Design and Simulation of Controller for Medium Voltage Thyristorised Induction Motor Soft Starter

Hiren Lakhani
Sr. Engineer
(R&D)
Amtech Electronics (I) Ltd.
Gandhinagar, India

Mr.Vinod Patel
Sr. Manager
(R&D)
Amtech Electronics (I) Ltd.
Gandhinagar, India

Prof. J.G.Jamnani
Dept. of Elect. Engg.
Institute of Technology
Nirma University
Ahmedabad, India

Swapnil Jani
Dept of Elect. Engg.
Institute of Technology
Nirma University
Ahmedabad, India

***Abstract*- Soft starters are used with induction motors in blowers, fans, pumps and the crane hoist drives. AC voltage controllers are used as soft starters in induction motors for starting and to adjust its speed. This paper presents a novel topology for ac voltage controller to generate the firing pulses for appropriate thyristors for any given operating torque, speed of the motor and the load. Simulation results presented in this paper explain the advantages of proposed soft starting method over conventional method. The advantages of proposed method are its simplicity, accuracy and fast response.**

I. INTRODUCTION

Due to the increased number of induction motors in industry applications and residential appliances especially air conditioners, many utilities and industry firms are affected by the high inrush current that may cause important failures. The problem is more severe in areas where the loads represent a high portion of the power demand. If soft starters are substituted in such applications, reduction of inrush current can be achieved and on the other hand, energy saving can also be possible. Energy savings by voltage control through soft starter is achieved by reducing the applied voltage if the load torque requirement can be met with less than rated flux. In soft starter fed induction motor system, smooth acceleration with reduced stress on the mechanical drive system is achieved. This is due to high starting torque hence increase the life and reliability of belts, gear boxes, chain drives, motor bearings and shafts. Smooth acceleration reduces also stress on the electrical supply due to high starting currents meeting utility requirements for reduced voltage starting and eliminating voltage dip and brown out conditions [3], [4].

Soft starters allow the machine to start, vary its speed and stop with minimum mechanical electric stresses on the equipment. This can be done by appropriate adjustment of the induction motor terminal voltage. However, adjusting the voltage for a given operating condition of speed and torque is not a simple task. To adjust the voltage, the firing angle of the thyristors shall be calculated for each operating condition. Firing angle α is a nonlinear function of motor speed and torque and it is very difficult to find the exact value of α for any motor speed and torque [5], [6].

This paper proposes a new starting topology for selection of firing angles for thyristors in voltage controlled induction motor. In this paper simulation procedure and results have been presented for the proposed method and they have been compared with the conventional soft starter results.

Fig. 1 illustrates a typical thyristor gate current waveform to turn-on [2].

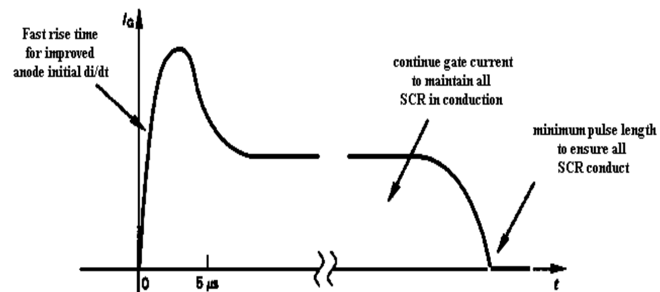

Fig.1 Generalized MVGD gate current profile

The initial high and rapid current quickly turns on the device so as to increase the anode initial di/dt capability. After a few microseconds the gate current can be decreased to a value in excess of the minimum gate requirement. After the thyristor has latched on, the gate drive may be removed in order to reduce gate power consumption, namely the losses. In some inductive load applications, where the load current lags, a continuous train of gate pulses is usually applied to ensure turn-on.

II. PRINCIPLE OF SOFT STARTER

A soft starter is an ac voltage controller in which the voltage is adjusted through the setting of the thyristor firing angle α. Fig. 2 shows the typical block diagram of a symmetrical voltage controller or soft starter.

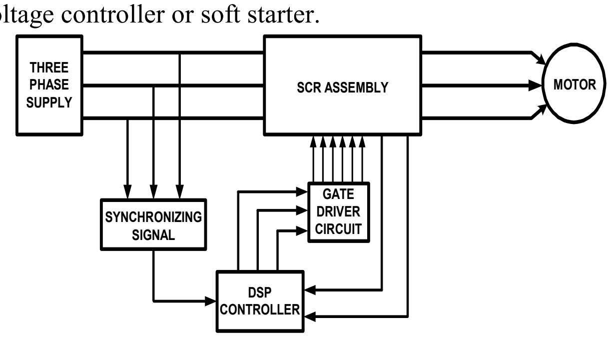

Fig. 2 Block diagram of medium voltage soft starter of Induction motor

Each phase has two thyristors and which are connected in anti-parallel connection. Thyristors in this configuration are fired according the sequence of firing pulses. Here synchronizing signal is generated by sensing the supply voltage and current. According to synchronizing signal DSP generates the control pulses for the gate driver circuit. As shown in block diagram there are four different parts of the medium voltage soft starter, which are explained as follow:

(A) Synchronization circuit:

It generates synchronized signals as the basic reference of phase displacement control, ensuring the correct phase firing. In the Soft Starter circuit it is necessary to provide synchronization in order to get correct phase firing.

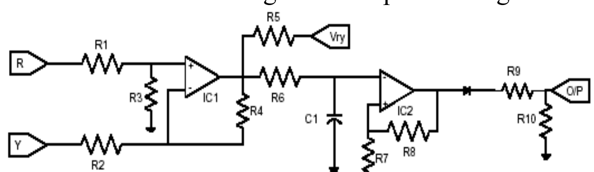

Fig. 3 Synchronizing circuit

Fig. 3 shows the synchronization circuit for Soft Starter.

This circuit includes an op-amp working as a differential amplifier and schmitt trigger. This circuit receives the voltage signals from control power transformer (R–Y phase). These signals are given to the differential amplifier circuit, which generates the reference signal V_{RY}. The reference signal V_{RY} is given to the ADC, which is used to calculate the supply voltage. This reference signal is also given to the RC circuit, which gives phase shift to the reference signal and it also eliminates the effect of distortions at zero crossing of reference signal. The output of RC circuit is given to the schmitt trigger circuit, which generates DSP receivable square wave signal.

(B) DSP control card:

It uses 32-bit high-performance Digital Signal Processor. The control board generates the control signals for soft starter operation. It accepts various inputs from different control circuits i.e. synchronizing circuit, feedback circuit and digital operation panel (LCD keypad) to generate the necessary control signals, which will go the gate driver circuit.

(C) Gate driver card:

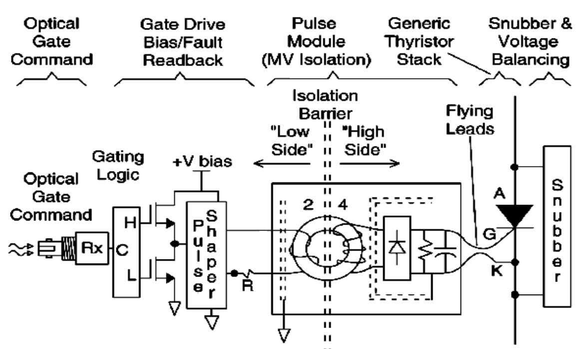

Fig. 4 Block diagram of gate driver card for thyristor

Fig. 4 shows block diagram of gate driver circuit for medium voltage thyristor [1]. Each channel of a gate driver board is made up of four sections: (1) Fiber optic receiver and gating logic, (2) Driver stage and pulse forming network, (3) Isolation transformer, and (4) Output rectifier and terminating resistor.

Fig. 4 is essentially a push-pull switch mode converter with virtually no output capacitance and a transformer capable of handling the first half-cycle switching event without saturation. The output's rectified square wave has an amplitude profile that is enhanced with a primary side pulse shaper to provide a strong leading edge.

The fiber optic receiver (Rx) converts the gate command light signal into the logic signal that is characterized by a square wave pulse train. The gating logic converts the signal into an even number of high side and low-side pulses suitable for a totem pole drive stage. The transformer is generally a powder coated ferrite core of low turn count (1:1.6 ratio) to reduce parasitic inductance and interwinding capacitance. The bipolar square wave signal derived from the secondary is full-wave rectified via fast recovery diodes into a dc pulse. A terminating impedance can be used to enhance the noise immunity and help to protect against transient gate reversal.

(D) Feed back circuit:

Fig. 5 shows the thyristor feed back circuit for one phase of Soft Starter. The output signals of feed back circuit are generally used to find the power factor angle, phase sequence and phase failure of the Soft Starter circuit.

This circuit mainly consists of opto-coupler, which isolates the control circuit from power circuit, and it converts the voltage signal into DSP receivable square wave signals. The transistor in feed back circuit is used to increase current gain of feed back circuit.

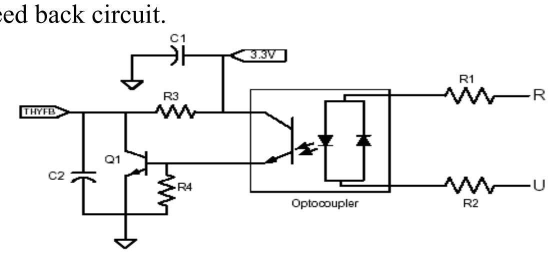

Fig. 5 Feedback circuit from thyristor

III. Proposed Control Strategy

The main circuit of the soft-starter for medium voltage induction motor is shown in Fig. 7. TI-T4, T3-T6 and T2-T5 are three pairs of thyristors connected in series into the motor's three phase circuits in opposite direction, respectively. To achieve smooth starting of motor, the firing angles of the six thyristors must be adjusted in certain time sequence to control the input voltage of motor to vary from low to high according to the predetermined voltage-time curve. For this kind of circuit, the essence of the method of phase-control reduced voltage is to cut the waveform of the power supply, namely, the voltage applied to the motor is non-sine wave, while the positive half period is symmetrical. The thyristor operating voltage waveform of one of the three phases is shown in Fig. 6. The voltage of power supply is a complete sine wave, α is the trigger angle of thyristor, φ is the power factor angle (or can be called continued flow angle); θ is the conduction angle of thyristor. According to Figure, the following relationship can be derive:

$$\theta = \pi - \alpha + \varphi \quad (1)$$

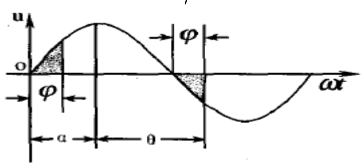

Fig. 6 Operating voltage waveform of one phase thyristors

The output voltage of thyristors is the segment of waveform in the region of [α, α + θ]; it is evident that the input voltage of motor can be changed by varying the magnitude of θ angle. The θ angle is related to α and φ angle. The output voltage of thyristor can be changed in the predetermined curve by changing the α angle only when φ is constant. Actually, the power factor angle φ of motor varies with the speed of the motor. The changing of the trigger angles of thyristors should consider the change of the power factor angle φ, and that is the only way to make input voltage of motor vary in certain predicted regular pattern [4], [6].

IV. Simulation of the Proposed Topology

Fig. 7 shows the basic circuit diagram to simulate the soft starter of medium voltage induction motor in PSIM 6.0 software tool. In this simulation input voltage signal is sense and given to the DLL block. The DLL block generates control signals according to synchronizing circuit and feedback circuit for gate driver card. Simulation parameters are given below.

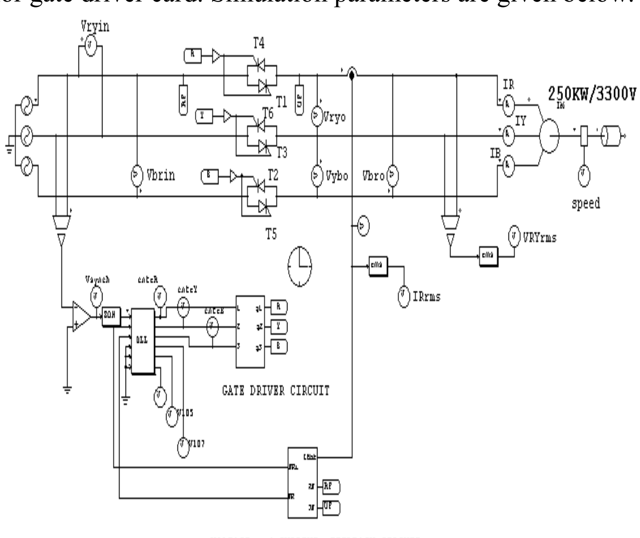

Fig. 7 Simulation diagram of medium voltage soft starter of induction motor

Medium voltage motor data [7]:
3-phase, Y-connected, 50 Hz, 8-pole, 250 kW induction motor Supply voltage: 3.3kV, Rated current: 31 A, Parameters referred to stator side: R_1= 1.84Ω; R_2'= 3.72Ω; X_1= 10.05Ω; X_2'= 10.05Ω; X_m=20 Ω .

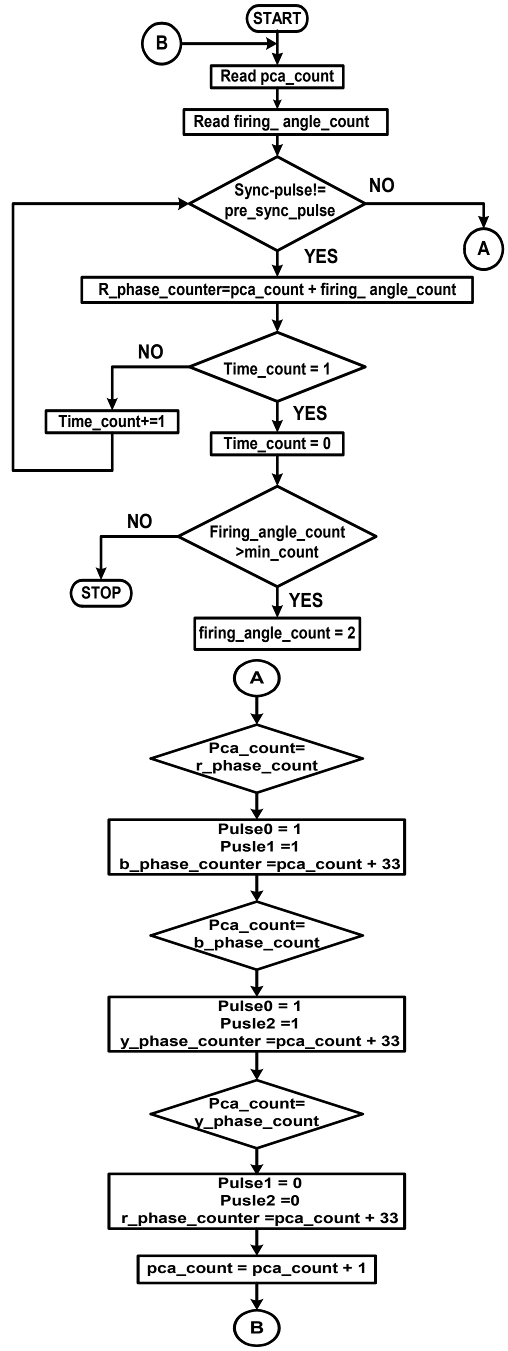

Fig. 8 Algorithm for DLL block

For the voltage control in both the positive and negative cycles two anti-parallel thyristors are arranged for each phases. Fig.8 Shows algorithm for DLL block to generate control signals for gate driver circuit. Fig. 9 shows the synchronizing pulse and control signals for gate driver card.

Fig. 10 shows the gate pulses for the thyristors. The pattern of the gate is shown identical for the thyristors as same as in fig.1, it gives fast rise time to improved anode initial di/dt, slow fall to prevent unwanted turn-off of thyristor, continues gate current to maintain SCR at conduction and minimum pulse length to ensure all SCRs to conduct. From Fig. 10, it should be noted that at least two thyristors must conduct simultaneously to allow current to flow through the load. Fig. 11 shows waveforms of the starting current, speed of the motor, motor torque for 3300 V, 250 kW induction motor without soft starting. It is clearly seen that starting current is not linearly increase and also torque pulsations are present at the point of starting. With the help of soft starting all problems related to starting are eliminated which is shown in fig. 12. Fig. 12 represents the waveforms of the starting current, speed of the motor and motor torque with soft starting.

Phase current during starting condition is shown in Fig. 13. Similarly phase current during ramp up condition is shown in fig. 14. As shown in Fig. 15 the phase current during normal running operation, this is purely sinusoidal. Similarly waveforms of the line voltage during starting condition, ramp up condition and normal condition are shown in Fig. 16, Fig. 17 and Fig. 18 respectively.

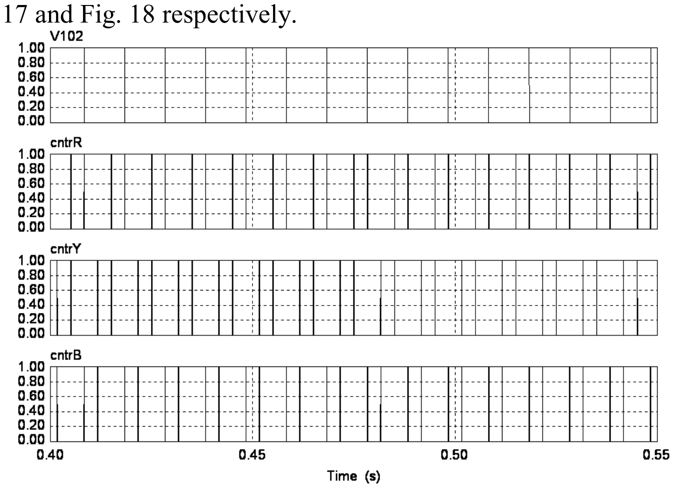

Fig. 9 Synchronizing signals and control signal generated by DLL block

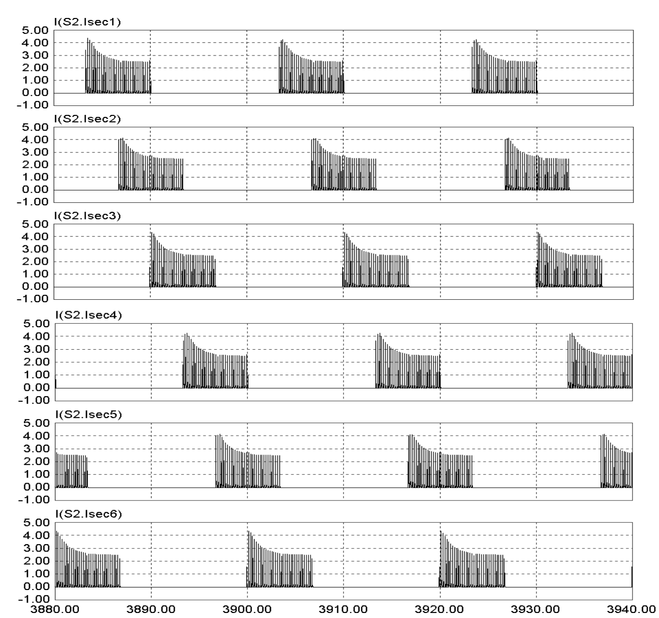

Fig. 10 Gate pulses for thyristors

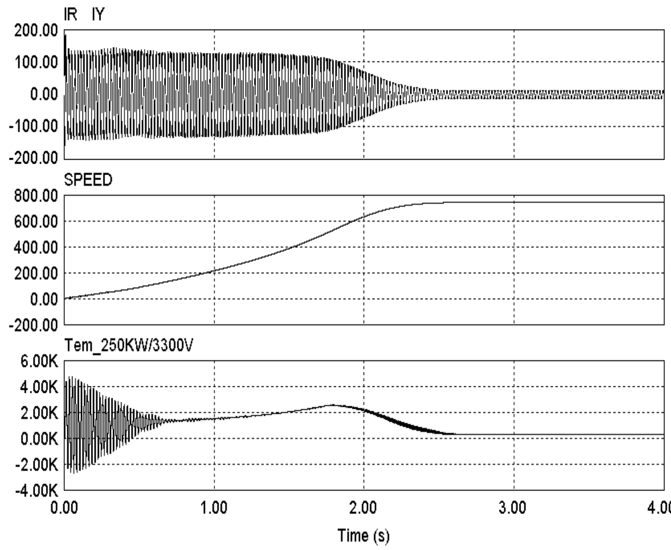

Fig. 11 Starting current, speed, torque of 3300V, and 250KW induction motor without soft starting.

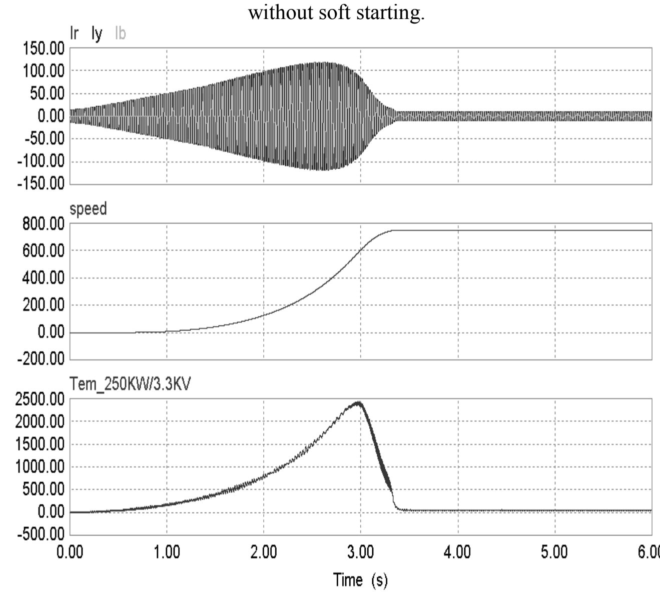

Fig. 12 Starting current, speed, torque of 3300V, 250KW induction motor with soft starter

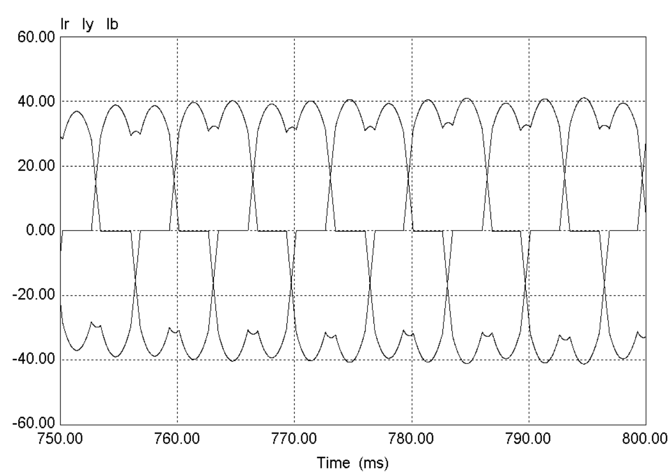

Fig. 13 Phase current during starting condition

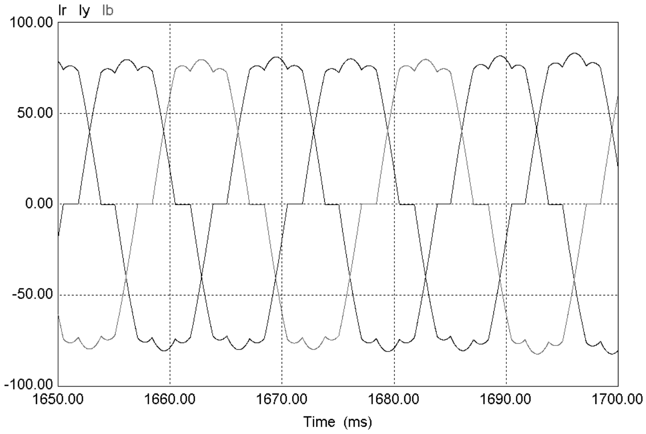

Fig. 14 Phase current during ramp up condition

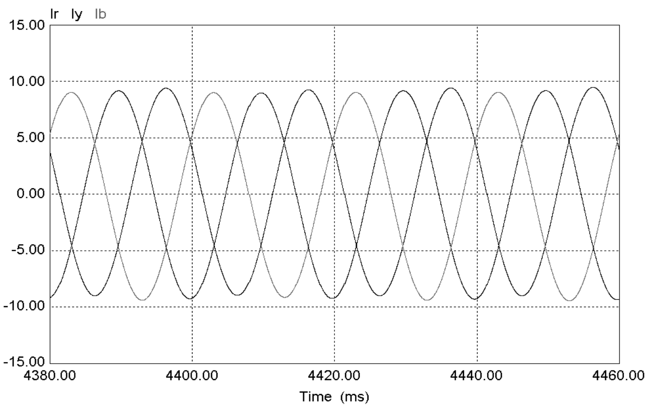

Fig. 15 Phase current during normal running condition

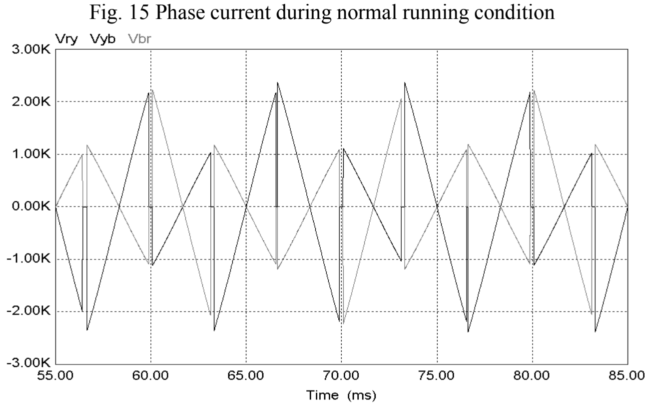

Fig. 16 Line voltage during starting condition

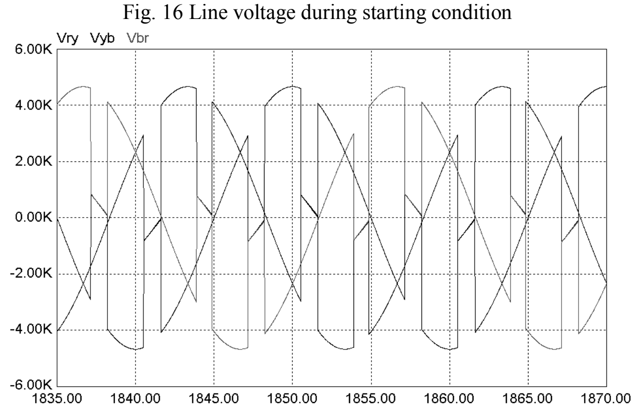

Fig. 17 Line voltage during ramp up condition

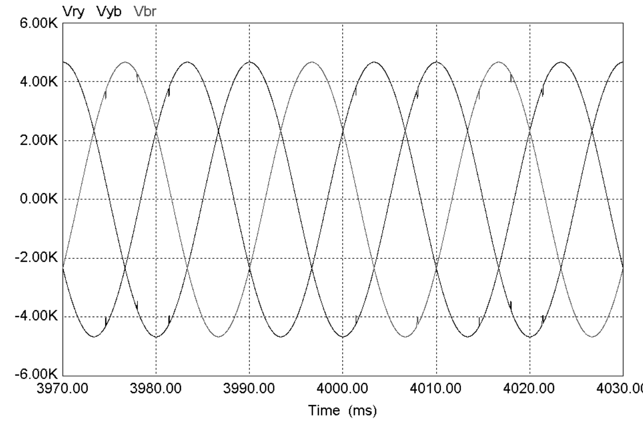

Fig. 18 Line voltage during normal condition

V. CONCLUSION

A voltage-controlled, thyristorized medium voltage induction motor soft starter is carried out by the use of a simple control strategy implementable on a digital signal processor at no additional cost. Nearly perfect current and torque profile can be obtained during starting for better utilization of the available starting facility. The identical pulse shape of gate pulse is achieved by this topology, which is sufficient to trigger the thyristors. From the simulation of proposed strategy, a good acceleration profile can be tailored by smooth, pulsation-free torques over the entire starting period.

REFERENCES

[1] Frank Peter Wahl III, “Firing Series SCRs at Medium Voltage: Understanding the Topologies Ensures the Optimum Gate Drive Selection”, *Power Systems World Conference*, Chicago, Illinois, Oct. 31, 2002.

[2] “*Gate Driver recommendations for thyristors*”, Application note no. 5SYA2034-02, ABB Switzerland Ltd, June 2007.

[3] K. B. Khanchandani “*Power Electronics*”, New Delhi, Tata McGraw-Hill, sixteenth reprint 2005, ch. 3, pp 110-120.

[4] Gürkan Zenginobuz, Isik Cadirci, Muammer Ermis, Cüneyt Barlak, “Performance Optimization of Induction Motors During Voltage-Controlled Soft Starting*”, IEEE transactions on energy conversion,* vol. 19, no. 2, June 2004, pp 278-288.

[5] Wei Gu, Jianxin Chu, Shihong Gan, ”Starting Performance Research of a High-power Middle-voltage Induction Motor Soft Starter Based on the On-off Transformer”, *IEEE ISIE 2006*, July 9-12, 2006, Montreal, Quebec, Canada, pp 2063-2068.

[6] G. Zenginobuz, I. Cadirci, M.Ermis, and C. Barlak, “Soft Starting of Large Induction Motors at Constant Current With Minimised Starting Torque Pulsations”, *IEEE Trans. Ind. Applicant.* vol. 37, no.5, pp. 137-144, Sep./Oct. 2001.

[7] Bora Alboyaci, Nuran Yorukeren, Hasan Basri Cetynkaya, Turhan Turker “The evolution of medium voltage motor’s current and voltage harmonics during the loading condition”, *Electrical power quality and utilization, Magazine* Vol. 1, No. 2, 2005.