic function applied for more time the peak torque and current will be less. In result figure 22 and figure 23 shows the results for dynamic functions having different time durations.

Figure 5 shows the simulation model for this controlling scheme. First block of this model consist of a dynamic firing angle triggering function generator which generates triggering function shown in figure 3 and figure 4 Output of which is given to a firing angle control input of the gate of the thyristors of voltage controller.
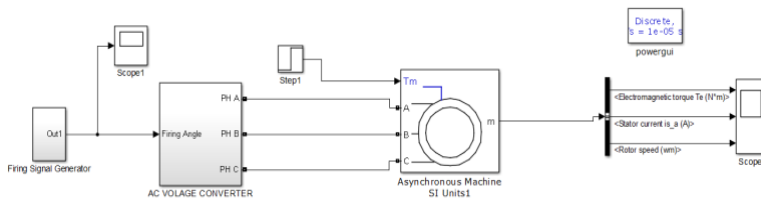

Fig 5 Simulation model of open loop soft starter

Voltage controller consists of back to back connected thyristors, below fig shows the simulation model of voltage controller and pulse generator for six thyristors. A three phase induction motor (parameters specified in appendix section) is fed by this voltage controller.
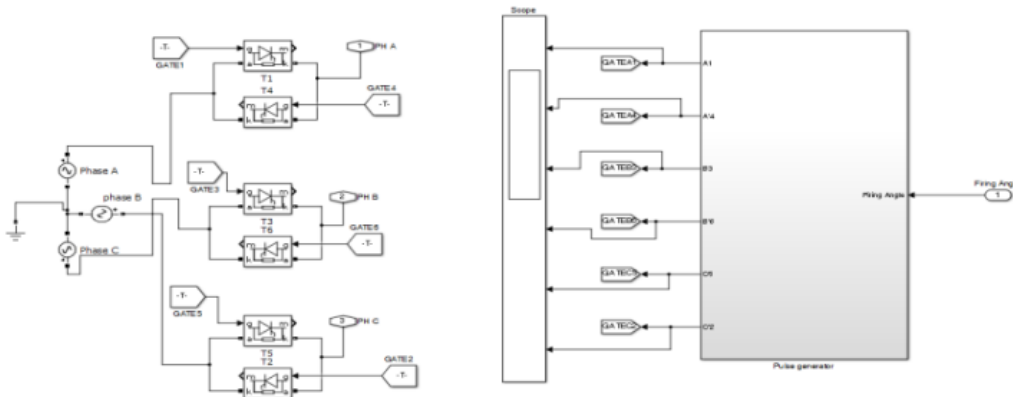
Fig 6 Simulation model of three phase ac voltage controller

3.2 Intial switching control

In above describe technique starting torque pulsation is reduced but it is not completely eliminated. To eliminate this pulsation initial switching control is used in which the instant at which the power supply is connected is controlled with the help of AC voltage controller. [4] describes the nature of induction motor torque when it is connected directly to the power supply and said that it is possible to eliminate this pulsation by maintaining magnetizing current symmetry. Later [2] provided initial switching strategies for eliminating these torque pulsations. Using curve fitting techniques and different results obtained the optimum switching at which torque pulsations are eliminated is obtained for continuous and discontinuous line currents. Continuity or discontinuity of line current is decided by initial value of firing angle α_o.

Foe eliminating torque pulsations first voltage cycle of the supply voltage should be controlled by controlling initial instant of turning on all the thyristors shown in figure 1.

For continuous current operation i.e. $\alpha_o \leq \sigma$ (where α_o is initial value of firing angle and σ is critical angle), switching instants for thyristors T_1, T_2 and T_3 (shown in figure) are α_o, 120° and 210° respectively and that of for T_4, T_5 and T_6 are $180+\alpha_o$, $240+\alpha_o$ and $300+\alpha_o$ respectively. After first switching instant system the firing will be normal for remaining cycles.

For discontinuous current operation there are two conditions first is when $\sigma < \alpha_o < \theta_o$ (where θ_o is power factor angle of machine at unity slip) and the second one is when $\theta_o \leq \alpha_o$. For first condition switching instants for T_1, T_2 and T_3 (shown in figure) are α_o, $(1.7\alpha_o+5.50)^o$ and $(1.7\alpha_o+95.50)^o$ respectively and for second condition switching instants for T_1, T_2 and T_3 (shown in figure) are α_o, $(\alpha_o+60)^o$ and $(0.37\alpha_o+203.70)^o$ respectively. Initial switching instants for T_4, T_5 and T_6 for discontinuous current operation are same that of for continuous current operation.

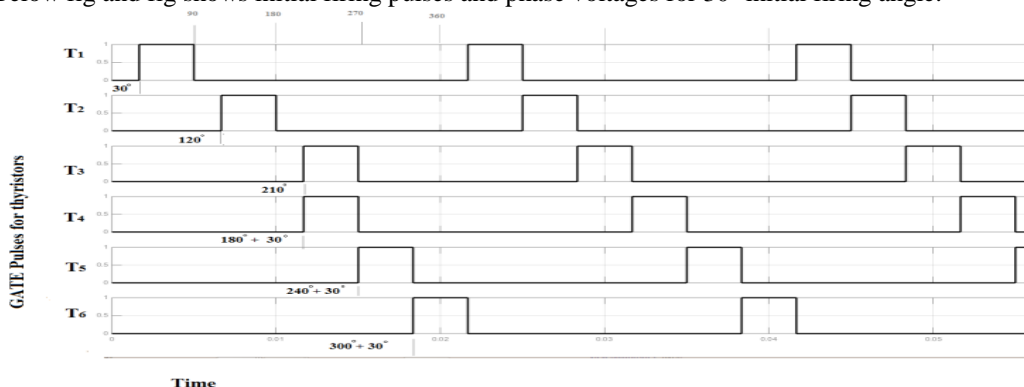Below fig and fig shows initial firing pulses and phase voltages for 30° initial firing angle.

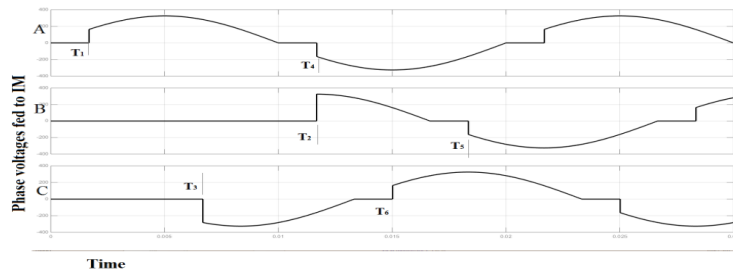Fig 7 GATE pulses for a voltage controller having $\alpha_o = 30^o$

Fig 8 Phase voltages for a voltage controller having $\alpha_o = 30^o$

3.3 Constant current control

In constant current control method of controlling starting current of three phase induction motor the current is maintained constant to a preset value. In this control scheme a band having a minimum and maximum value of current is selected. Initially the firing angle 'α' is allowed to decrease cosinusoidally so voltage and hence current starts increasing and if the value of current crosses the upper limit of band firing angle is kept constant until current reaches to lower limit of band and when current reaches the lower limit the firing angle 'α' is allowed to decrease cosinusoidally again. This controlling process continues over whole starting period and current is maintained constant.

Fig shows the triggering function and RMS current of constant current control scheme.
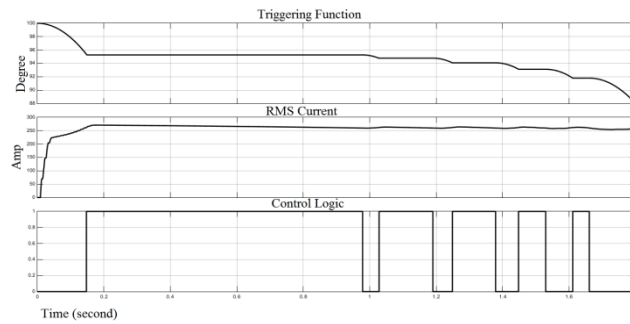
Fig 9 Triggering function of constant current control scheme

Fig shows the block diagram for constant current control method. The RMS value of the motor is measured and given to current controller unit. Current controller generates firing angle function to maintain the current near about constant.
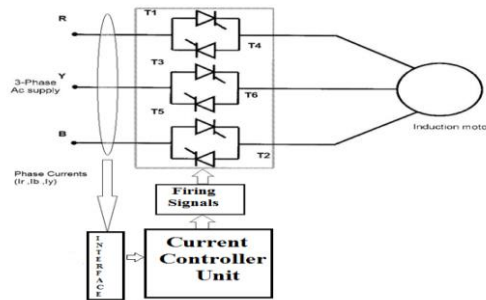

Fig 10 Schematic diagram of constant current control scheme

The combination of above initial switching control to control starting torque pulsation along with constant current control i.e. first voltage cycle instants are taken according to initial switching method along with current controller gives good torque and current profile during starting shown in figure 26.

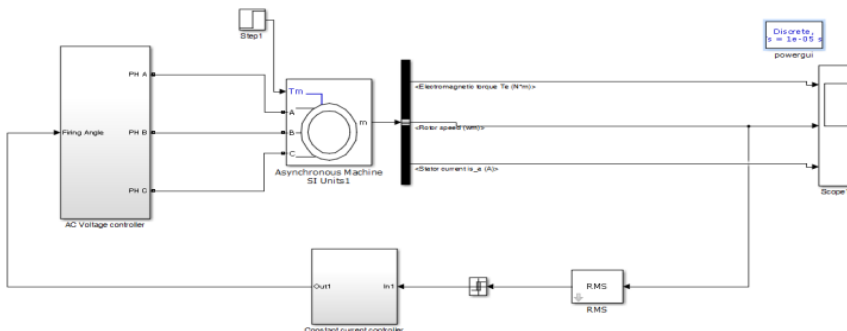Fig shows simulation model of scheme describe above i.e. constant current control along with initial switching control

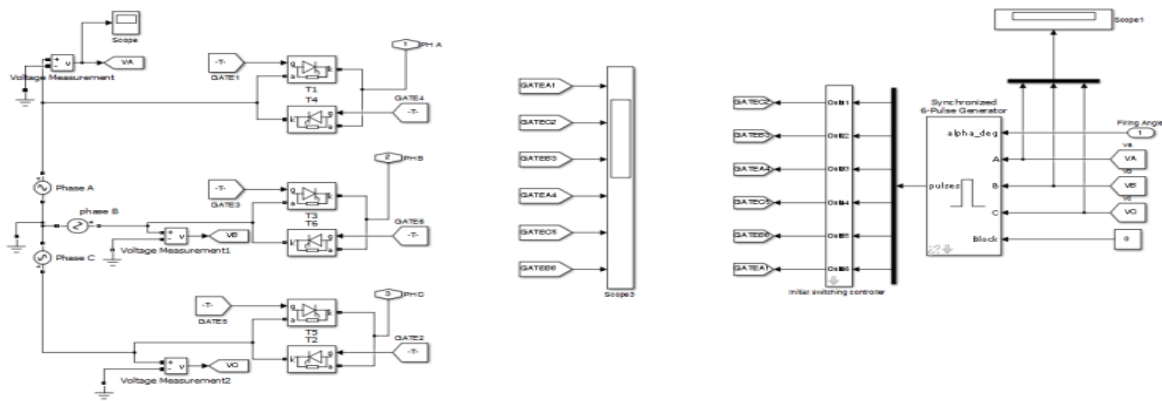Fig 11 Simulation model of constant current control scheme

Fig 12 Sub blocks for voltage controller and initial switching

3.4 Torque control using feedback

Torque control scheme torque is maintained nearly constant by using torque as a feedback signal. Figure 13 shows the schematic diagram of torque control scheme. In this scheme a torque estimator block is used to estimate electromagnetic torque of three phase induction motor, in which estimation of torque is based on two axis theory model of three phase induction motor and estimated torque is given by ,

$$T_{em} = \frac{3}{2}\frac{p}{2}(\lambda_{s\alpha}.I_{s\beta} - \lambda_{s\beta}.I_{s\alpha})$$

Where p is numbers of poles, $\lambda_{s\alpha}$ and $I_{s\alpha}$ are α axis component of stator flux and current respectively and $\lambda_{s\beta}$ and $I_{s\beta}$ are β axis component of stator flux and current respectively.
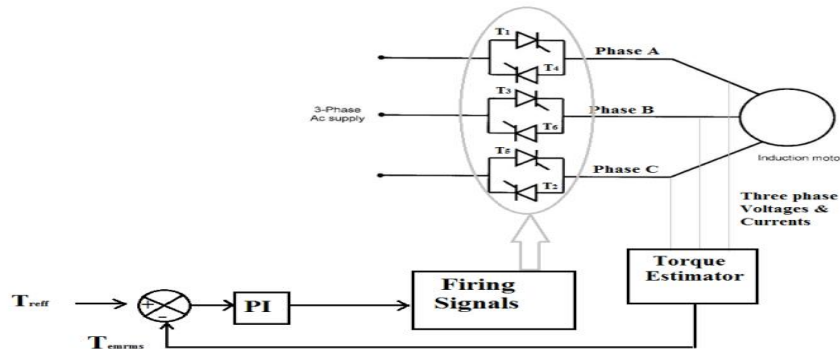

Fig 13 Schematic diagram of torque control scheme

For torque estimation three phase voltages and currents are taken as inputs for torque estimator block which are transformed to two phase for torque estimation. The estimated torque is filtered using a low pass filter.

The torque signal filtered by low pass filter is compared with a reference torque to generate error signals. These error signals are given to a PI controller block which generates firing angle function for voltage controller, so that the output torque should be controlled during starting. After the transient starting period full supply voltage is applied to the motor.

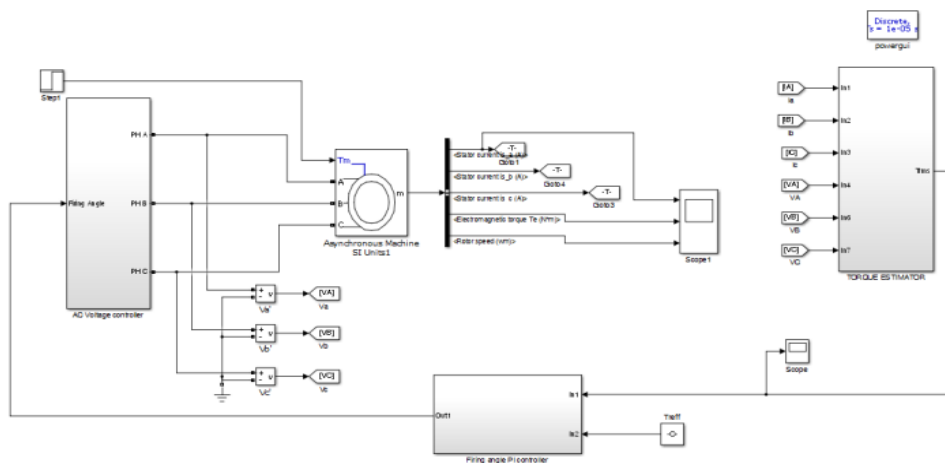Fig shows simulation diagram for torque control scheme along with torque estimator and PI controller sub-blocks.

Fig 14 Simulation model of torque control schem
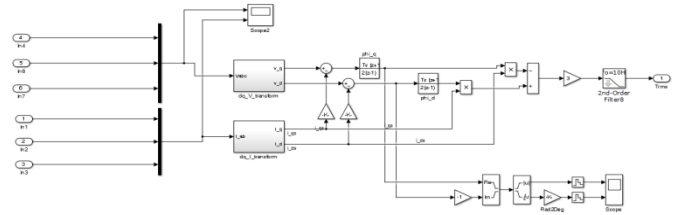
Fig 15 Sub block for PI controller   Fig 16 Sub block for torque estimator

IV. SIMULATION RESULTS AND DISSCUSION

 All the techniques describe in above section are implemented in MATLAB & SIMULINK 2014 and simulation results are obtained for different conditions.

 A three phase induction motor having parameters specified in appendix section is used for simulation. Figure 17 shows starting torque, current and speed of induction motor when motor is started directly online. In direct online continuous starting pulsation in torque can be observed having peak value 930 N-m. Various control strategies are used to control this starting torque and result is obtained.

Figure 20, 21, 22 and 23 shows starting torque, current and speed profile for triggering functions shown in figure 3, 19, 4 and 18 respectively in open loop system.

Figure 24 and 25 show results of initial switching control technique. Figure 24 shows torque, current and speed profile for $\alpha_o = 30^o$ i.e. continuous current operation and figure 25 shows results for $\alpha_o = 80^o$.

 Figure 26 shows torque, current and speed profile for constant current control technique. The RMS value of current is kept constant to 260 amp value at the time of starting. Finally figure 27 shows torque control technique.
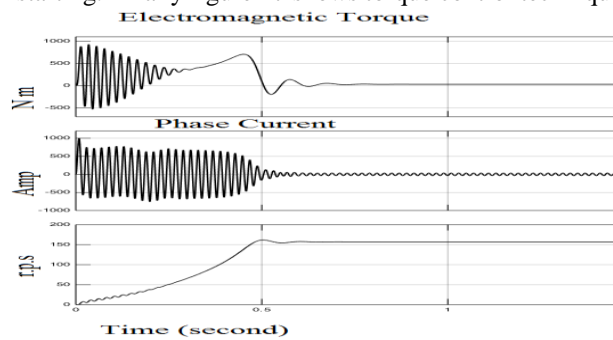

Fig 17 Response of three phase induction motor (D.O.L.)
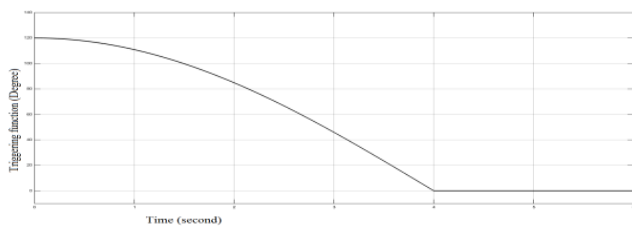

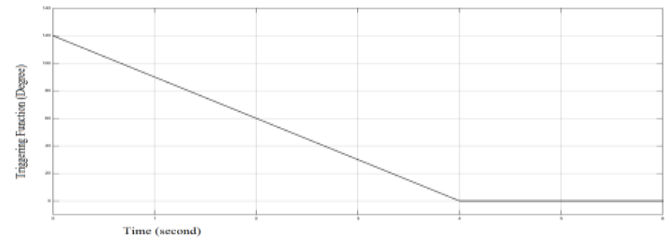Fig 18 Three phase ac voltage controller cosinusoidal triggering function

Fig 19 Three phase ac voltage controller cosinusoidal triggering function
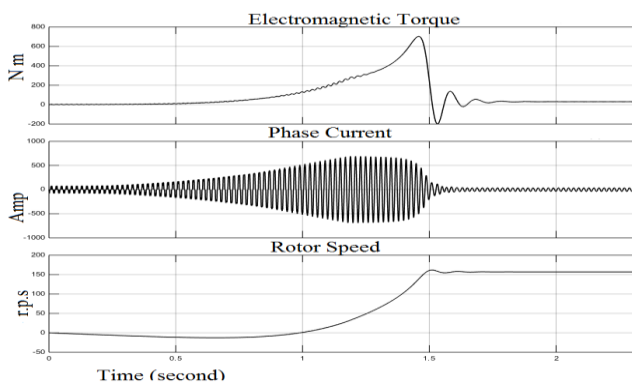

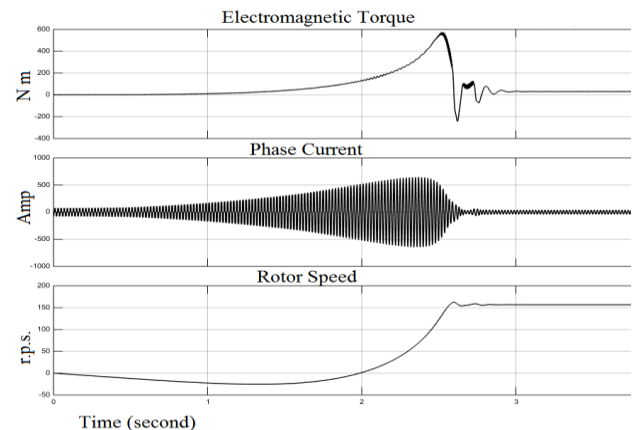Fig 20 Response of IM fed by soft starter in open loop (cosine function I)

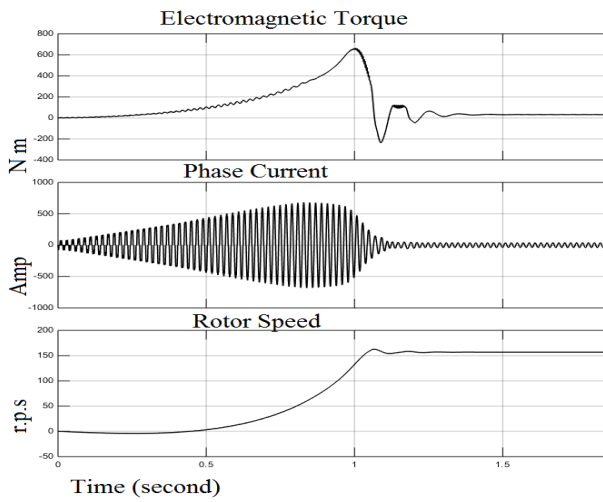Fig 21 Response of IM fed by soft starter in open loop (cosine function II)

Fig 22 Response of IM fed by soft starter in open loop (linear function I)
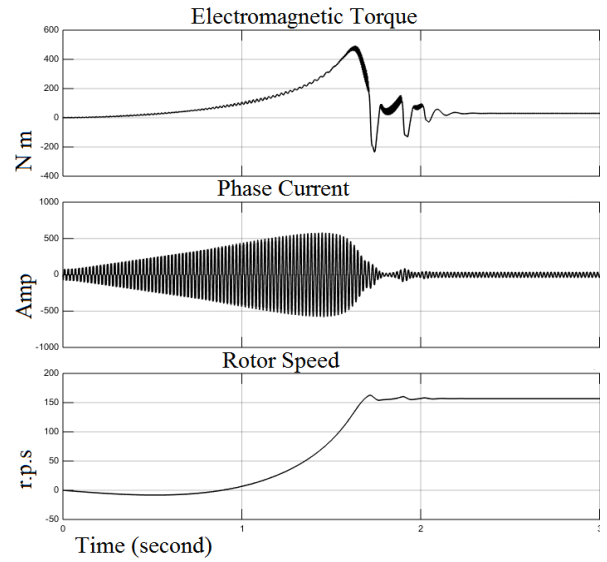

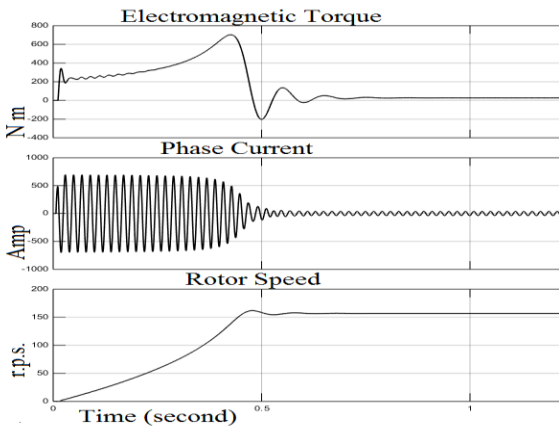Fig 23 Response of IM fed by soft starter in open loop (linear function II)

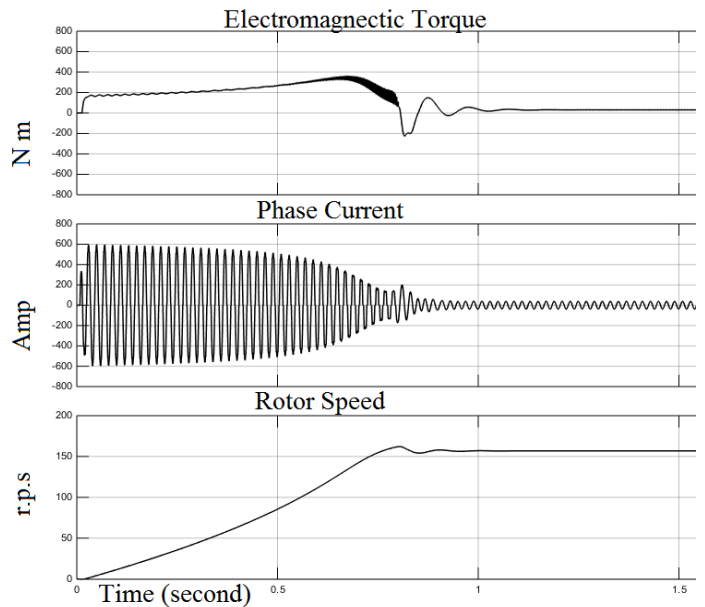Fig 24 Response of IM fed by soft starter initial switching control ($\alpha_o=30°$)

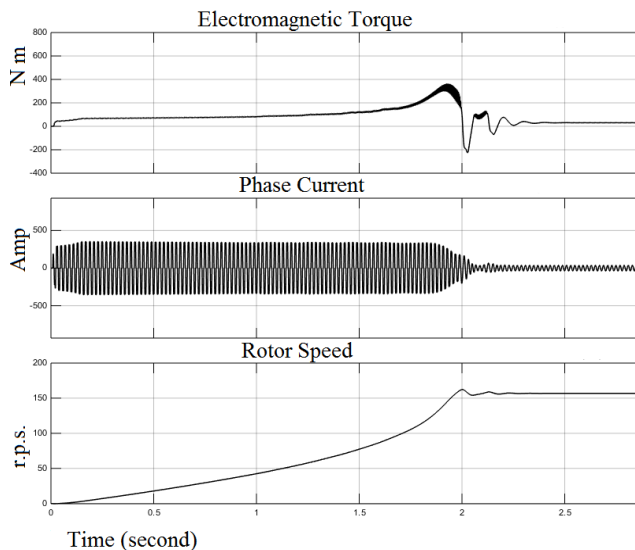Fig 25 Response of IM fed by soft starter initial switching control ($\alpha_o=80$

Fig 26 Response of IM fed by soft starter constant current control scheme
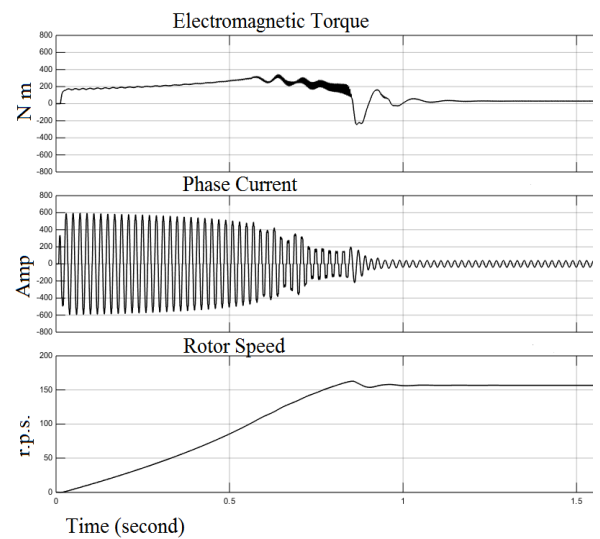

Fig 27 Response of IM fed by soft starter Torque control scheme

V. CONCLUSION

From the above discussion and results obtained it can be said that starting transient torque of three phase induction motor can be controlled using voltage controller based soft starter.

Performance of the motor fed by voltage controller based soft starter as compare to direct online starting is much better. Initial switching control is best scheme to control initial starting torque pulsations. To control torque in last stages of stages of starting close loop systems are better than open loop.

There are industrial applications where speed control is not required, in these application induction motor fed by voltage controller based soft starter can be used efficiently. There are many advantages of soft starters as compare to conventional starters. By applying proper control technique satisfactory starting performance can be obtained using voltage controller in a cost efficient way.

APPENDIX

PARAMETER OF THREE PHASE SQUIRREL CAGE INDUCTION MOTOR

Nominal power	50hp (37KW)
Voltage (line to line)	400 V
Frequency	50 Hz
Speed	1480 R.P.M
Stator Resistance	$R_s = 0.08233\Omega$
Rotor resistance	$R_r = 0.0503\ \Omega$
Stator leakage inductance	$L_s = 0.724mH$
Rotor leakage Inductance	$L_r = 0.724mH$
Mutual Inductance	$L_m = 27.11mH$
Number of Poles	P = 4
Moment of inertia of motor and load	J = 1 Kg-m2
Friction factor	F = 0.02791 N-ms

REFERENCES

[1] Gürkan Zenginobuz, Student Member, IEEE, Isik Cadirci, Member, IEEE, Muammer Ermis, Member, IEEE, and Cüneyt Barlak "Performance Optimization of Induction Motors During Voltage-Controlled Soft Starting". IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 19, NO. 2, JUNE 2004.

[2] G. Zenginobus, I. Cadirci, M. Ermis, and C. Barlak, "Soft-Starting of Large Induction Motors at Constant Current with minimized Starting Torque Pulsations", IEEE Transactions on Industry Applications, vol. 37, no. 5, pp. 1334-1347, September/October 2001.

[3] Ademir Nied, José de Oliveira, Rogério P. Dias, Luiz C. de Souza Marques," Soft Starting of Induction motor with Torque control", IEEE Transaction on Industrial Applications VOL 46 May /June 2010

[4] W. S. Wood, F. Flynn, and A. Shanmugasundaram, "Transient torques in induction motors due to switching of the supply," Proc. Inst. Elect. Eng., vol. 112, no. 7, pp. 1348–1354, July 1965.

[5] G. Nath and G. J. Berg, "Transient analysis of three-phase SCR controlled induction motors," IEEE Trans. Ind. Appl., vol. 17, pp.133- 142, Mar./Abr. 1981.

[6] J. Faiz, M. Ghaneei, and A. Keyhani, "Performance analysis of fast reclosing transients in induction motors," IEEE Transactions on Energy Conversion, vol. 14, pp. 101-107, Mar. 1999.

[7] I. Çadirci, M. Ermis, E. Nalçaci, B. Ertan, and M. Rahman, "A solid state direct-on line starter for medium voltage induction motors with minimized current and torque pulsations," IEEE Trans. Energy Conversion, vol. 14, pp. 402–412, Sept. 1999.

[8] Wei Gu, Jianxin Chu, Shihong Gan Institute of Electrical Automation, Shanghai Maritime University : "Starting Performance Research of a High-power Middle-voltage Induction Motor Soft Starter Based on the On-off Transformer"

[9] R. H. Daugherty, "Analysis of transient electrical torques and shaft torques in induction motors as a result of power supply disturbances," IEEE Power. Syst., vol.101, Aug1992

[10] "Modern Power Electronics and A.C. Drives" by Bimal K. Bose, 2005 Prentice Hall

[11] Krause P. C,"Analysis of Electric Machinery" Mc Grow-Hill, New York, 1986

[12] R.Krishnan ,"Electric motor drives-modelling, analysis & control", 2001 Prentice Hall

[13] "Power Electronics Circuit ,Device & Applications" by Muhammad H. Rashid 2007, Elsevier Inc

[14] "MODELING & Simulation using MATLAB – SIMULINK" Dr. Shailendra Jain Wildey India publication 2011

[15] http://:www.mathwork.com