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A Novel Technique for Energy & Cost Effective Drives for AC & DC Motors

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Abstract

This paper presents a new approach to reduce the losses of A.C & D.C motor by using the modified system. Energy Conservation is the starting point of an Energy Management plan to reduce the overall cost of production and operation. Normally AC and DC motor consumes large amount of electrical power. Energy conservation in AC motors can be achieved by using voltage control with respect to load current. In the conventional Star-delta starter the motor is switched over to delta mode after fixed starting time delay, the applied voltage remains same independent of the load conditions. Thus even during light load conditions the motor continues to draw the same magnetizing current thereby reducing the power factor and hence the overall efficiency of the motor reduces, this can be avoided by using a modified star-delta starter. If full voltage (rated voltage) is applied at no load condition, then the power consumption for the DC and AC motors will be increased. In this paper we are sensing the load current and changing the star or delta mode of connection at the input of the motor, so that the efficiency and the power factor can be improved. The calculated values are compared with the measurement, in order to evaluate a validity of the proposed method.

Introduction

An electric motor is usually switched on to the supply through a starter. If it is directly switched on, it draws starting current equal to 5 to 8 times of full load current and develop starting torque only 1 to 1.5 times of full load torque[1]. This amount of starting current is objectionable because it affects the system voltage momentarily. The starting torque developed may not be starting current and to improve the starting torque, we are going for starters.

A number of starters are available for different electric motors. For three-phase induction motors, Star-delta starter can be used. To improve the starting torque, power factor, to reduce the copper loss, core loss and hence to improve the efficiency, we are adding an external circuit with the existing automatic star-delta starter. This modified automatic star-delta starter is used for variable load three phase induction motor.

By use of this starter the efficiency of the AC motor can be improved, when load increases above 50 % of full load current, the motor will run at delta connection and if it's less than 50 % of full load current, it will run at star mode, so that efficiency and power factor can be improved. If low voltage(reduced voltage) is applied to the armature winding of DC motor, then power consumption will be very low and hence overall efficiency of motor is increased[8]. These are applicable to industries where variable load conditions exist.

Existing System

Starters for 3-phase squirrel-cage Induction motors often use star-to-delta converters. The stator coils of the motor are connected in star configuration at the time of power on and switched to delta configuration when the motor reaches 3/4th of its full speed, after the stator coils have developed sufficient back electromagnetic force.

Losses in Induction Motors

Losses in motor are divided into a number of different components. These are friction losses, windage losses, copper and iron losses. The major losses are the iron and copper losses. Worthwhile power savings are only achievable, where the iron losses is in appreciable portion of the total power consumed by the motor and where the amount of the iron loss is significant to the motor rating.

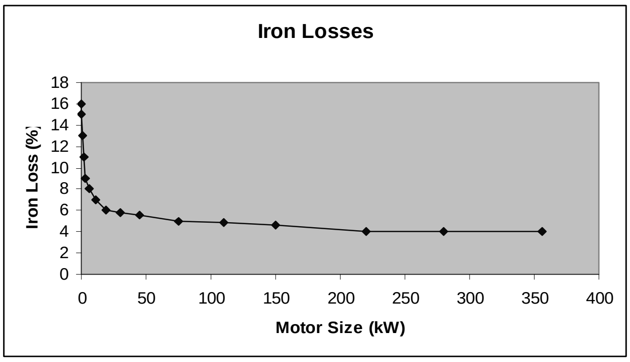

Figure 1- Iron losses vs motor size

Need for Starters

The need for starting devices for motor will become apparent by considering the case of a usual 10 HP, 230 volts motor, which may have a stator resistance about 0.25 ohm. At the moment of starting the motor, the stator is stationary, so no back emf is there. If the motor is connected directly across a 230 V power source, the only factor which limits the current drawn from the supply is the stator circuit resistance, which is very low and the current drawn will be very large (230/0.25 or 920 A) while the rated current may be only about 30 to 40 A. It will damage the brushes, winding of the motor and blow out the main fuses. Such a large current is not desirable. To guard against that excessive starting current, a resistance may be inserted in series with the motor stator during the starting period, which may gradually be cut-out as the back emf develops.

Almost all heavy induction motors make use of star-delta motor starters to reduce the starting current. In simple words, starting current I = (V-E)/Z where V is the applied voltage, E is the back emf and Z is the impedence of the rotor. Since back emf E is directly proportional to the speed of rotation of rotor, initially when the motor starts from rest, this back emf is zero. Thus if full voltage is applied to the motor winding, a very large initial current may be set up in the winding resulting in large copper loss. To prevent this, various kinds of starters are used. The conditions depend on the position of the tapping on the transformer winding, i.e. on the secondary voltage. Usually three or more tappings are provided so that there is a choice of starting conditions such as 40, 60 or 75% of line voltage[2]. The starting torques on these different tappings can be estimated as they are proportional to the square of the voltage. On the 60% tapping the torque will be approximately the same as with star-delta starting, and on the 40 and 75% tapping it will be proportionately lower and higher respectively.

Star-Delta Starter

At start, the line voltage is applied to one end of each of the three windings, with the other ends bridged together, effectively connecting the windings in star configuration. Under this connection, the voltage across the windings is $1\sqrt{3}$ of line-to-line supply voltage and so the current flowing through each winding is also reduced by this factor. Compared to delta connection, the resultant current flowing from the supply, as also the torque, is reduced by a factor of 1/3 is star configuration.

Modified System

During the light loading conditions the external circuit added will make the star-connection at the input of the induction motor and during heavily loaded conditions,[3] the external circuit added will make the delta connection at the input of the three phase induction motor and hence the overall efficiency and the power factor will be improved.

Advantages of reduced voltage to motor under low loading

Under reduced voltage conditions the magnetizing current and hence the overall current drawn by the motor is less. This not only reduces the copper loss and core loss, but also improves the power factor and the overall efficiency. It can only be improved when it is dropped considerably below the maximum efficiency of the motor as shown in the figure[6].

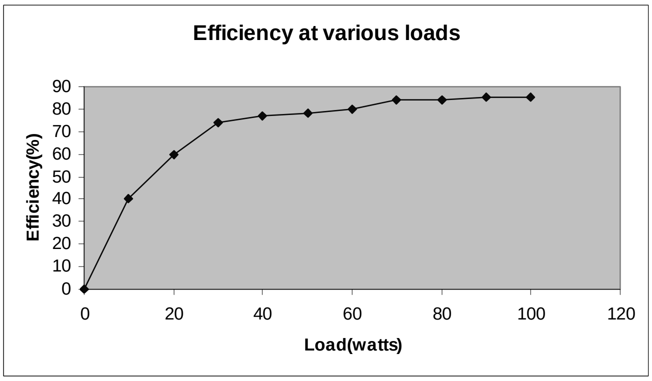

Fig 2-Efficiency at various loads

As the maximum energy that can be saved is the portion of the iron loss, best saving are going to be in motors with high iron losses. Therefore the maximum energy savings can be made below 50% load in small motors of less than 10kw rating.

Experimental Setup and Procedure

The Star Delta Starter can only be used with a motor which is rated for connection in delta each of the three windings available individually. At start, the line voltage is applied to one end of each of the three windings, with the other end bridged together, effectively connecting the windings is 1/(1/732) of line voltage and so the current flowing in each winding is also reduced by this amount[5]. The resultant current flowing from the supply is reduced by a factor of 1/3 as is the torque.

A low voltage is applied to the motor in the initial stage for fixed duration of time. During this interval, the motor gains appreciable speed, thereafter, full voltage is applied. Since line-to-line voltages in Delta mode is 1.732 times in Star mode, the motor is started with star connections, which ultimately change over to Delta mode after a fixed interval of time. The motor remains in Delta mode till next start up.

Both ends of each phase of the motor starter windings must be brought out and connected to starter. In the start position the windings are connected in star; in the running position they are reconnected in delta. The voltage across each phase winding in the start position is 58% of line voltage, with consequent reduction of starting current. The starting torque is also reduced to one-third of that which would obtain with D.O.L. starting. With a single-cage or double-cage rotor of average performance, this represent about 80% of full-load torque, assuming normal line voltage, but if there is appreciable line drop the torque will be proportionately lower. These factors must be taken into account when deciding whether star-delta starting is acceptable for the driven machine. It will be acceptable for centrifugal fans and pumps if, in the later case, the friction at starting is not excessive.

When the operating handle is placed in the ‘start’ position the motor stator windings are connected in star across the supply. As the motor approaches normal running speed the operator must quickly change the handle to run position which changes the motor connection from star to delta. If the operator does not move the handle quickly from start to run the motor may be disconnected from the supply long enough for the motor speed to fall considerably. When the handle is eventually put into the run position the motor will take a large current may be large current and accelerate up to speed again[7]. This surge current may be large enough to cause appreciable voltage dip. To prevent this, a mechanical interlock is fitted to the operating handle. The handle must be moved quickly from start to run otherwise the interlock jams the handle in the start position.

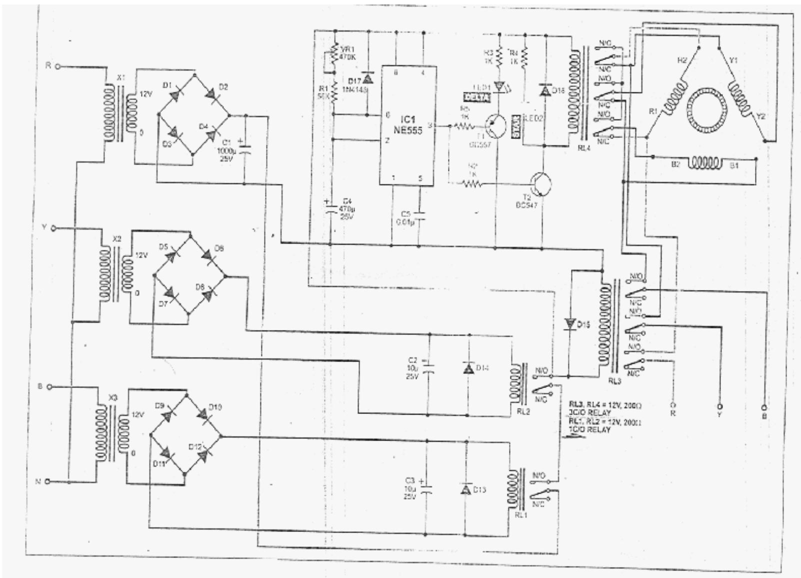

Figure 3- Modified Automatic 3-phase induction Motor Starter

Three single-phase transformers are used to step-down the 3-phase supply separately. Phases R, Y and B are stepped down by transformers X1, X2 and X3 to deliver the secondary output of 12V at 300mA. The transformer output is rectified by a full-wave rectifier and filtered by a capacitor.

The three 12V DC supplies drive relays RL1, RL2 and RL3, respectively. When all the three phases are present, the 12V DC supply derived from the R phase is fed to the coil of relay RL3 and the timer circuit through the contacts of relays RL1 and RL2. As a result, relay RL3 energises.

Simultaneously, timer NE555 (IC1), which is configured as a monostable multivibrator, is also triggered. Its time period is determined by capacitor C4, resistor R1 and preset VR1. Preset VR1 is used to set the time period required to reach $3/4^{th}$ of the full speed of the motor. The negative triggering pulse for IC1 is provided by the combination of resistor VR1, R1 and capacitor C4. The timer output at pin 3 is connected to the base of transistor T2 via resistor R2. As a result, transistor T2 is driven to saturation and relay RL4 energises (indicated by glowing of LED2). Thus at power-on, relay RL3, as also R4, energises (if all three phases are present) to connect the stator windings in star configuration. On tracing the connections you will observe that R phase is connected to R1 end of R windings, Y phase is connected to Y1 end of Y windings and B phase is connected to B1 terminal of B stator windings. The other ends of all the stator windings (i.e., R2, Y2, and B2) gets bridged together to form star connection.

After the specified delay, which is provided for the speed of the motor to 3/4th of its full speed value, the monostable output goes low to cut off transistor T2 and de-energise relay RL4. The motor stator coils now switch to delta configuration. Now you will observe that R phase gets connected to the junction of R1 and B2 terminals, Y phase is connected to Y1 and R2 terminals and B phase is connected to B1 and Y2 terminals of the stator windowing. This connection conforms to delta configuration. Since the output of IC1 is low in this state, pnp transistor T1 is forward biased to light up LED1 and indicate delta configuration[9].

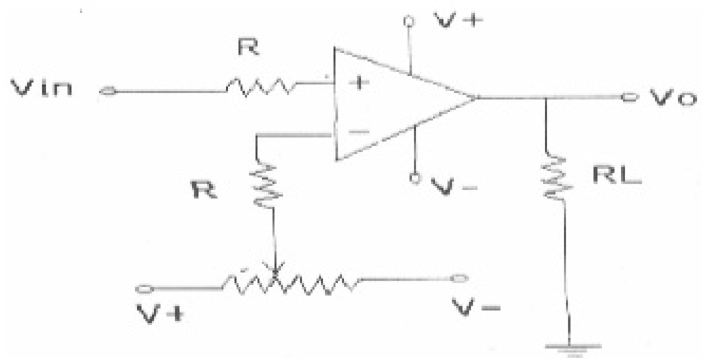

Figure 4: Comparator

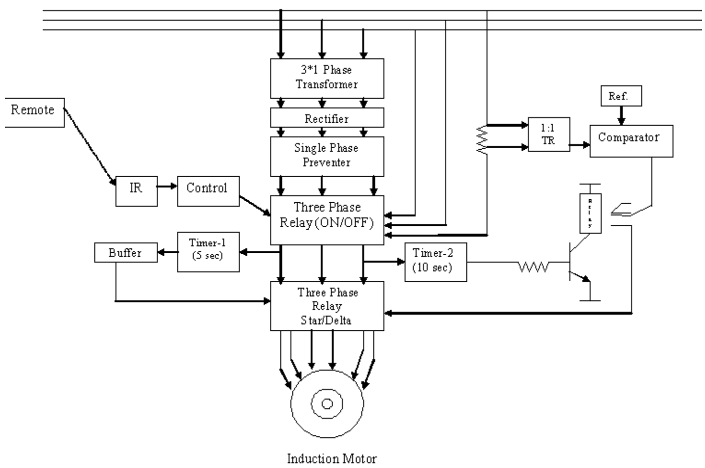

Figure 5: Over all Block Diagram –Energy savings in three phase induction motor by using modified automatic star -Delta starter

Table.1: Result for modified star delta starter.

Sl. No.	Existing System at no load			Modified System at no load		
	Voltage(V)	Current(A)	Power(W)	Voltage(V)	Current(A)	Power(W)
1.	420	3	1008	420	2.2	734
2.	415	3.4	1110	415	2.6	866
3.	400	4.2	1338	400	3	958
4.	395	5.6	1765	395	3.8	1198
5.	390	7	2178	390	4.2	1310

Energy Savings in DC motor by using PIC Controller

The DC motor is a self regulating machine because the development of back emf makes the DC motor to draw as much armature current which is just sufficient to develop the required load torque[4].

Armature current $I_a = \frac{V - E_b}{R_a}$

Existing System

No Load Conditions

When the DC motor is operating on no load condition, small torque is required to overcome the friction and windage losses. Therefore back emf is nearly equal to input voltage and armature current is small i.e., Ia is very low.

$$E_b = V$$

During the light load conditions at the rated voltage the magnetizing current drawn by the DC motor is high. Where the Core losses and Copper losses of a DC motor are not reduced and hence the over all efficiency of the DC motor is reduced.

Load Conditions

When the DC motor is operating on loaded condition, driving torque of the DC motor is not sufficient to counter the increased retarding torque due to load. Hence, armature slows down (motor speed decreases) and motor back emf Eb also decreases. Corresponding armature current Ia increases. The increase torque, the motor continues to slow down till the driving torque matches the load torque and then steady state conditions are reached.

When the load on DC motor is decreased, the driving torque developed is momentarily in excess of the load requirement so that, motor armature is accelerated (motor speed increases). As the motor speed increases, the back emf Eb also increases causing armature current to decrease. The decrease in armature current causes decrease in driving torque and steady state conditions are reached, when the driving torque is equal to the load torque.

Under rated Voltage at Load Conditions the magnetizing current drawn by the DC motor is less. Under full load condition efficiency of the DC motor is high. The maximum efficiency of the DC motor is as shown in the following figure

Modified System

No Load Conditions

During the light load conditions the PIC controller will reduce the input armature voltage of the DC motor at no load current and hence overall efficiency of the DC motor will be increased.

Load Conditions

During heavily loaded conditions the PIC controller circuit added will increase the armature voltage of the DC motor at load current and hence overall efficiency of the DC motor will be increased.

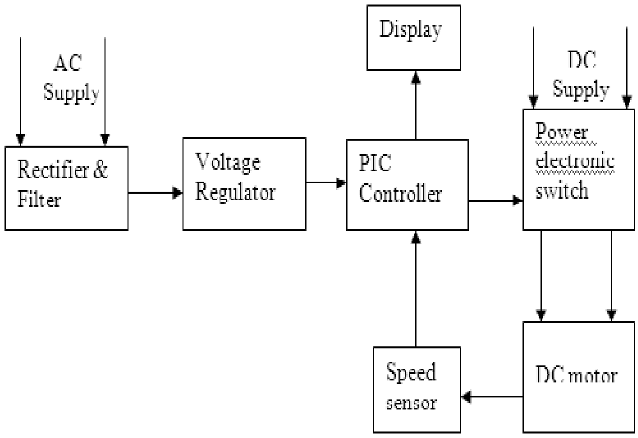

Figure 7: Modified system using PIC controller on D.C motor

Table.2: Result for modified D.C motor converter(Armature 190V)

Sl. No.	Armature Voltage	Current	Torque in N.m	Input Power	Output Power	Efficiency
1.	170	4.2	0.736	714	98.15	13.74
2.	170	5.2	2.06	884	270.38	30.58
3.	170	7.5	4.42	1275	612.61	48.04
4.	170	9.2	6.03	1564	785.1	50.19

Table.3: for modified D.C motor converter(Armature 170V)

Sl. No.	Armature Voltage	Current	Torque in N.m	Input Power	Output Power	Efficiency
1.	190	4.2	0.44	798	62.83	7.8
2.	190	5.2	1.18	988	168.50	17.05
3.	190	7.5	4.12	1425	596.99	41.89
4.	190	9.2	5.89	1748	847.28	48.47

Under the above conditions the magnetizing current and the overall current drawn by the motor is constant. The total power consumed by the motor is very low .This not only reduces the copper loss, but also improves the overall efficiency of the DC motor.

Conclusion

We can observe that in AC motors the automatic star delta starter circuit presented here offers two main advantages. First one is single phase prevention and next is automatic start Delta conversion. The load sensing circuit is added to this starter. It improves the efficiency of the AC motor because in no load conditions the motor runs in star mode and in loaded condition the AC motor runs in delta mode. So the efficiency is increased. In DC motor the external electronics circuit is very useful to change the voltage with respect to load current for better Energy conservation.

Further advantages of these methods are of

- Less expensive
- Easy maintenance
- Noiseless
- Compact

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