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Energy Efficient Operation of Three Phase Induction Motor using Delstar Converter for Machine Tools

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ABSTRACT

DELSTAR converter is an electronic system to be interfaced with the existing STAR – DELTA starter for machine tools. Induction motor consumes more power while it is operated at DELTA mode for a long time under no load condition. The proposed system gives the solution for the above stated problem. When the load on the motor is less than 40% of full load, it switches the motor to operate in STAR mode to save energy. When the load increases beyond 40%, it automatically switches the motor to operate in DELTA mode. The starting regimen is not disturbed. The proposed converter is recommended for applications where load changes are not more than 120 times/hour. This can be used with any capacity motor by choosing appropriate current transformers and setting the current level using the potentiometer built in. The proposed converter is designed for 5HP induction motor and experimentally tested.

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1. INTRODUCTION

Lathes will perform as many operations like face, turn, neck, taper, drill, bore, spin, file, polish, hone, buff, knurl, cut internal and external threads and cut off work. Relatively hard materials are handled by a metal lathe. For repetitive production of parts, turret lathes and capstan lathes are used. Induction motor of several HP is coupled with turret lathe and CNC machines too.

In industries, the induction motors in machine tools are controlled through thyristor control and extinction angle control is used and the values are obtained analytically to obtain performance of thyristor-controlled induction motor [1]. Induction motors draw higher currents during their starting operations than is the case under full load running conditions. The star-delta starter is used to reduce the starting current during start as a way of dwindling and interventing the electrical supply [2]. But in the early days Direct-on-Line have been used. The short duration inrush currents, greatly exceeds the starting currents. Complex starting methods to reduce starting currents is compromised by other inrush currents [3]. Unlike synchronous motor, Induction motors do not present the types of starting problem. In many cases, induction motors can be started by directly connecting them to the power line. However, the starting current required may cause dip in the power system voltage that across-the-line starting is not acceptable [4].

The various method of starting large AC induction motors such as full voltage, reduced voltage either by autotransformer or star-delta, and soft starter can all have potential advantages and tradeoffs. The auto transformer or star-delta starting can lower the starting torque and help to prevent damage to the load. The proper starting method for a motor includes an analysis of the power system to ensure that the motor is to deliver the needed performance [5]. Recently, the motor is controlled with the help of power electronic

converter efficiently. The behavior of the thyristor based reduced voltage starter inside a delta connected induction motor is shown to be different when operated inside the delta than when operated in the AC lines [6].

In most of the industries, the low rated induction motors are started normally with direct on line (DOL), but when large motors are started with DOL starter, due to starting surge current, the supply line voltage is disturbed. To limit the starting surge current, reduced voltage is given to induction motors at start and then have full supply voltage when they run up to near rated speed. Comparison between the different starting methods of induction motor in terms of power quality is to figure out the reliable starting method which has the less power quality problems [7].

The reduction in cost of installation and less utilization of the system, it is important to reduce the heavy inrush current at starting of induction motor without the loss of torque generation and it will enhance the VA capability of the motor and improve the overall performance of the motor [8]. Efficient torque/current characteristics are provided by STAR-DELTA, industries prefer STAR-DELTA starters for their application. The large amounts of losses which occur at low speeds determine the users given by the wound rotor only for starting. The losses specific to the additional rotor resistor are quite important while analyzing the performance of the induction motor [9].

Industries will operate three phase induction motors at delta connection mode since machine runs very efficiently when the machine under fully loaded condition. When the motor is loaded less than 40% of the full load, it runs under inefficient energy zone. So, the induction motor will consume more power from the supply side during partially loaded condition. In order to compensate the power consumption, the motor load is virtually added by connecting stator winding from delta mode to star mode. If the load on the motor is increased above 40% of full load current, winding connection automatically changes from star to delta for efficient operation. The proposed converter is experimentally verified on three phase induction motor with variable load.

2. RESEARCH METHOD

2.1. Existing System

Motor draws more current than the full load at the time of starting, resulting in burnout of motor winding and / or starter. When DOL starter is used, because of high starting current, there is a big voltage dip in the electrical installation and therefore DOL starter is not suitable for higher rating squirrel cage induction motors. Significant energy wastage results reduced motor life. The system which exists is starting current reduction and the starters at the time of start of motor is star-delta starter. The STAR-DELTA starter is used at the time of starting only, not under running condition. The starter may be operated semi-automatically or fully-automatically. The semi-automatic operation is done by the push button switch. Fully-automatic starter is built with the timer which is used to change the STAR to DELTA connection after some predefined time. The both types of STAR-DELTA starter changes the winding connection from STAR to DELTA, and it is not possible to change the winding connection from the DELTA to STAR during running of induction motor. This problem is overcome by employing proposed starter with induction motor which changes the winding connection during both starting and running condition.

2.2. Explored Technology

The block diagram of the proposed delta-star-delta converter is shown in Figure 1. The converter is to change the winding connection from STAR to DELTA and vice versa at the running condition of the induction motor. The switching process is done according to the load variation of the motor at particular instant. The construction of the converter is also similar to the starter with the small modification in the circuit. It is an automatic converter and the automatic process is made by the microcontroller.

In the ancient system, there is no microcontroller available. Any one of the phase is taken for the current sensing using current sensor. The sensor circuit continuously senses the load variation in the motor and the output is produced according to the variation of load. When the load on the motor is less than 40% of the full load rated current, the controller activates the STAR connected contactors, so that the motor can run at STAR connection. When the load on the motor is above 40% of full load rated current, the controller activates the DELTA connected contactors, so that the motor can run at DELTA connection. The converter accurately operates for the pre-setting value of the current sensor. If the motor load current reaches to 41% of the full load rated current the converter switches the motor from STAR to DELTA. And, if the motor load current comes 39% of the full load current, the converter switches the motor from DELTA to STAR. The converter can sense the current continuously so that the losses are reduced by maximum amount. Moreover, the converter can also be used as star-delta starter.

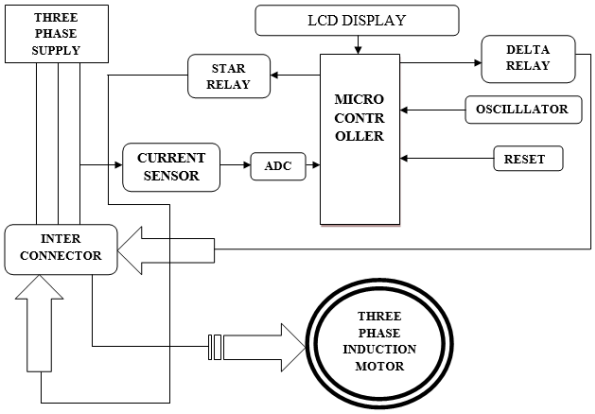

Figure 1. Block Diagram of Proposed System

3. SYSTEM SPECIFICATION

Hardware units are split into many sub units and each unit requires power supply to energize the circuit.

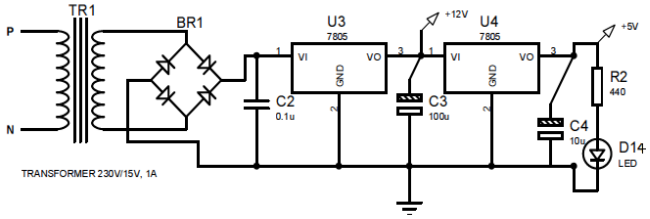

Figure 2. Power Supply Unit for Relays and Microcontroller

+12V SPDT relay and +5V SPDT relay were used here. So that relay requires +12V supply and +5V also for microcontroller unit. The LM7812 and LM7805 are the voltage regulators which is used to regulate the output voltage of the bridge rectifier in Figure 2. Then the output is again filtered with the capacitor. +24V power supply is used to energize the sensor unit. The current is sensed with the help current transformer with buffer unit to adjust the current setting. This circuit is designed with the help of LM317k voltage regulator in Figure 3.

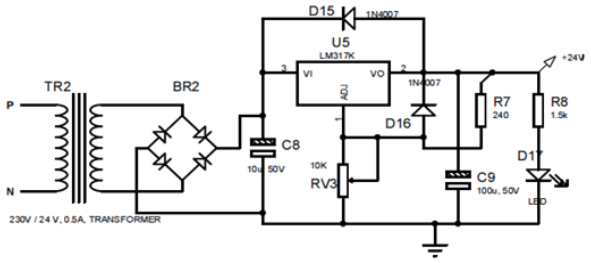

Figure 3. Power Supply Unit for Current Sensor

Above the preset value, the transistor operates and relay gets energized so that microcontroller switches the operation into DELTA mode. Microcontroller switches the operation into DELTA mode. The conversion process takes minimal time in milli seconds and give accurate change over from STAR to DELTA and vice versa. ULN2003 is a driver which drive the signal input from current sensor to the microcontroller and also the STAR and DELTA contactor. The analog output from the microcontroller is not suitable to operate the +12V relay. So the analog output of the microcontroller is changed from the +5V to +12V with the help of driver unit as shown in Figure 4.

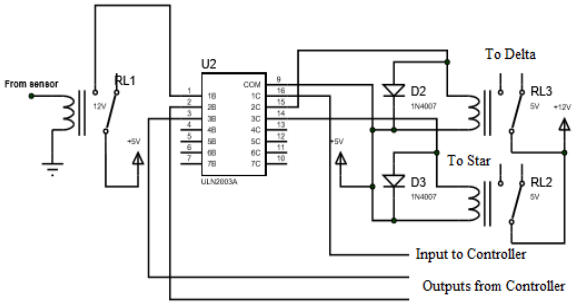

Figure 4. Relay Driver Unit

The microcontroller is to control the switching of STAR or DELTA relay while the motor is under the running condition. When the load is current is below the predefined value, the controller will energize the STAR contactor and if the controller input is high, it will activate the DELTA contactor. The input and output are enabled in the same port of the microcontroller. The pin 2 is enabled for STAR and the pin 3 is enabled for DELTA. The mode of operation is displayed in the Liquid Crystal Display. XTAL1 and XTAL2 are the input and output respectively of an inverting amplifier which is used as a crystal oscillator in the frequency range of 1.2 MHz to 12 MHz. The RESET circuit is connected with the microcontroller in pin 9. The overall schematic of the control unit is shown in Figure 5.

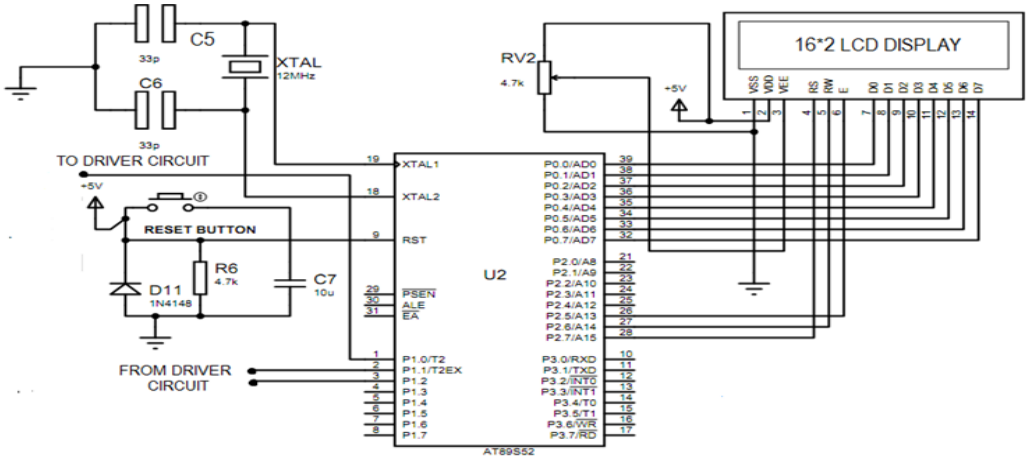

Figure 5. Schematic Diagram of the Controller Unit

The output of the relay driver is given to the relay coil for energizing. The output of the relay driver unit is either 0V or 5V. The relay is connected in 15th pin of the driver IC. So, whenever the output of the relay is +5V then the star contactors will be activated. The delta unit is also used to connect the motor with the converter part. The relay/contactor wiring diagram for the star connected mode is shown in Figure 6.

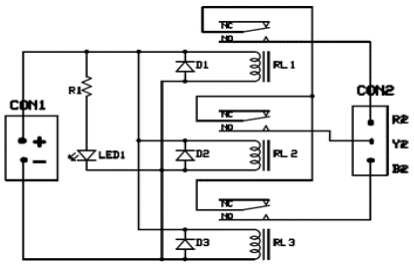

Figure 6. Wiring Diagram of Star Contactor

The output of the delta relay driver unit is either 0V or 5V. So, whenever the output of the relay is +5V then the delta contactor will be activated. The relay/contactor wiring diagram for the star connected mode is shown in Figure 7.

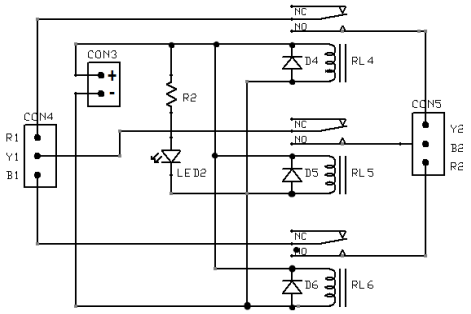

Figure 7. Wiring Diagram of Delta Contactor

With the help of the above arrangements, the contactors change the winding connection from STAR to DELTA and DELTA to STAR simultaneously while the motor is under running condition. The LCD display unit will display the motor running condition and also the load current. LEDs are used to indicate the status of the relays.

4. RESULTS AND DISCUSSION

The converter is tested with 5HP squirrel cage induction motor by conducting simple brake test in laboratory. The power factor of the machine is on par with the star for the same loading of the motor. The performance of the induction motor is good in delta connection but only when the motor is under fully loaded condition. Under no load or partially loaded condition, the motor operated in inefficient zone since machine consumes more energy than star mode. The table given below proves that the converter can improve the efficiency of the motor at the same time; it can reduce the energy consumed by the motor significantly. Table 1 shows experimental data of proposed converter on 5 HP induction motor.

Table 1. Experimental Data of Proposed Converter on 5 HP Induction Motor

Load Current A		Power Factor		Output Power Watts		Input Power Watts		% Efficiency	
Delta	Star	Delta	Star	Delta	Star	Delta	Star	Delta	Star
3.7	0.8	0.17	0.23	245	108	392	127	62.51	85.03
4.4	0.95	0.25	0.34	512	187	762.1	224	67.12	83.55
4.7	1.0	0.35	0.42	798	228	1140	291	70.01	78.30
4.8	2.8	0.68	0.65	1622	781	2261	1261	71.70	61.94
5**.0**	4.4	0.71	0.81	1798	1518	2459	2470	73.12	61.40
5.5	5.1	0.75	0.84	2147	1740	2858	2969	75.11	58.62
6.3	6.0	0.80	0.86	2658	1979	3498	3574	76.12	55.40

The tests conducted on a 5 HP motor with a full load current of 7.5 A, the energy savings on no load is 67.6%, reduction in no load operating current is up to 79.4%, reduction in demand is 67.2% and improvement in power factor 58%.

The load characteristic of the experimented induction motor is shown in Figure 8 which gives the variation of the load current for every loading condition. As per the actual load characteristics, the load current is smooth and less in star connected mode up to 35-50% of the load. Threshold value will be varied according to the manufacturer and power rating of the machine. After 40% of the load, there is a sudden rise in current which will reduce the performance of the machine and produces numerous vibration even though load current is less than that of in actual delta mode. So, that to reduce the vibration and to improve the performance, the winding connection needed to be change to delta.

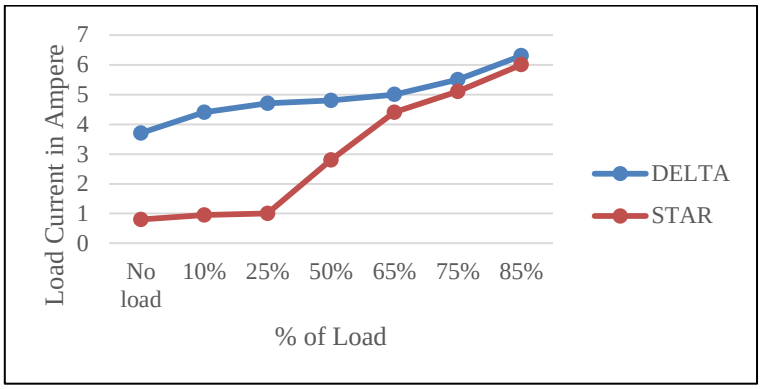

Figure 8. Load Characteristics of Motor on Delta and Star Winding Mode

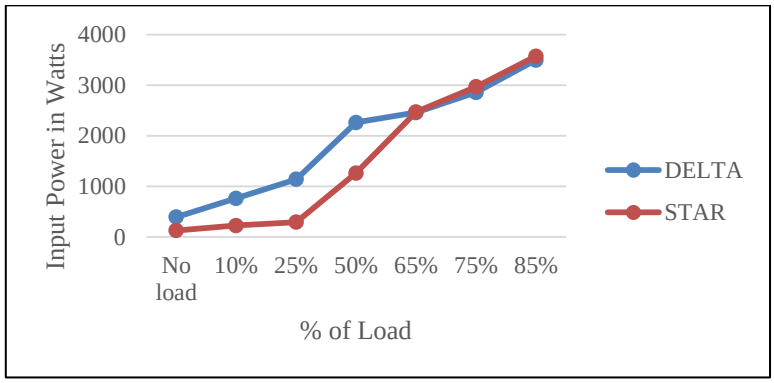

Figure 9. Power Consumed by the Motor on Delta and Star Winding Mode for Varible load

The power consumption of the motor is plotted against percentage load of the motor as shown in Figure 9. As per the winding connection, the power consumed by the machine keep changes against load. When the load on the motor is nearly between 50-55% (varies depends on the manufacturers and ratings), the power consumption of the motor is equal on both the modes but the consumption is reduced than the star connected mode if changed to delta mode.

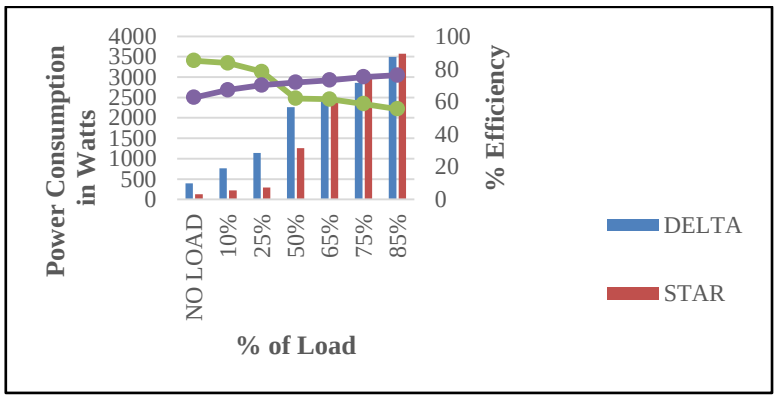

Figure 10. Energy Efficiency Characteristics

The energy saved by the motor and performance of the motor is plotted and discussed in figure 10. The machine performance is fairly good in star connected mode up to 45% of the full load on the machine. At 45% of the load, efficiency of the motor is same on both the modes of operation but delta connected mode

consumes more energy than that of star connected mode. If the load on the motor is greater than 45% of the full load, the machine delivers high output power and also the efficiency of the machine is high. If the load is above 65% of full load, delta connected mode consumes less energy than star connected mode.

Moreover, the load on motor is ≥45%, the saved energy by induction motors with star-delta-star connection is greater than induction motors with thyristor controller. As per [1], the power consumption is reduced in thyristor controlled induction motor only at load ≤ 50-60% of the rated load. However, the power saving disappears at load ≥ 40% of the rated load, and the motor drive losses increase because of loss in controller.

More than 80% of the induction motors are light loaded, in delta connection, stator winding half phase voltage is reduced to 0.866 V, and the total loss is reduced. It is necessary to change one of two possible connections, star connection or delta connection, on the mean value of the base load. From the result shown in figure 10, the research concludes that the significant amount of energy is saved during partial load to full load on the machine.

5. CONCLUSION

This work concluded that the star delta converter is very useful for all the kind of three phase induction motors from smaller rating to the larger rating, the converter can be designed accordingly. In the present days, the starters only used and it has low sensitivity. If the automatic star-delta-star converter is replaces the conventional starter, the performance and hence the life time of the motors will be increased. Since the converter can be operated at both starting and running time of the motor, it reduces the starting current and reduces the losses during operation. The converter is designed and implemented with the simple hardware units and it is very easy to install in most of the machine tools. The converters is very economical and investment on the converter will be taken back within a year by saving energy which will reduce the electricity bill. This converter will reach the market with cheaper cost soon and reduces the energy consumption.

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