Simulation of Three Phase Electronic Soft Starter Using Four Thyristors

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Abstract— **Soft starter is generally used to control high starting current flowing through the induction motor. The power section of conventional soft starter is equipped with three set of thyristor connected back to back in parallel. This paper presents soft starter using only four thyristors instead of six. As the thyristor is a only cost driving factor of the soft starter it can reduce cost of the device. It also reduces size, complexity & losses as number of thyristor used here are reduced. Simulation result of proposed topology is compared with the conventional topology.**

***Index Terms*— Soft starter, induction motor, two phase control, torque pulsation.**

I. INTRODUCTION

Induction motor is widely used in industrial as well as domestic applications. Soft starter is used for reducing high starting current as well as torque pulsation. In commercially available soft starter, a three-phase bypass contactor is usually connected in parallel with the back-to-back thyristors of each phase. The purpose of this three-phase contactor is to reduce any further thermal stress and power loss imposed on these thyristors after completion of the starting transient of the motor. That is, when the motor reaches its full speed and rated current, the contactor will be "pulled-in" to bypass these thyristors. During this time, all the thyristors will be in their "turned-off" state and the motor will be directly energized from the grid through the bypass contactors [3]. Fig 1 shows schematic of conventional soft starter with bypass contactor.

Soft starter works on principle that by reducing impressed voltage upon the motor during starting, reduces the starting current & torque pulsation [1]. This is due to the fact that the starting torque is approximately proportional to the square of the starting current and consequently it is proportional to the square of the starting voltage [2]. Therefore, by properly adjusting the applied effective voltage during start up, the starting torque and current can be reduced.

In the commercially available soft starters, this firing angle profile is preset by the user based on the initial setting of the locked-rotor torque (LRT) and the ramp time, a simple illustration of which is shown in Fig 2.

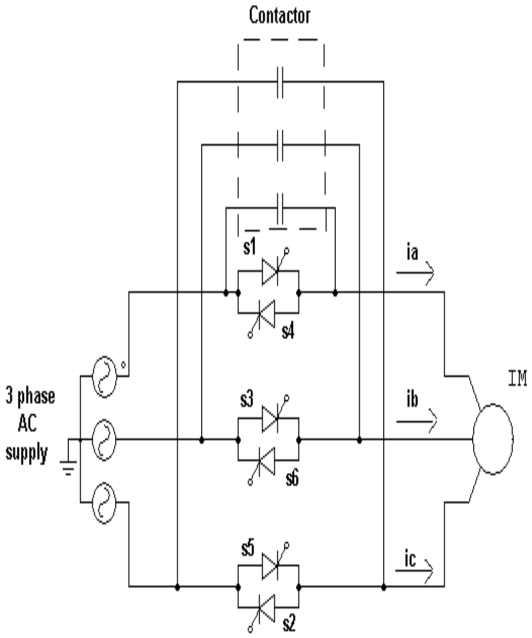

Fig. 1. Schematic of conventional soft starter.

The LRT is the initial starting torque that is required to accelerate the motor during starting, and the ramp time is the time it takes for the voltage to go from the initial voltage value at the LRT setting to the maximum full voltage that is being applied to the motor. By adjusting the ramp time, the acceleration time of the motor can be controlled. Accordingly, the firing angle which controls the amount of applied motor voltage is reduced gradually depending on the ramp time during the period of starting until the motor has reached its full speed and rated current, where upon the contactors are closed to bypass the thyristors.

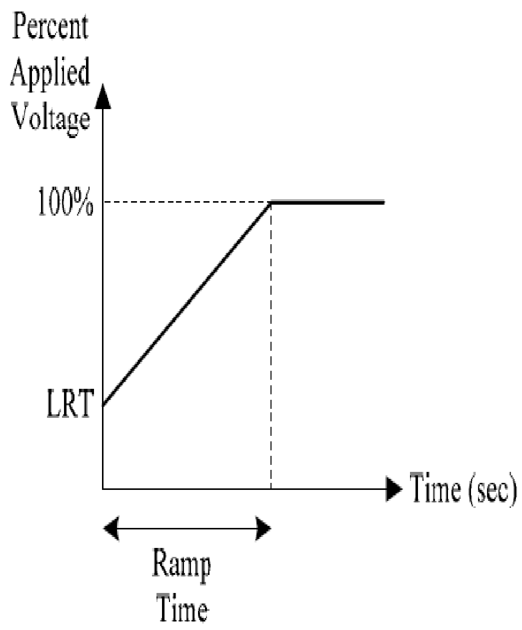

Fig. 2. Voltage ramp profiles.

II. Proposed Topology

Because of the advanced technology and revolution in power electronics, devices are going more & more compact. In this competitive world, everyone is worried about cost, power consumption and size of the device. This proposed topology is totally focused on these criteria. Figure 3 shows schematic of proposed topology. In this topology soft starter is consist of four silicon controlled thyristors (SCRs). It means anti parallel set of thyristors are connected to two phase while one phase is directly connected to the motor and hence it is also known as two phase controlled three phase soft starter.

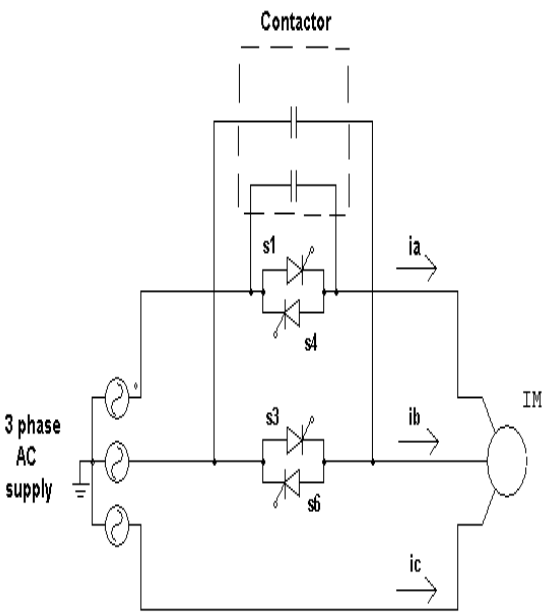

Fig. 3. Schematic of two phase controlled three phase soft starter

Table. 1. Relation between current flows in motor and controlled strategy

Controlled phases	Phase contain more current		Phase contain less current	
	Forward	*Reversed*	*Forward*	*Reversed*
R & Y	R	Y	Y	R
Y & B	Y	B	B	Y
B & R	B	R	R	B

In this type of soft starter any two phases can be controlled. It can be R and Y phase, Y and B phase or R and Y phase. R and Y phase controlled soft starter is shown in Fig. 3. In R and Y phase controlled soft starter, R phase contains higher current than the Y phase when motor runs in forward direction because of unbalanced voltage supplied to the motor. Table 1 shows the relation between current flows in motor with the different controlled strategy of proposed topology.

In soft starter voltage supplied to the motor is controlled by varying firing angle of the SCRs. In conventional soft starter all three phases are controlled and hence balanced voltage is applied to the motor while in proposed topology one phase is directly connected to the soft starter and hence unbalance voltage supply is given to the motor. Because of unbalanced voltage, unbalanced current flow through the soft starter. Because of unbalanced current, unbalanced thermal stress is applied to the SCRs of controlled phase. Further it increases the harmonic content and optionally even turned into an additional direct current component of the current. This in turn causes an asymmetrical power distribution within the load. In an electric motor overload occurs thereby increased torque fluctuation. It can damage device as well as motor.

III. Control Strategy

In proposed topology as unequal voltage supply is given to the motor, current flowing through it is also unequal. To control the unbalanced current we need to apply firing angle α with a corrective angle Δα. The continuous monotonic function between fixed starting and ending points is interpreted as a function of the load to be controlled. The function is preferably empirically determined by simulation process. In this scheme corrective angle is added with the firing angle of phase which contains higher current while corrective angle is subtracted from the firing angle of phase which contains less current. Corrective angle can be finding out by equating voltage at motor load. By try and error method we are able to find out the range for the corrective angle. The corrective angle varies in range of 0˚ to 30˚. At firing angle (α) 0˚ to 60°, a corrective angle Δα = 0˚ while at firing angle (α) 150° to 180˚, Δα = 30˚. The graph for corrective angle Δα is shown in Fig. 4.

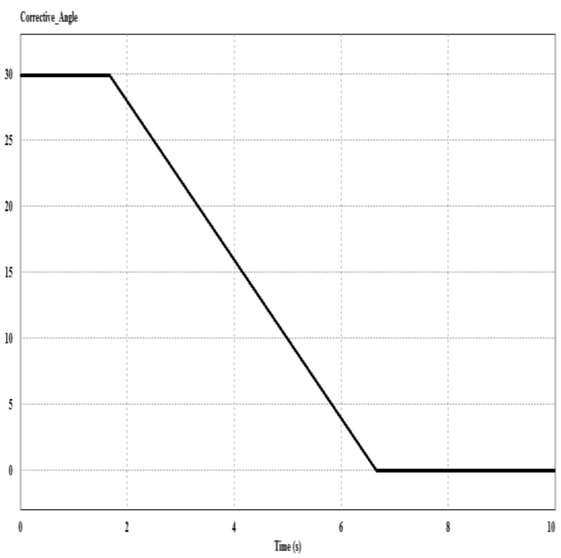

Fig. 4. Variation of corrective angle with firing angle.

In open loop control current pulsation is arise. Closed loop control is required to avoid these current pulsations. For closed loop, voltage across thyristor is taken as feedback. Power factor of motor is suddenly reduces when transition takes place from transition phase to normal run phase. Because of this current pulsation arises. Zero crossing of current find out by taking voltage across thyristor as feedback. Current pulsation is avoided by applying firing angle from zero crossing of current instead of voltage. Bypass contactor is also connected in parallel with the soft starter. Bypass contactor is operated when ramp up time is completed and motor get accelerated. During bypass phase soft starter is disconnected from the motor and supply is directly connected to the motor. Because of bypass contactor losses are reduce as thyristors are bypassed.

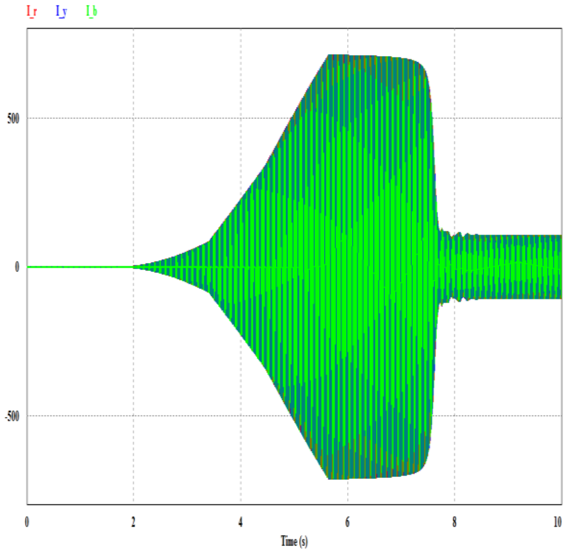

Fig. 5. Motor current in conventional topology.

IV. Simulation Results

Simulation result on motor starting performance of conventional & proposed topology were obtained for a 60hp, 440V, four-pole, three phase induction motor, the characteristics of which are given in Appendix. Two simulation cases were conducted for comparisons, namely: 1) conventional soft starter; 2) proposed topology with proposed control. The simulation work was carried out in a PSIM. Meanwhile, the load is of fan type: $T_L = k_L \omega_m{}^2$, where ω_m denotes the motor speed in mechanical radians (mech.rad)/sec and k_L is the load coefficient in N.m/(mech.rad/s)^2.

The three phase conventional soft starter was first simulated. The results of the three phase motor currents are shown in Fig 5. As one can observe therein, the motor currents have smooth starting profiles as the firing angle is decreasing, with low starting currents. Here current in all three phases are equal while current in proposed topology with conventional control strategy has unequal current. To equalize this current, corrective angle is added or subtracted to the firing angle which leads to equal voltage supply which results in a balanced current. As may be seen in Fig 6, the three phase motor currents have reasonably smooth starting profiles, which indicate significant starting transient improvement than the conventional control. In this topology current in uncontrolled phase is slightly higher than the current in controlled phase. Once normal speed is achieved, soft starter gets disconnected from the supply while bypass contactor connects power supply to the motor. It reduces losses of the circuit as thyristor are bypassed.

The developed motor torque profile for conventional soft starter is depicted in Fig 7. Again, one can see a smooth starting profile with minimum torque pulsation. An improved staring torque profile for the proposed approach is illustrated in Fig 8. It can be seen from the figures that the starting transient torque pulsation for both the topology is nearly same.

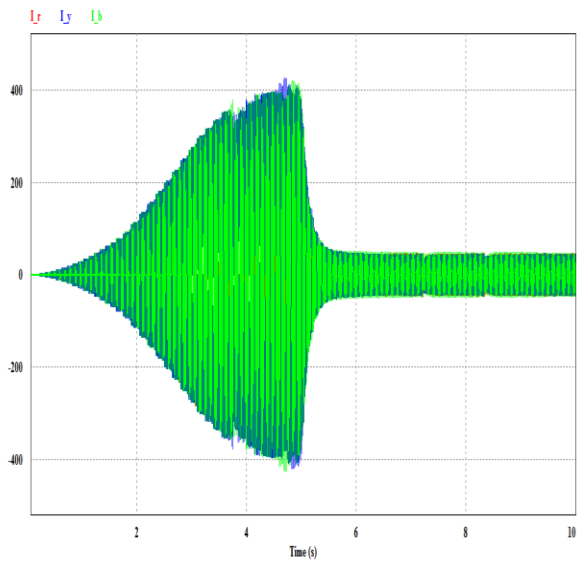

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Fig. 6. Motor current in proposed topology.

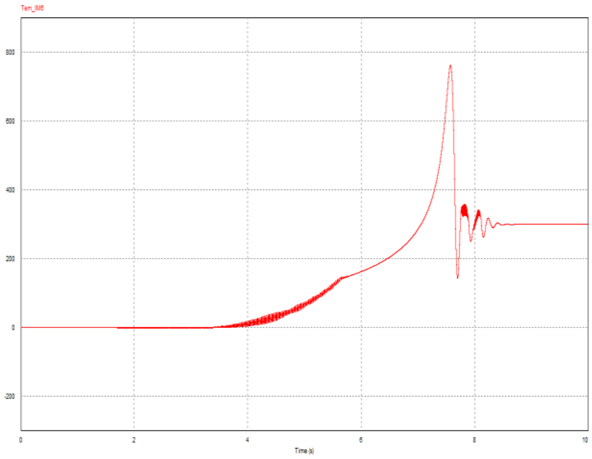

Fig. 7. Motor torque developed by conventional soft starter.

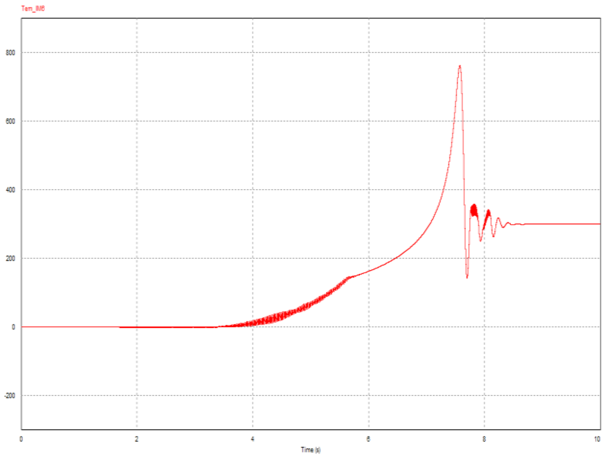

Fig. 8. Motor torque developed by proposed soft starter.

V. CONCLUSION

In two phase controlled three phase soft starter, because of corrective action nearly balanced current flow in two controlled phases while slightly higher current flow through the uncontrolled phase. Average current flow through the motor in both the topology i.e. conventional and proposed is nearly equal. Proposed topology use only four SCR instead of six SCR and provide same result as that of conventional topology. By eliminating two SCRs it can reduce cost of the soft starter. It also helps to minimize the size of the soft starter.

APPENDIX

Rated Power:-	60 hp
Rated Voltage (Line-Line):-	440 Volts
Rated Current:-	81 Amps
Rated Frequency:-	50 Hz
Rated Speed:-	1470 RPM
Phase:-	3
Number of Poles:-	4
Stator Resistance:-	0.07 Ω
Stator Inductance:-	0.008 H
Rotor Resistance:-	0.025 Ω
Rotor Inductance:-	0.0008 H
Magnetising Inductance:-	0.0228 H
Moment of Inertia:-	0.42 Kg.m²

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