Soft Starter for Three Phase Induction Motor

Praful V Nandankar[#1], Akshay Rathod[*2], Shivam Shukla[#3]

Electrical Engineering Department,
Government Engineering College, Chandrapur

Abstract *- An induction motor draws current more than the rated capacity during starting phase which might damage stator windings of three phase induction motor. To avoid the problem of high starting current, voltage is increased gradually from lower to higher level using smooth and soft starters. A smooth and soft starter is employed in a three phase induction motor to eliminate the surge in current and electromagnetic torque during starting. The surge in current and torque are eliminated temporarily using soft started at the time of starting. This in turn reduces the stress applied on an electric motor and shaft attached with rotor. The soft starter also eliminates the unwanted effects in electric cables and power distribution network. This paper provides a detailed description of soft and smooth start to an induction motor. At the time of starting, an induction motor draws significant amount of current from the supply and this drawn current is higher than the rated current of three phase induction motor. The motor reaches the full rated speed instantaneously as soon as the voltage is applied. The smooth start of three phase induction motor is based on the delay angle of TRIAC circuit. The firing angle is delayed during starting and delay angle reduces as the motor picks up the speed. The firing delay angle is further reduced to zero when motor reaches full speed. This proposed technique provided reduced voltage at the time of starting and full rated voltage when motor reaches full speed. Due to proposed technique, motor starts at a slow speed and gradually increases to full rated speed. By using soft starters, performance of induction motor is improved and it also improves load torque characteristics.*

Keywords—*TRIAC triggering, firing angle delaying, opto-isolators, zero crossing detector circuit*.

I. INTRODUCTION

The ac motor starters are increasingly becoming popular due to its controlled soft-starting capability. The ac motor starter provides limited starting current and hence conventional electromagnetic line starters and reduced-voltage starters are replaced with ac motor starters. Thyristor-based soft starters have many desirable properties and provide a viable solution to starting problems in three phase induction motors. These power semiconductor based starters are cheap, simple, and reliable and occupies less volume. The power density of these soft starters is also very high. A three phase induction motor produces electromagnetic torque on its shaft but initial switching instants of all three phases to the supply produces pulsations on the electromechanical torque when it is controlled by a direct- online starter. These severe pulsations in electromagnetic torque might cause shocks to the shaft and hence to the driven equipment. These pulsations might damage mechanical system components, such as shafts, couplings and gears etc. The electromagnetic torque pulsations also causes long term effects on various mechanical system components if the strength of materials is exceeded which might lead to fatigue also.

The reduced voltage starting by soft starters eliminates stress from the electrical supply and it also reduces the possibility of voltage dip and brown out conditions. Soft and smooth starters provide smooth acceleration of rotor of three phase induction motor. Reduced voltage starting reduces high amount of starting torque applied on the shaft and therefore eliminates the shock on the driven load. An instantaneous high amount of starting torque can cause a jolt on the conveyor which can damage products, pump cavitations and water hammer in pipes. Therefore, a soft starter ramps up the voltage applied to the motor from the initial voltage to the full voltage. The voltage is initially kept low to avoid sudden jerks during the start. The voltage and torque increases gradually so that the induction motor starts to accelerate. This ramp up voltage provides sufficient torque for the load to accelerate gradually and hence mechanical and electrical shocks are minimised from the system, The voltage supplied to stator windings are adjustable and it has ramp characteristics.

II. OPERATING PRINCIPLE OF SOFT STARTER

A soft starter provides reduced voltage to stator windings of three phase induction motor by controlling the acceleration of an electric motor. A three phase induction motor is a self-starting motor and electromagnetic torque is produced due to an interaction between revolving magnetic field around rotor and rotor current. Initially during starting, a rated voltage is applied which causes high current to flow through stator windings. Now this high current is greater than the rated current which can cause heating of the stator windings and

eventually damaging the insulation applied on stator windings. To avoid the problem of high starting current, there is a need of motor starters in an electric motor.

The motor can be started in three ways. Firstly by applying full load voltage i.e. direct on line starting. Secondly, by applying voltage gradually using star-delta starter and soft starter. Thirdly, by applying part winding starting i.e. autotransformer starter.

A soft starter provides reduced voltage and hence reduced torque on electric motor. A soft starter comprises of solid state devices like thyristors. The supply voltage to the motor is controlled by power semiconductor devices like thyristors. In a three phase induction motor, the torque is proportional to the square of the starting current which in turn, is proportional to the applied voltage. The starter works on the principle described above. Therefore, the torque and the current can be controlled by applying the reduced voltage at the time of starting of an electric motor. The two types of control are possible using soft starter. The first one is open loop control and second is closed loop control.

In an open loop control, a start voltage is applied with time. This start voltage is applied irrespective of the current drawn or the speed of the motor. For each phase, two SCRs are connected in antiparallel direction and SCR are initially started at a delay angle of 180^0 during respective half wave cycles. Each SCR conducts in each half cycle. This delay is reduced gradually with time when applied voltage reaches to the full supply voltage. The reduced voltage ramps up to the full voltage and simultaneously, the firing angle is reduced from 180^0 to 0^0. This type of system is known as time voltage ramp system. This method has a drawback that it cannot control the acceleration of motor.

In a closed loop control, any characteristic of the motor is monitored for the desired response. The starting voltage is modified depending on required motor current or motor speed. The current in each phase is monitored properly and time voltage ramp is stopped when current in each phase exceeds a certain set point. The supply voltage applied to stator windings of three phase induction motor is controlled by controlling the conduction angle of SCRs.

A soft starter basically comprises of two anti-parallel SCRs in each phase of three phase induction motor. There are total six SCRs required for all three phases for smooth acceleration of electric motor. These SCRs are power semiconductor devices which normally are in OFF state but these SCRs starts to conduct when firing signals are given to them and hence allows voltage and current to pass through them.

Initially to perform soft starting, a firing pulse are given to the SCRs so that only the remaining part of each half period of sinusoidal voltage curve passes through them. Then the instants of firing pulses are reduced which allows larger part of the voltage to pass through SCRs. Finally, the firing pulses are applied exactly at the zero crossing of the voltage which allows 100% of the voltage to pass through. This is also seen as the ramping up of voltage from reduced voltage at starting by allowing more voltage to pass through SCRs. In this way, a full voltage is applied from reduced voltage at the starting. The opposite procedure is followed for soft stop. The full voltage is allowed to pass through the thyristors and when the stop time is about to reach, the firing pulses are delayed which allows less voltage to pass through. The instants of firing pulses are increased till the end of voltage is arrived. Then, no more voltage is applied to the motor and in this way, the motor is stopped.

III. CIRCUIT DIAGRAM

The circuit diagram of soft-starting of three phase IM is shown in Fig.1. The circuit diagram comprises of voltage regulator, zero crossing detector, bridge rectifier, 4N25 opt-Isolator, Atmega 328P microcontroller and TRIAC circuit. TRIAC circuit performs the role of soft starter in each phase of three phase induction motor. TRIAC circuit basically consists of two antiparallel SCRs connected back to back. This soft starter is used to give soft starring to Induction motor.

A 12 V DC regulated supply is obtained with the help of step-down transformer and bridge circuit. The step down transformer converts 230V to 12V ac supply and then it is fed to bridge circuit. The bridge circuit in turn converts ac supply to dc supply. This dc supply is given to regulator IC to get positive 12V dc regulated supply. The main part of the circuit is zero crossing detector circuit which is made up of four diodes connected to form bridge rectifier circuit and output of bridge rectifier is fed to 4N25 optoIsolator. Then output of 4N25 optoIsolator is applied to interrupt pin of Atmega 328P. Whenever the input AC waveform crosses the zero reference point, a high pulse signal triggered from 4N25 optoIsolator is given to interrupt pin of Atmega 328P. When Atmega 328P receives high signal from interrupt pin, it interrupts Atmega 328P by providing high signal on interrupt pin and then it initiates delay counter from that point and hence it provides triggering pulse to gate signal of TRIAC through MOC3021 optoIsolator.

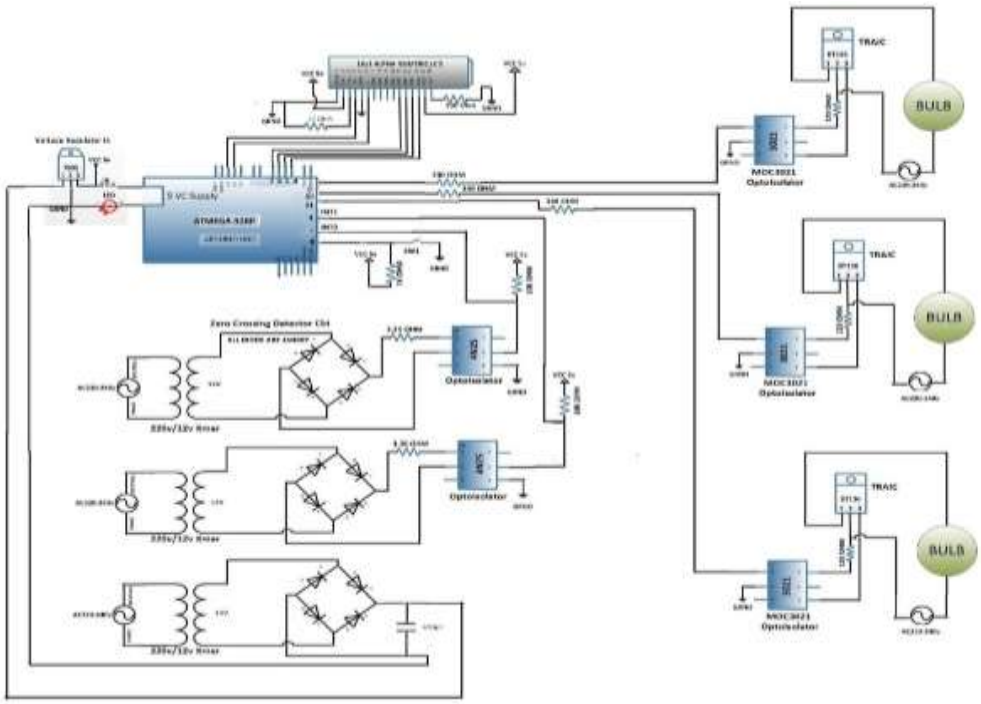

Fig. 1 Circuit diagram of soft-starting of three phase IM

Initially, the program provides maximum time delay to reduce the power supplied to motor and gradually decreases the delay to zero value and therefore provides full power to the motor. The capacitors are used in above circuit diagram to provide voltage regulation. The cathode of SCRs in TRIAC circuit are connected to load terminals of induction motor.

IV. HARDWARE PROTOTYPE OF SOFT STARTING OF INDUCTION MOTOR

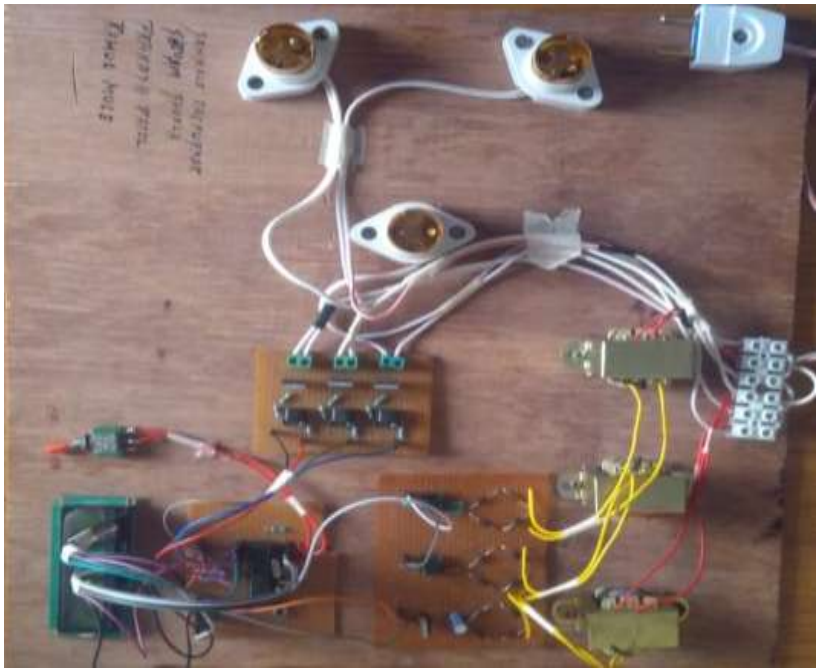

Fig. 2. Experimental hardware prototype of soft-starting of three phase induction motor

The proposed soft starter is tested and hardware prototype is created to understand the operation of starter for three phase Induction motor. The hardware prototype for soft-starting is shown in Fig. 2. The components used in soft-starters are shown in tabular form.

Sr. No.	Name of component used	Rating of component	Number of components
1	Transformer	220-240/12V	3
2	Diode	1N4007	12
3	Opto-isolator	4N25	2
4	Arduino	ATMEGA328P	1
5	LCD Display	16*2	1
6	Voltage regulator IC	7805	1
7	Capacitor	470uF	1
8	TRIAC	BT136	3
9	Toggle switch	-	1
10	Resistance	120 Ω 330 Ω 1000 Ω 3.3 kΩ 10 kΩ	3 4 3 2 2
11	Bulb	60W	3

After a series of experimentation on hardware prototype, it is found that the voltage limiting process in the soft starting is efficient method as compared to direct on line and star-delta starter. The amount of voltage is controlled or adjusted by changing the firing angle of SCRs.

V. Advantages And Disadvantages Of Soft Starters

The soft starters used in three phase induction motor eliminates high inrush current and high mechanical torque on startup. It reduces cable and switch-gear rating in power supply network. It prevents any dip in line voltage. The soft starter has desirable features of soft, step-less acceleration & deceleration. It also avoids current and torque peaks and provides less electrical stress on the power supply network and mechanical stress on entire drive. It reduces stress on couplings and other transmission devices such as gear boxes, shafts, belts etc. The soft starters also suffers from certain drawbacks like harmonics, problems of speed regulation, dependency of acceleration and deceleration time on load etc. It produces harmonics less than inverter. The operating speed of an electric motor is fixed throughout the operation. The speed regulation of an electric motor is not possible when soft-starters are employed in three phase induction motor. The speed regulation is possible only at the time of starting and stopping of motor. The acceleration & deceleration time also depend on load.

VI. Conclusions

An effective and efficient technique has been presented in this paper which provides reduced voltage and reduced current at starting and at the same time, a control in an electromagnetic torque is also obtained. The motor torque is varied according to load torque and acceleration is maintained constant over the entire starting period with the help of this technique. The proposed approach eliminates shaft torque pulsations at the time of starting. The starting current is reduced significantly with the use of soft-starter circuit. The soft starter also eliminates the starting losses in the motor and hence it results in increased life and increased efficiency of an electric motor. It is found that the heating losses are reduced by 50% when soft-starters are employed during starting of three phase induction motor.

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