Simulation of 2-phase Soft Starter control for Induction Motor with Minimized Starting Torque Pulsation

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***Abstract*— AC voltage controllers are used as soft starters for smooth starting of induction motors. Soft starters are used for induction motor drives having fan, pump and blowers types load where load torque is directly proportional to square of speed. This paper presents a novel control technique for ac voltage controller using 2- phase in place of 3-phase. Control circuit generates the firing pulses for appropriate thyristors for any given operating torque and speed of the motor. Out put voltage can be controlled by controlling firing angle. Simulation results presented in this paper elucidates the advantages of proposed soft starting method over conventional method. Finally features and benefits of the proposed technique are concluded.**

Keywords—induction motor; thyristors; soft starter; electromagnetic torque

I. INTRODUCTION

DUE to the extensive use of induction motors in industrial and residential applications, precise and smooth control of induction motor is essential requirement. High inrush current may cause adverse effects on induction motors. The problem is more severe in areas where the loads represent a high portion of the power demand. Medium or large induction motors draw such large current during direct-on-line starting process that it can pull down the voltage of the power supply net, which will severely influence the other electrical devices in the same power net. On the other hand, it also makes the temperature of motor become higher, which may lead to motor damage. Therefore, the motor's starting process needs to he controlled to reduce the start-up current to safe value. The traditional reduced voltage starting methods, such as star-delta reduced voltage method, can not adjust the stator voltage continuously during the start-up process, so the start-up current is still large. With the development of power semiconductor technology and digital signal processors, it is proposed to achieve the soft starting of induction motor. In recent years, some foreign scholars and enterprises have already been started to develop this new type of soft-starting controller for induction motors [2].

Now a days energy saving is an important issue in electrical drive systems. Energy saving is also possible with soft starter. 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.

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 tricky to find the exact value of for any motor speed and torque. This paper proposes a new starting topology for selection of firing angles for thyristors in voltage controlled induction motor. In this paper simulation procedures and results have been presented for the proposed method.

Principle of Soft Starter

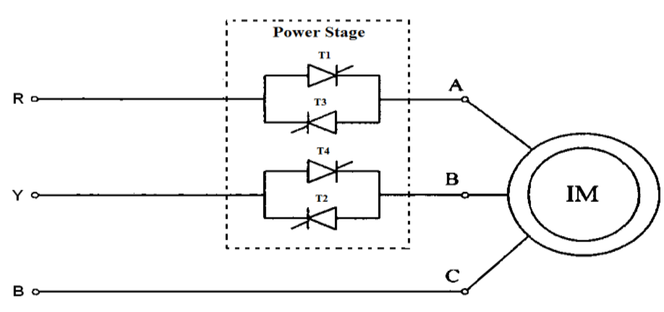

Fig 1 Schematic of 2-phase control soft starter

A soft starter is an ac voltage controller in which the voltage is adjusted through the setting of the thyristor firing angle α. Fig. 1 shows the typical schematic of a symmetrical 2-phase voltage controller or 2-phase control soft starter. Each phase has two thyristors and which are connected in anti-parallel connection. Thyristors in this configuration are fired according the sequence of numbering. Fig. 2 shows the firing sequence of six thyristors in soft starter circuit. From this figure, it should be noted that at least two thyristors must conduct simultaneously to allow current to flow through the load and that the firing angle α is measured from the zero crossing of phase A voltage

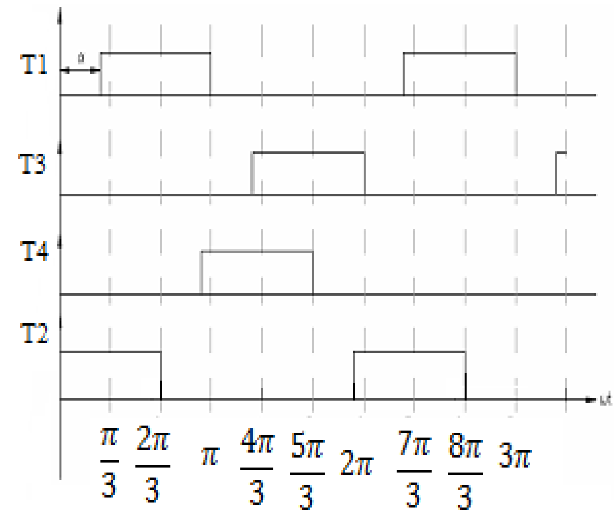

Fig 2 Firing sequence of Thyristor

Block diagram of Soft Starter

A soft starter is basically ac voltage controller in which two thyristors are connected back to back. Voltage is adjusted by controlling firing angle α. Fig. 3 shows the typical block diagram of a symmetrical ac voltage controller or soft starter. Thyristors in this configuration are fired according the sequence of firing pulses.

(1) Thyristor Assembly:

In each phase two anti parallel SCRs are connected. Which are fired using the control card & gate driver card.

(2). DSP control card:

It uses 32-bit high-Performance Digital Signal Processor TMS320F28069 (Piccolo Microcontrollers). 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.

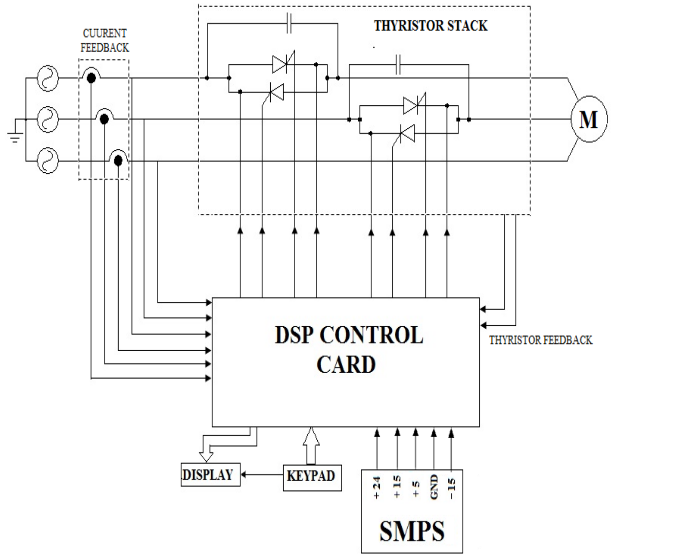

Fig.3 Block diagram of medium voltage soft starter of Induction motor

(3). Gate driver Circut

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) Gate command from DSP, 2) driver stage and pulse forming network and isolation pulse transformer, and 4) Output rectifier and terminating resistor.

It 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.

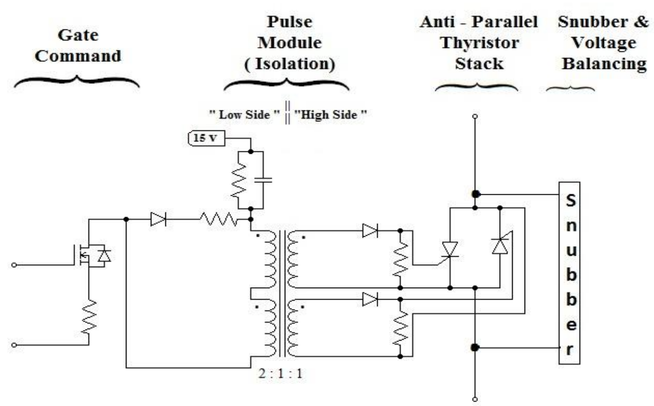

Fig.4 Block diagram of gate driver card for thyristor

The output's rectified square wave (dc) has an amplitude profile that is enhanced with a primary side pulse shaper to provide a strong leading edge.

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

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transformer is generally a high permeability ferrite core of low turn count (2:1:1 ratio) to reduce parasitic inductance and inter winding capacitance. The bipolar square wave signal derived from the secondary is half-wave rectified via fast recovery rectifiers into a dc pulse. Terminating impedance can be used to enhance the noise immunity and help protect against transient gate reversal.

(3) SMPS:

SMPS is used to provide the control voltage to the DSP control card

Control Strategy

The main circuit of the soft-starter for rated voltage induction motor is shown in Fig.1 TI-T4, T2-T3 are two pairs of thyristors in opposite direction, respectively connected in series into the motor's three phase circuits. To achieve smooth starting of motor, the trigger angles of the four thyristors must be adjusted in certain time sequence to control the terminal 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 symmetrical. The thyristor operating voltage waveform of one of the two phases is shown in Fig. 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 Fig. 6, the following relationship can be got [3]:

$$\theta = \pi - \alpha + \varphi$$

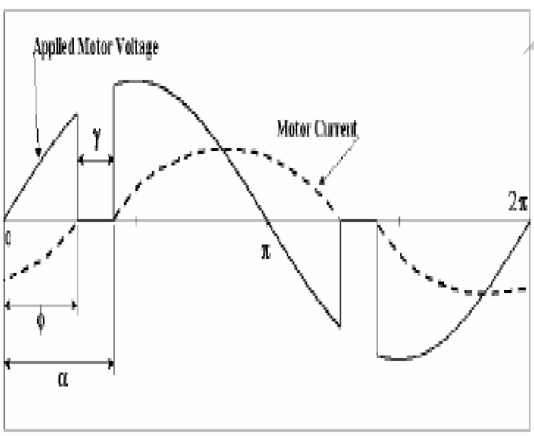


Fig 5 Definitions of firing angles.

Voltage control of soft starter is implemented by adjusting the delay angle α or γ, of the conduction cycle of the approaching thyristor with respect to either the zero crossing of the supply voltage (α) or the zero crossing of the line current (γ), respectively, as shown in Fig. 3. The thyristors are then selectively fired to conduct current in the appropriate phase, and naturally commutate off when the current reaches zero. The larger the delay angles α the larger the notch width in the applied motor voltage, which consequently reduces the effective (rms) value of such voltage impressed upon the motor. However, improper control of the α or γ firing angles may result in inferior performance of induction motor and supply current oscillations. Therefore, optimum starting profiles of the firing angle(α) have been extensively investigated to produce smooth starting torque and current profiles.

The output voltage of thyristors is the segment of waveform in the region of [α, $\alpha + \theta$]; 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 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 varies in certain predicted regular patted.

Simulation Results

Fig.6 shows the basic simulated circuit diagram of soft starter for induction motor in PSIM 6.1 software tool.

Induction motor data:[4]

3-phase, 415 V, 2.2 kW, 50 Hz, 4-pole, 7.5 A , 5 hp induction motor has following parameters referred to stator side:

R1 = 3.098 Ω; R2'= 9.280 Ω; X1= 134.958 Ω; X2'=134.958Ω; Xm=126.958 Ω; moment of inertia = 0.016 Kg.m2.

Parameters of pulse transformer:

No. of primary (Np) turns = 66

No. of first secondary (Ns1) turns = 33

No. of second secondary (Ns2) turns = 33

Primary winding resistance (Rp) = 1.266 Ω

First Secondary winding resistance (Rs1) = 0.591 Ω

Second Secondary winding resistance (Rs2) = 0.503 Ω

Primary winding inductance (Lp) = 6.086 mH

First Secondary winding inductance (Ls1) = 1509.9 µH

Second Secondary winding inductance (Ls2) = 1422.7 µH

Winding capacitance (Cp) = 16 µF

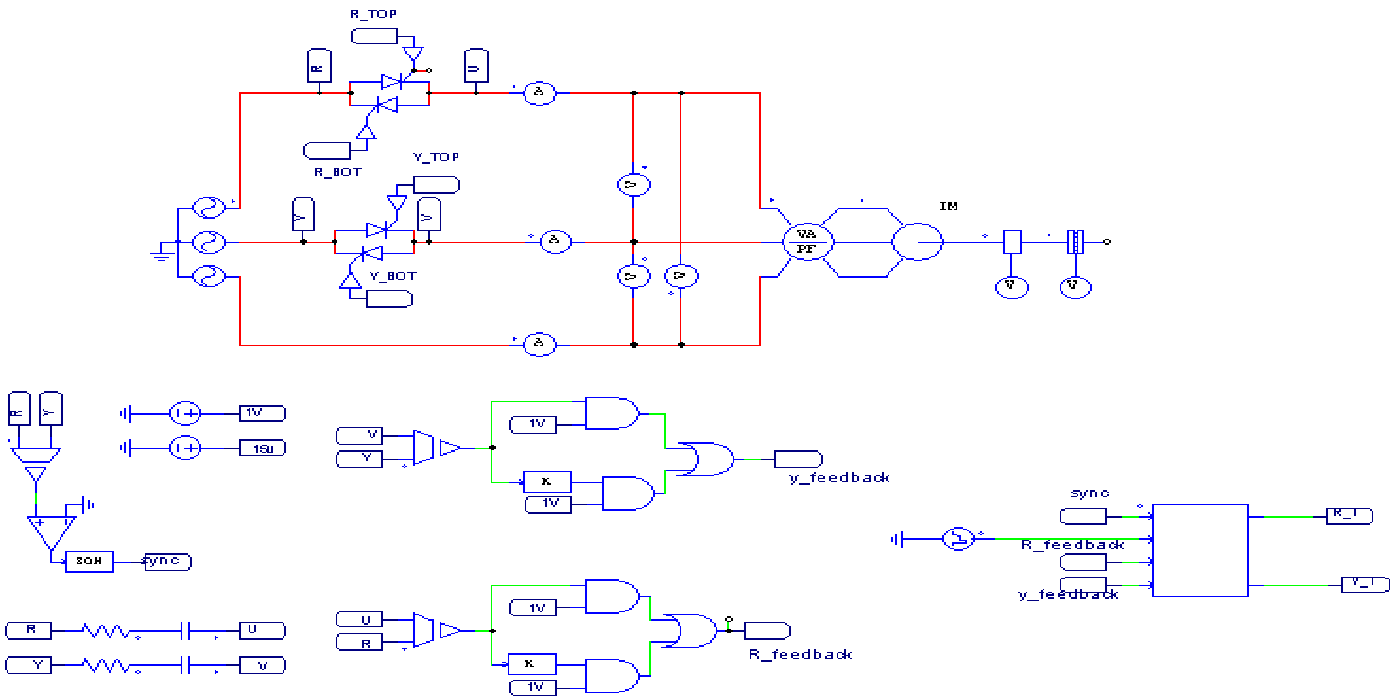
Mutual inductance (Lm) = 171.5 µH.

There are various methods for triggering of thyristor that are used to trigger thyristor. Here one new control technique is developed. In this technique first of all the zero crossing of the phase voltage is detected and according to that the first counter is started.

According to set firing angle and pulse width the first thyristor is triggered and with respect to first thyristor the respective thyristor triggered at shift of 60º consecutively.Fig.8 Shows algorithm for simplify c block to generate control signals for

Fig.6 Simulation diagram of soft starter of induction motor

gate driver circuit. In order to implement simplify c programming first step is to set the firing angle and ramp up time. So output voltage is varies linearly from zero to full voltage according to set firing angle & ramp up time.



For the voltage control in both the positive and negative cycles two anti-parallel thyristors are arranged for each phases. In this simulation input voltage signal is sense and given to simplify c block. simplify c block generates control signals for gate driver card according control logic shown in the algorithm.

Fig.8 shows the gate pulses for all four the thyristors. Thyristors are fired in specific sequence. There is 60 ° phase shift between two pulses. It gives fast rise time to improved anode initial di/dt, slow fall to prevent unwanted turn-off of thyristor. Minimum pulse width is selected to minimize gate losses. High frequency carrier gating is required to ensure reliability.

Fig. 9 shows waveforms of the starting current and torque of induction motor without using soft starter. So the heavy inrush current and torque pulsation is there in the waveform. With the help of soft starter all the problems related to starting i.e. starting high inrush current and torque pulsation are eliminated as shown in fig 10. The phase current during starting condition is shown in Fig. 11. Similarly phase current during ramp up condition is shown in Fig. 12. Phase current during normal running operation, which is purely sinusoidal, is shown in Fig. 13. Similarly waveforms of the line voltage during starting condition, ramp up condition and normal condition are shown in Fig.14, Fig.15 and Fig.16 respectively.

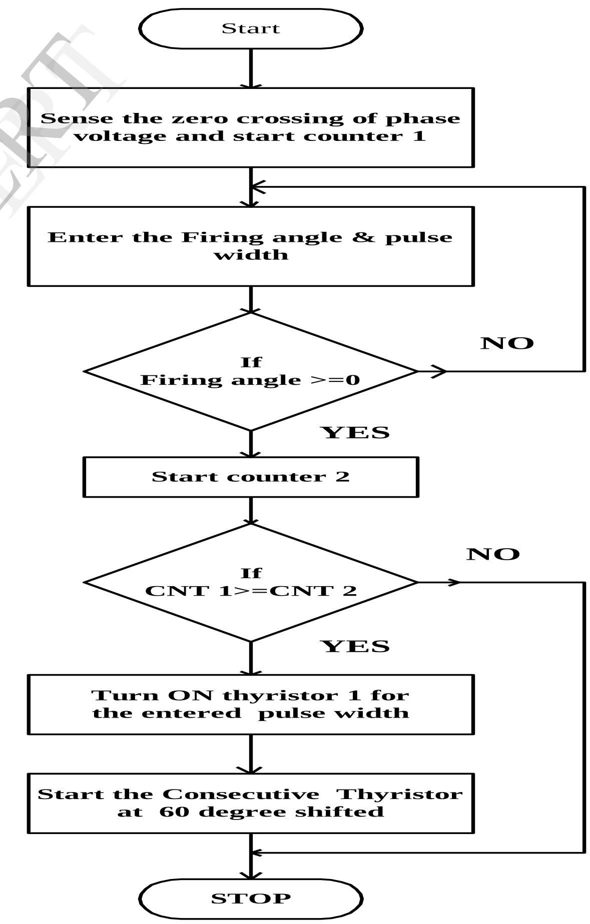


Fig 7 Flowchart of control logic.

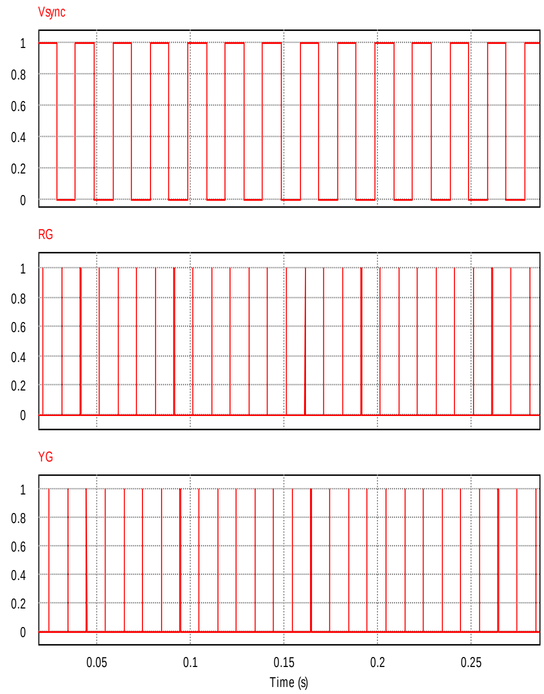


Fig.8 Gate pulses for thyristors

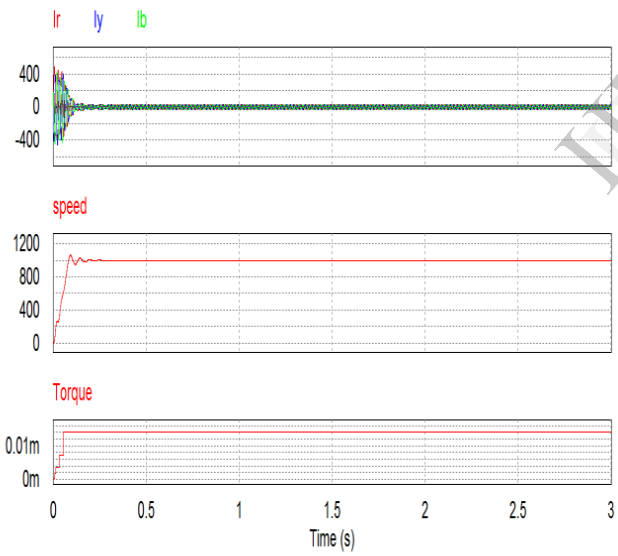


Fig 9 current & torque waveform of induction motor without using soft starter

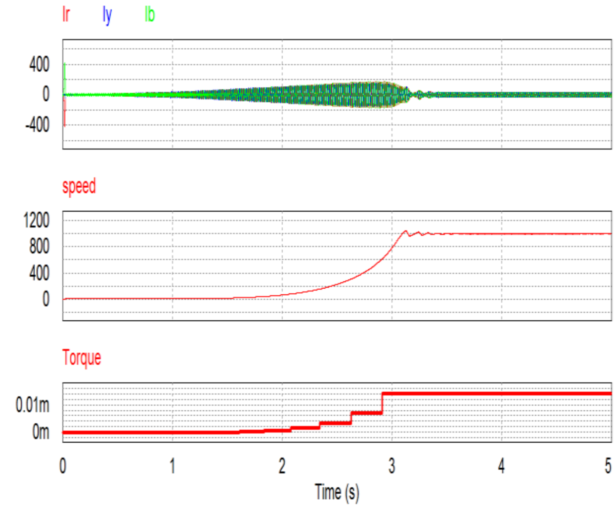


Fig.10 The starting current, speed, torque of 3300V, 250KW induction motor using soft starter

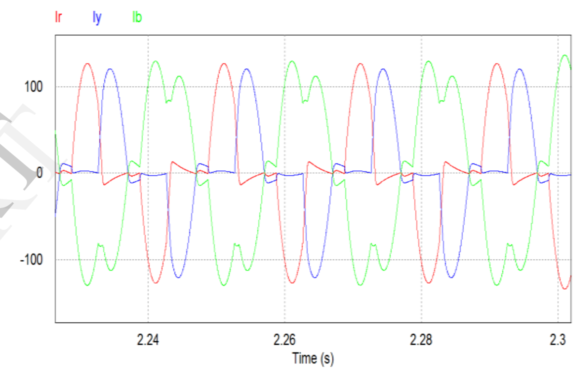


Fig.11 Phase current during starting condition

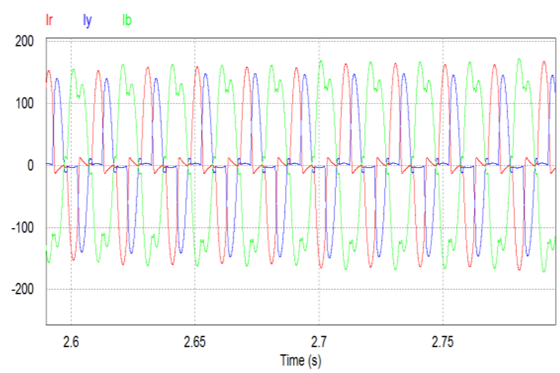


Fig.12 Phase current during ramp up condition

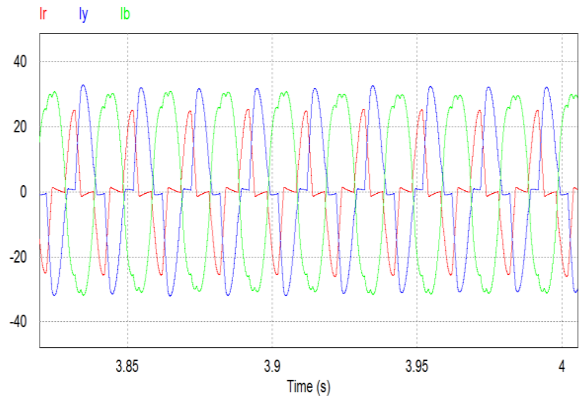


Fig.13 Phase current during normal running condition

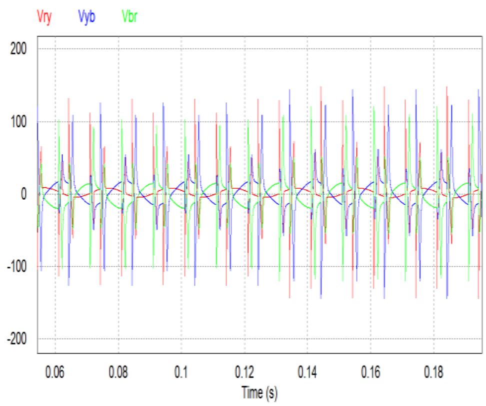


Fig.14 Line voltage during starting condition

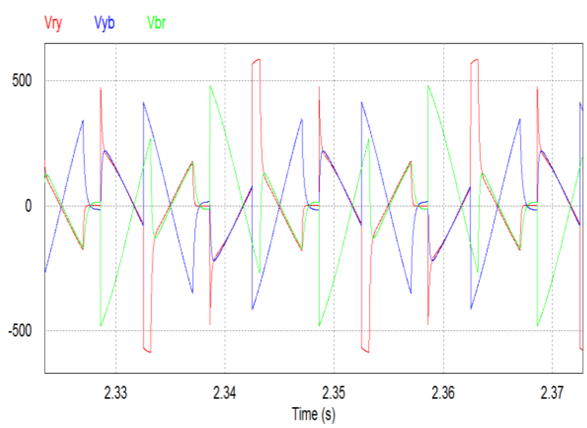


Fig.15 Line voltage during ramp up condition

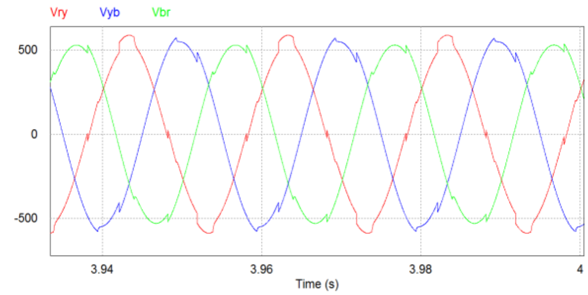


Fig.16 Line voltage during normal condition

CONCLUSIONS

A thyristorized induction motor soft starter can be realized with the use of 4 thyristor in place of six thyristor. Four thyristor firing scheme which can be practically implemented using digital signal processor to obtain superior performance of induction motor. Nearly perfect current and torque profiles are obtained with simulation. From the simulation of proposed strategies, a good acceleration profile can be tailored by smooth, utmost pulsation-free torques over the entire starting period.

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