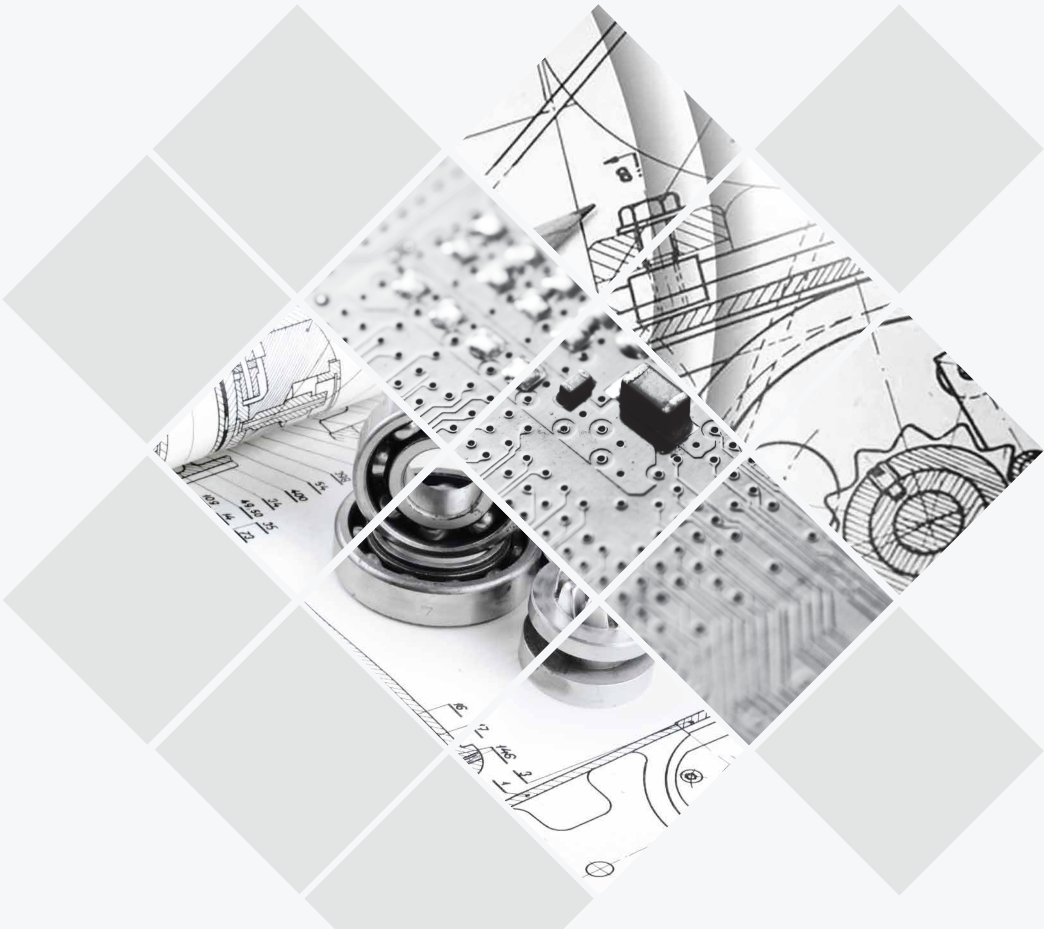
electric fault motor protection systems

It could be assumed that properly planned, dimensioned, designed, installed, operated and maintained motor systems and drives should not break down; in reality however, these conditions are hardly ever ideal.



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Abstract

It could be assumed that properly planned, dimensioned, designed, installed, operated and maintained motor systems and drives should not break down; in reality however, these conditions are hardly ever ideal. Statistics show that an annual downtime of 0.5-4% is to be expected, of which 30% of the motor breakdowns can be attributed to motor overloads. Insulation damage accounts for 20% of all breakdowns while phase failure, bearing damage and ageing account for 14%, 13 % and 10% respectively. Breakdowns in motor operations result in tremendous losses both in time and money. Hence it is extremely important to select proper protection systems to prevent damage to motors caused by electrical faults.

Causes of Faults and Their Effects

Electric motors encounter two types of faults, namely internal faults which occur within the motor and external faults.

Internal faults (faults within the motor)

- Phase to ground short circuit
- Phase to phase short circuit
- Internal winding short circuit
- Overheating of windings
- Broken bar in squirrel cage motors
- Problems in windings

Stator or rotor windings failure

The stator windings in an electric motor consist of copper conductors insulated by a varnish. A break in this insulation can cause permanent short circuit between a phase and ground, between two or three phases or between windings in one phase.

The cause for this can be electrical (superficial discharge, voltage surges), thermal (overheating) or mechanical (vibration, electrodynamic stress on the conductors). Insulation faults can also occur in the rotor winding with the same result: ultimate breakdown of the motor.

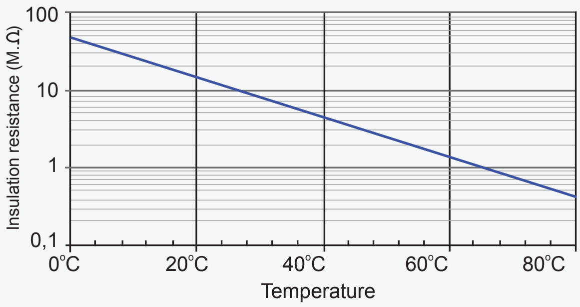

Fig 2: Insulation resistance temperature

Overheating is the most common cause of failure in motor windings. Overloads cause a rise in the temperature leading to a power-surge in the windings.

Moreover, insulation resistance changes with temperature; as the temperature rises, insulation resistance decreases (see Figure 2) as a result of which the lifetime of the windings and the motor decreases greatly. Figure 3 shows that an increase of 5% in the current, equivalent to a temperature rise of 10°, reduces the lifetime of the motor windings by half.

Protection against overload is mandatory to prevent overheating and reduce the risk of motor failure caused by a break in winding insulation

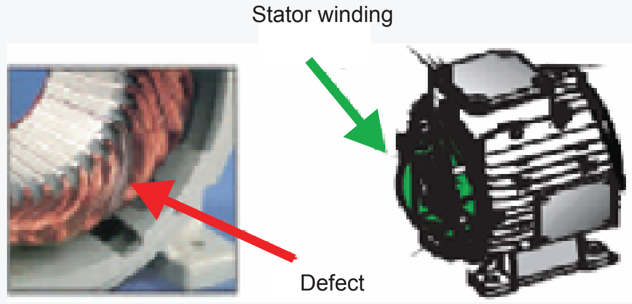

Fig 1: Windings are the motor parts most vulnerable to electrical faults and operating incidents

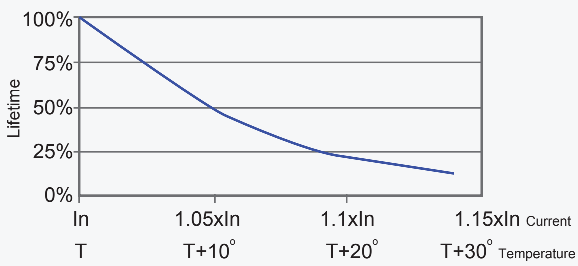

Fig 3: Lifetime of motor depending on operating temperature

External faults (faults that lie outside the motor)

The table below enumerates the faults caused by factors external to the electric motor.

Power supply to the motor	Motor's operating conditions	Motor installation conditions
• Voltage surge • Inverted or unbalanced phases • Voltage drops and breaks • Voltage harmonics • Power failure	• Overload states • Excessive number of starts or braking • Abnormal starting state • High load inertia	• Misalignment • Unbalance • Stress on shaft

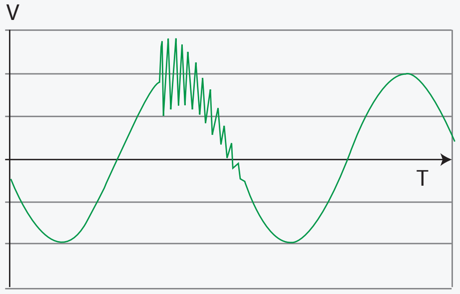

Fig 4: Example of a voltage surge

The main characteristics are described in the table

Type of surge	Duration	Raising time-frequency	Damping
Atmospheric	Very short (1a 10 µs)	Very high (1000 kV/µs)	Strong
Electrostatic discharge	Very short (ns)	High (10 MHz)	Very strong
Operation	Short (1ms)	Medium (1 to 200 kHz)	Medium
Industrial frequency	Long (> 1s)	Mains frequency	Nil

Fig 5: Characteristics of the types of voltage surge

Voltage surge

A voltage surge is an input voltage with a peak value exceeding the limits defined by a standard or a specification. In most cases, voltage surges result in dielectric breakdown of the motor windings which destroys the motor.

Inverted or unbalanced phases

A three-phase system is unbalanced when the three voltages are of unequal amplitude and/or not phase-shifted by 120° in relation to each other. Unbalance can be due to phase opening (dissymmetry fault), single-phase loads in the motor's immediate vicinity or the source itself. This unbalance in the voltage power supply results in an increase of current for the same torque, invert component, thereby overheating the motor.

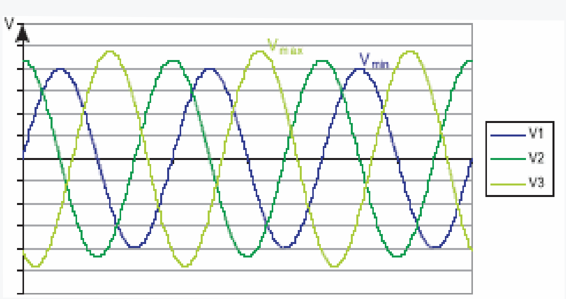

Fig 6: 3 phase unbalanced voltages

Voltage drops and breaks

A voltage drop is a sudden loss of voltage at a point in the power supply.

As per the EN50160 standard, voltage drops are limited to 1 to 90 % of nominal voltage for half a cycle at 50 Hz, that is, 10 ms to 1 minute.

Voltage variations can be caused by random external phenomena (faults in the mains power supply or an accidental short-circuit) or phenomena related to the plant itself (connection of heavy loads such as big motors and transformers). These can have a radical effect on the motors.

Synchronous motors sustain greater voltage drops, without stalling, compared to asynchronous motors (about 50% greater). This is primarily due to their greater general inertia and lower impact of the voltage on torque as compared to asynchronous motors.

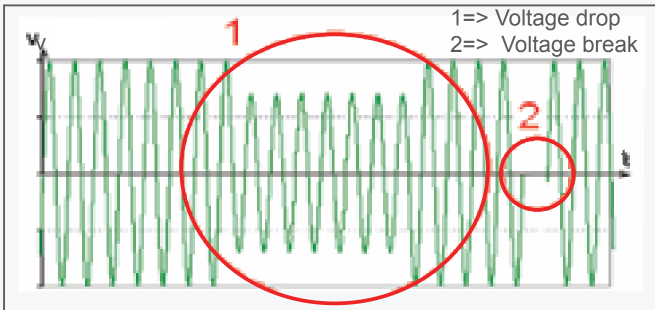

Fig 7: Example of a voltage drop and short voltage break

Voltage harmonics

Voltage harmonics in motors increases losses by eddy currents and cause further heating. Harmonics can also give rise to pulse torque's (vibrations, mechanical fatigue) and noise pollution and restrict the use of motors on full load.

Motor starting: too long and/or too frequent

Given its intrinsic characteristics, a motor can only sustain a limited number of starts, usually specified by the manufacturer (number of starts per hour). If the starts are too frequent, it can lead to over-heating of the windings and damage the motor.

Motor locks

Motor locks from mechanical causes lead to an over-current approximately the same as the starting current. However, the heat which results is much greater because rotor losses stay at their maximum value throughout the lock and cooling stops as it is usually linked to rotor rotation. Rotor temperatures can rise to 350°C.

Overload (slow motor overload)

Slow motor overload is caused by an increase in the resistant torque or a drop in the mains voltage (> 10% of nominal voltage). The increase in current consumption causes heating which shortens the lifetime of the motor and can be fatal to it, both in the short and long run.

Summary

The following table shows possible causes of each type of fault, the probable effects and inevitable outcome if no protection is provided. As a general conclusion, motors always require two types of protection:

- Protection against short circuits
- Protection against overloads (overheating)

Faults	Causes	Effects	Effects on the motor
Short circuit	• Phase-to-phase, Phase-to-ground, winding to winding	• Current surge • Electrodynamic stress on conductors	• Windings destroyed
Voltage surge	• Lightning • Electrostatic discharge • Disconnection of a load	• Dielectric breakdown in windings	• Windings destroyed by loss of insulation
Unbalanced voltage	• Phase opening • Single-phase load upstream of motor	• Decrease of the available torque • Increased losses	• Overheating (*)
Voltage drop and dip	• Instability in mains voltage • Connection of high loads	• Decrease of the available torque • Increased losses	• Overheating (*)
Harmonics	• Mains supply pollution by non linear loads	• Decrease of the available torque • Increased losses	• Overheating (*)
Starting too long	• Too high a resistant torque • Voltage drop	• Increase in starting time	• Overheating (*)
Locking	• Mechanical problem	• Overcurrent	• Overheating (*)
Overload	• Increase in resistant torque • Voltage drop	• Higher current consumption	• Overheating (*)
(*) And in the short or long run, depending on the seriousness and/or frequency of the fault, the windings short-circuit and are destroyed.			

Fig 8: Summary of possible faults in a motor with their causes and effects

Protection against short circuits

A short circuit is a direct contact between two points of different electric potential and results in a sudden surge of current which can reach several hundred times the working current within milliseconds. A short circuit can have devastating effects and can severely damage equipment. It is therefore imperative to guard against short-circuits with protection devices that can detect faults and interrupt the short circuit rapidly, before the current reaches its maximum value.

Two protection devices are commonly used for this purpose:

- Fuses, which break the circuit by melting and must be replaced afterwards
- Magnetic circuit breakers which automatically break the circuit and only require to be reset

Protection can also be built into multifunction devices such as motor starter protection and contactor breakers

The main characteristics of short-circuit protection devices are:

Breaking capacity: Highest value in the estimated short-circuit current that a protection device can break at a given voltage.

Closing capacity: Highest value a protection device can reach at its rated voltage in specified conditions.

Fuses

Fuses perform phase-by-phase (single pole) protection with a high break capacity at low voltage. The fuses used for motor protection are specific in that they let through the over-currents due to the magnetizing current when motors are switched on. They are not suitable for protection against overload so an overload relay must be added to the motor power supply circuit. In general, their size should be just above the full-load current of the motor.

Magnetic circuit breakers

These circuit breakers protect the plant from short circuits within the limits of their breaking capacity and by means of magnetic triggers (one per phase).

Most magnetic circuit breakers for motor protection are current-limiting devices and so contribute to the coordination. Their very short cut-off time breaks the short circuit before it reaches its maximum amplitude. This limits the thermal and electrodynamic effects and improves the protection of the wiring equipment.

Protection against overload

One of the most common faults in motors, overload causes an increase in the current absorbed by the motor and the thermal effects which follow as a result. The insulation category sets the normal motor heating at an ambient temperature of 40°C. Exceeding this operating limit causes premature ageing of the insulating material, reducing the lifetime of the motor. Short and infrequent overloads which cause overheating do not have any detrimental effects on the motor.

Such overloads do not necessarily interrupt motor operations. However, it is necessary to restore normal conditions very quickly.

Proper protection against overload is necessary for:

1. Preserving the lifetime of motors by preventing them from working in overheating conditions
2. Ensuring operating continuity
3. Preventing motors from stopping abruptly
4. Enabling restart in the best conditions, after tripping, for the safety of people and equipment

Depending upon the level of protection required, overload protection can be provided by relays:

1. Thermal (bimetal) or electronic relays, which provide minimum protection against:
   - 1.1 Overload, by controlling the current absorbed on each phase
   - 1.2 Unbalanced or missing phase, by a differential device
2. Positive Temperature Coefficient (PTC) thermistor probe relays
3. Overtorque relays
4. Multifunction relays

Protection relays do not break a circuit. They are designed to open a breaking device with the requisite breaking capacity for the faulty current, usually a contactor. For this purpose, protection relays have a fault contact fitted in series with the contactor coil.

Motor Starters

AC motor starters are used on electric motors that utilize a start and stop button or switch for the operation. Safety switches can also be employed in the low-voltage circuit that controls the power to the AC motor starter. AC motor starters are also used on large motors in which the electrical power requirements are so large that it would be unsafe to operate a single switch to turn the motor on. The motor starter can also be located at a great distance from the electric motor, so remote or automatic operation of the motor is made possible. The AC motor starter generally has three main components, the pull-in coil, the electrical contacts and the overcurrent protection.

Direct on Line Motor Starters

The simplest form of motor starter for the induction motor is the Direct on line (DOL) starter. The DOL starters consist of an MCCB or circuit breaker, contactor and an overload relay for protection.

The electromagnetic contactor can be opened by the thermal overload relay under fault conditions. Typically, the contactor will be controlled by separate start and stop buttons, and an auxiliary contact on the contactor is used, across the start button, as a hold in contact, that is, the contactor is electrically latched closed while the motor is operating.

Principle of DOL starter

To start, the contactor is closed, applying full line voltage to the motor windings. The motor will draw a very high inrush current for a very short time, the magnetic field in the iron, and then the current will be limited to the locked rotor current of the motor.

The motor will develop locked rotor torque and begin to accelerate towards full speed.

As the motor accelerates, the current will begin to drop, but will not drop significantly until the motor is at a high speed, typically about 85% of synchronous speed. The actual starting current curve is a function of the motor design, and the terminal voltage, and is totally independent of the motor load.

The motor load will affect the time taken for the motor to accelerate to full speed and therefore the duration of the high starting current, but not the magnitude of the starting current.

Provided that the torque developed by the motor exceeds the load torque at all speeds during the start cycle, the motor will reach full speed. If the torque delivered by the motor is less than the torque of the load at any speed during the start cycle, the motor will stop accelerating. If the starting torque with a DOL starter is insufficient for the load, the motor must be replaced with a motor which can develop a higher starting torque.

The acceleration torque is the torque developed by the motor minus the load torque, and will change as the motor accelerates due to the motor speed torque curve and the load speed torque curve. The start time is dependent on the acceleration torque and the load inertia. This may cause an electrical problem with the supply, or it may cause a mechanical problem with the driven load. So this will be inconvenient for the users of the supply line, always experience a voltage drop when starting a motor. But if this motor is not a high power one, it does not affect much.

Wiring of DOL Starter

1. Main contact

- Contactor is connecting among supply voltage, relay coil and thermal overload relay
- L1 of contactor connect (NO) to R phase through MCCB
- L2 of contactor connect (NO) to Y phase through MCCB
- L3 of contactor connect (NO) to B phase through MCCB

NO contact (-||-):

- (13-14 or 53-54) is a normally open NO contact (closes when the relay energizes)
- Contactor point 53 is connecting to start button point (94) and contactor point 54 is connected to common wire of start/stop button.

NC contact (-|/|-):

- (95-96) is a normally closed NC contact (opens when the thermal overloads trip if associated with the overload block)

2. Relay coil connection

- A1 of relay coil is connecting to any one supply phase and A2 is connecting to thermal overload relay's NC connection (95)

3. Thermal overload relay connection

- T1, T2, T3 are connect to thermal overload relay
- Overload relay is connecting between main contactor and motor
- NC connection (95-96) of thermal overload relay is connecting to stop button and common connection of start/stop button

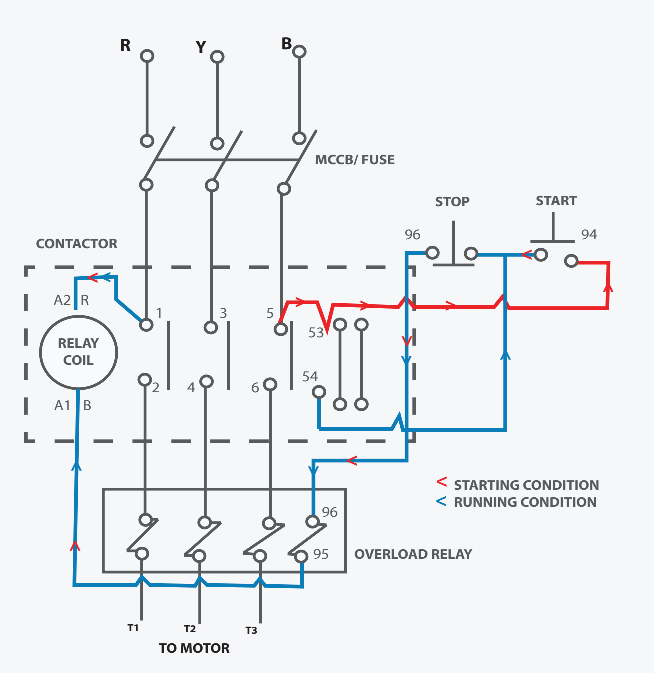

Fig 9: Direct on line starter - wiring diagram

Working principle of DOL starter

The heart of the DOL starter is the relay coil, which gets one phase constant from incoming supply voltage (A1). When the coil gets the second phase, it energizes and magnet of contactor produces electromagnetic field and due to this plunger of contactor will move and main contactor of starter will close and auxiliary will change its position from NO to become NC and NC becomes NO (shown Red Line in Diagram).

Pushing start button

When we push the start button, the relay coil will get second phase from supply phase-main contactor (5)-auxiliary contact (53)-start button-stop button-96-95-to relay coil (A2). Now coil energizes and the magnetic field produced by magnet and plunger of contactor move. Main contactor closes and motor gets supply at the same time auxiliary contact become (53-54) from NO to NC.

Release start button

The relay coil gets supply even though we release start button. When we release the start push Button the relay coil gets supply phase from main contactor (5)-auxiliary contactor (53) – auxiliary contactor (54)-stop button-96-95-relay coil (shown red/blue lines in diagram).

In the overload condition, the motor will be stopped by intermission of control circuit at point 96-95.

Pushing stop button

When we push the stop button control, the circuit of starter will break at the stop button and the

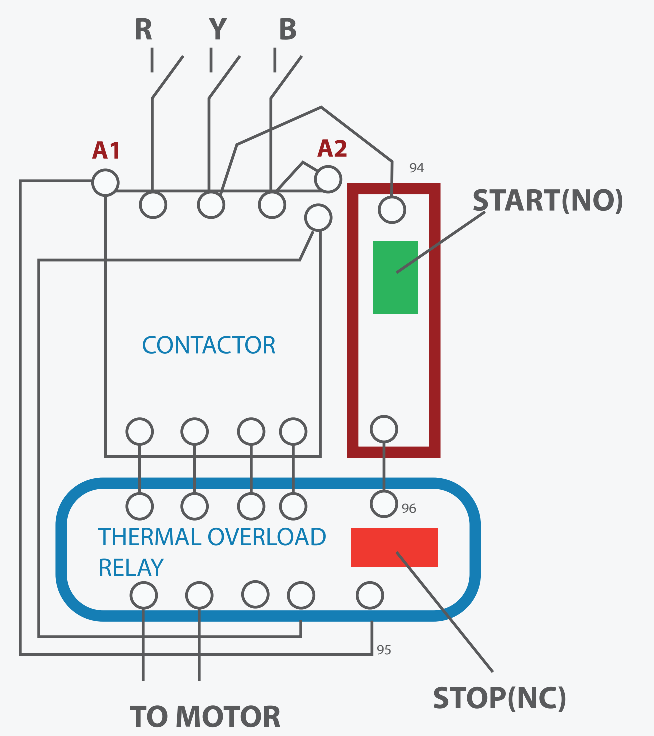

Fig 10: DOL - wiring scheme

supply of relay coil is broken, the plunger moves and the close contact of main contactor becomes open, and the supply of motor is disconnected. Relay coil is broken, Plunger moves and close contact of Main Contactor becomes Open, Supplyof Motor is disconnected.

Motor starting characteristics on DOL starter

- Available starting current: 100%
- Peak starting current: 6 to 8 Full Load Current
- Peak starting torque: 100%

DOL motor starter is suitable for

- A direct on line starter can be used if the high inrush current of the motor does not cause excessive voltage drop in the supply circuit. The maximum size of a motor allowed on a direct on line starter may be limited by the supply utility for this reason. For example, a utility may require rural customers to use reduced-voltage starters for motors larger than 10 kW
- DOL starting is sometimes used to start small water pumps, compressors, fans and conveyor belts

DOL motor starter is NOT suitable for

- The peak starting current would result in a serious voltage drop on the supply system • The equipment being driven cannot tolerate the effects of very high peak torque loadings
- The safety or comfort of those using the equipment may be compromised by sudden starting as, for example, with escalators and lifts

Star-Delta Motor Starter

Most induction motors are started directly on line, but when very large motors are started that way, they cause a disturbance of voltage on the supply lines due to large starting current surges. To limit the starting current surge, large induction motors are started at reduced voltage and then have full supply voltage reconnected when they run up to near rotated speed.

Working principle of star-delta starter

This is the reduced voltage starting method. Voltage reduction during star-delta starting is achieved by physically reconfiguring the motor windings as illustrated in the figure below. During starting the motor windings are connected in star configuration and this reduces the voltage across each winding. This also reduces the torque by a factor of three.

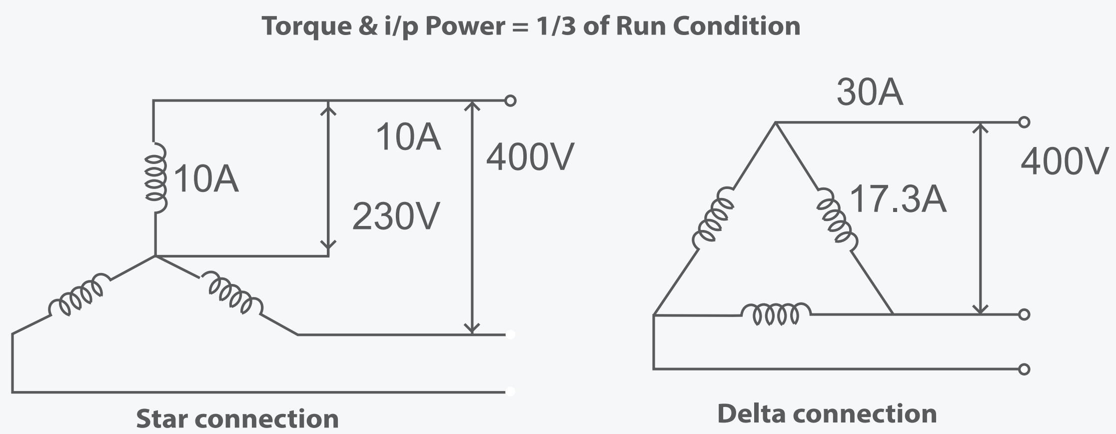

Fig 11: Scheme - working principle of star-delta starter

After a period of time the windings are reconfigured as delta and the motor runs normally. Star-delta starters are probably the most common reduced voltage starters. They are used in an attempt to reduce the start current applied to the motor during start as a means of reducing the disturbances and interference on the electrical supply.

Traditionally in many supply regions, there has been a requirement to fit a reduced voltage starter on all motors greater than 5HP (4KW). The star-delta (or wye/delta) starter is one of the lowest cost electromechanical reduced voltage starters that can be applied.

The star-delta starter is manufactured from three contactors, a timer and a thermal overload. The contactors are smaller than the single contactor used in a direct on line starter as they are controlling winding currents only. The currents through the winding are 1/root 3 (58%) of the current in the line.

There are two contactors that are closed during run, often referred to as the main contractor and the delta contactor. These are AC3 rated at 58% of the current rating of the motor. The third contactor is the star contactor and that only carries star current while the motor is connected in star.

The current in star is one third of the current in delta, so this contactor can be AC3 rated at one third (33%) of the motor rating.

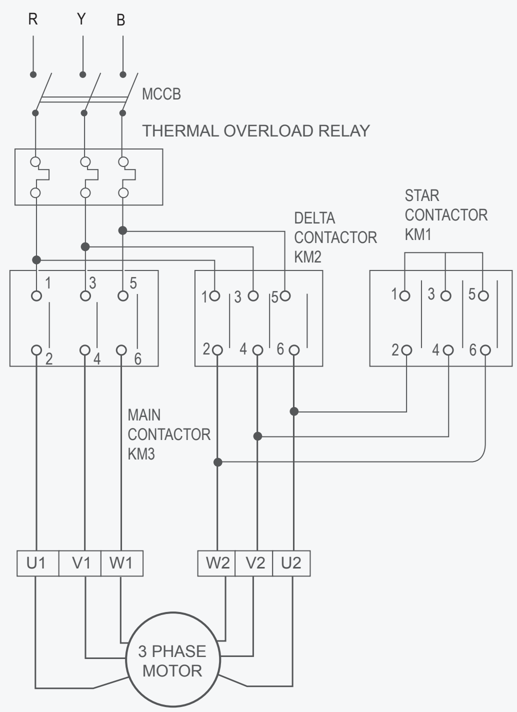

Fig 12: Configuration of a star-delta starter

Advantages of star-delta starter

- The operation of the star-delta method is simple and rugged
- It is relatively cheap compared to other reduced voltage methods
- Good torque/current performance
- It draws two times starting current of the full load ampere of the motor connected

Disadvantages of star-delta starter

1. Low starting torque (Torque = (Square of Voltage) is also reduced)
2. Break in supply – possible transients
3. Six terminal motor required (delta connected)
4. It requires two sets of cables from starter to motor
5. It provides only 33% starting torque and if the load connected to the subject motor requires higher starting torque at the time of starting, then very heavy transients and stresses are produced while changing from star to delta connections, and because of these transients and stresses, many electrical and mechanical breakdowns occur..
6. In this method of starting, initially the motor is connected in star and after change over, it is connected in delta. The delta of motor is formed in starter and not on motor terminals
7. **High transmission and current peaks** When starting up pumps and fans for example, the load torque is low at the beginning of the start and increases with the square of the speed. When reaching approx. 80-85% of the motor rated speed, the load torque is equal to the motor torque and the acceleration ceases. To reach the rated speed, a switch over to delta position is necessary, and this will very often result in high transmission and current peaks. In some cases, the current peak can reach a value that is even bigger than for a DOL start.
8. Applications with a load torque higher than 50% of the motor rated torque will not be able to start using the star-delta starter.
9. **Low starting torque** The star-delta (Wye-Delta) starting method controls whether the lead connections from the motor are configured in a star or delta electrical connection. The initial connection should be in the star pattern that results in a reduction of the line voltage by a factor of 1/√3 (57.7%) to the motor and the current is reduced to 1/3 of the current at full voltage, but the starting torque is also reduced from 1/3 to 1/5 of the DOLstarting torque.

10. The transition from star to delta transition usually occurs once nominal speed is reached, but is sometimes performed as low as 50% of nominal speed which make transient sparks.

Features of star-delta starting

1. For low-power to high-power three-phase motors
2. Reduced starting current
3. Six connection cables
4. Reduced starting torque
5. Current peak on changeover from star to delta
6. Mechanical load on changeover from star to delta

Application of Star-Delta Starter

The star-delta method is usually only applied to low to medium voltage and light starting Torque motors.

The received starting current is about 30% of the starting current during direct on line start and the starting torque is reduced to about 25% of the torque available at a DOL start. This starting method only works when the application is light loaded during the start.

If the motor is too heavily loaded, there will not be enough torque to accelerate the motor up to speed before switching over to the delta position.

Variable Frequency Drive (VFD) Starters

A variable-frequency drive (VFD) (also termed adjustable-frequency drive, variable-speed drive, AC drive, micro drive or inverter drive) is a type of adjustable-speed drive used in electro-mechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage.

VFDs are used in applications ranging from small appliances to the largest of mine mill drives and compressors. However, about a third of the world's electrical energy is consumed by electric motors in fixed-speed centrifugal pump, fan and compressor applications and VFDs' global market penetration for all applications is still relatively small. This highlights especially significant energy efficiency improvement opportunities for retrofitted and new VFD installations.

Over the last four decades, power electronics technology has reduced VFD cost and size and improved performance through advances in semiconductor switching devices, drive topologies, simulation and control techniques, and control hardware and software.

VFDs are available in a number of different low and medium voltage AC-AC and DC-AC topologies.

In Fig 14, drive applications can be categorized as single-quadrant, two-quadrant or four-quadrant; the chart's four quadrants are defined as follows:

- Quadrant I - Driving or motoring, forward accelerating quadrant with positive speed and torque
- Quadrant II - Generating or braking, forward braking-decelerating quadrant with positive speed and negative torque
- Quadrant III - Driving or motoring, reverse accelerating quadrant with negative speed and torque
- Quadrant IV - Generating or braking, reverse braking-decelerating quadrant with negative speed and positive torque

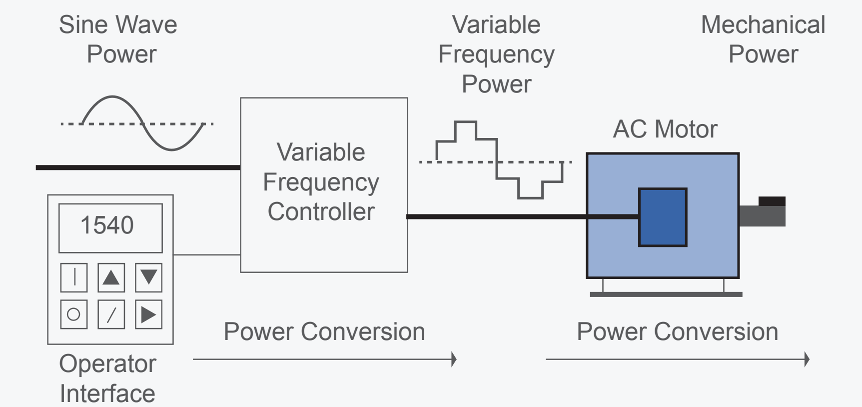

Fig 13: Configuration of a VFD starter

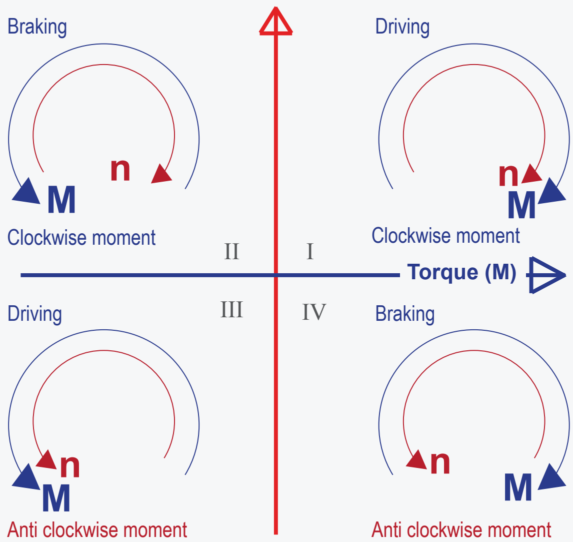

Fig 14: Categorization of drive applications

Most applications involve single-quadrant loads operating in quadrant I, such as in variable-torque (for example, centrifugal pumps or fans) and certain constant-torque (for example, extruders) loads.

Certain applications involve two-quadrant loads operating in quadrant I and II where the speed is positive but the torque changes polarity as in the case of a fan decelerating faster than natural mechanical losses. Some sources define two-quadrant drives as loads operating in quadrants I and III where the speed and torque is same (positive or negative) polarity in both directions.

Certain high-performance applications involve four-quadrant loads (quadrants I to IV) where the speed and torque can be in any direction such as in hoists, elevators and hilly conveyors.

Regeneration can only occur in the drive's DC link bus when inverter voltage is smaller in magnitude than the motor back-EMF and inverter voltage and back-EMF are of the same polarity.

In starting a motor, a VFD initially applies a low frequency and voltage, thus avoiding high inrush current associated with direct online starting. After the start of the VFD, the applied frequency and voltage are increased at a controlled rate or ramped up to accelerate the load. This starting method typically allows a motor to develop 150% of its rated torque while the VFD is drawing less than 50% of its rated current from the mains in the low speed range. A VFD can be adjusted to produce a steady 150% starting torque from standstill right up to full speed. However, motor cooling deteriorates and can result in overheating as speed decreases such that prolonged low speed motor operation with significant torque is not usually possible without separately-motorized fan ventilation.

With a VFD, the stopping sequence is just the opposite as the starting sequence. The frequency and voltage applied to the motor are ramped down at a controlled rate. When the frequency approaches zero, the motor is shut off. A small amount of braking torque is available to help decelerate the load a little faster than it would stop if the motor were simply switched off and allowed to coast. Additional braking torque can be obtained by adding a braking circuit (resistor controlled by a transistor) to dissipate the braking energy. With a four-quadrant rectifier (active-front-end), the VFD is able to brake the load by applying a reverse torque and injecting the energy back to the AC line.

Soft Starters

A motor soft starter is a device used with AC electric motors to temporarily reduce the load and torque in the powertrain of the motor during startup. This reduces the mechanical stress on the motor and shaft, as well as the electrodynamic stresses on the attached power cables and electrical distribution network, extending the lifespan of the system.

Motor soft starters can consist of mechanical or electrical devices, or a combination of both. Mechanical soft starters include clutches and several types of couplings using a fluid, magnetic forces, or steel shot to transmit torque, similar to other forms of torque limiter. Electrical soft starters can be any control system that reduces the torque by temporarily reducing the voltage or current input, or a device that temporarily alters how the motor is connected in the electrical circuit.

Soft starters can be set up to the requirements of the individual application. In pump applications, a soft start can avoid pressure surges. Conveyor belt systems can be smoothly started, avoiding jerk and stress on drive components. Fans or other systems with belt drives can be started slowly to avoid belt slipping. In all systems, a soft start limits the inrush current and so improves stability of the power supply and reduces transient voltage drops that may affect other loads.

Electrical soft starters can use solid state devices to control the current flow and therefore the voltage applied to the motor. They can be connected in series with the line voltage applied to the motor, or can be connected inside the delta (Δ) loop of a delta-connected motor, controlling the voltage applied to each winding. Solid state soft starters can control one or more phases of the voltage applied to the induction motor with the best results achieved by three-phase control.

Typically, the voltage is controlled by reverse-parallel-connected silicon controlled rectifiers (thyristors), but in some circumstances with three-phase control, the control elements can be a reverse-parallel-connected SCR and diode.

Another way to limit motor starting current is a series reactor. If an air core is used for the series reactor then a very efficient and reliable soft starter can be designed which is suitable for all type of three phase induction motor [synchronous/ asynchronous] ranging from 25 KW 415 V to 30 MW 11 KV. Using an air core series reactor soft starter is common for applications like pump, compressor, and fan. Usually, high starting torque applications do not use this method.

Electronic/thermal Overload Relays

These relays protect motors against overload. However, they must sustain the temporary overload of starting and only trip when starting lasts too long. Depending upon its use, motor starting can range from a few seconds (no-load starting, low resistant torque) to a few dozen seconds (high resistant torque, high inertia of the driven load).

Hence, relays adapted to the starting time are needed. To meet this need, the IEC 60947-4-1 standard has several categories of overload relay, each defined by its tripping time as shown in Figure 15 below:

	Tripping time from: Cold to 1.05 x I_r	Warm to 1.2 x I_r	Warm to 1.5 x I_r	Cold to 7.2 x I_r	Lower tolerance (band E)
Classes					
10 A	> 2 h	> 2 h	> 2 min	2 s < tp < 10 s	
10	> 2 h	> 2 h	> 4 min	4 s < tp < 10 s	5 s < tp < 10 s
20	> 2 h	> 2 h	> 8 min	6 s < tp < 20 s	10 s < tp < 20 s
30(*)	> 2 h	< 2 h	< 12 min	9 s < tp < 30 s	20 s < tp < 30 s

(*) category little used in Europe but widespread in the USA.
Cold: initial state with no previous load
Warm: thermal balance reached at I_r
I_r***:*** overload relay current setting

Fig 15: Main categories of overload relay tripping according to the IEC 60947-4-1 standard

The relay size should be chosen on the basis of the motor's rated current and the estimated starting time.

These relays have a thermal memory (apart from some electronic ones, indicated by their manufacturers) and can be connected either in series with the load or, for high powers, to current transformers fitted in series with the load.

Bimetal Thermal Overload Relays

These are linked to a contactor to protect the motor, the power supply and the equipment against low prolonged overload. They are thus designed to enable the motor to start normally without tripping. However, they must be protected from strong overcurrents by a circuit breaker or fuses.

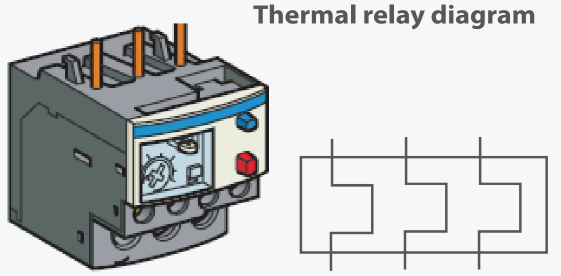

Fig 16: Bimetal thermal overload relays

Operation

The operating principle of a thermal overload relay is based on the distortion of its bimetal strips heated by the current that crosses them. As the current crosses them, the strips distort and depending upon the setting can cause the relay contact to open suddenly. The relay can now only be reset when the bimetal strips have adequately cooled down.

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Thermal overload relays work with alternating and direct current and are usually 3-pole. They are also compensated, that is, insensitive to ambient temperature variations (same tripping curve from 0°C to 40°C) on a standard gauge. Moreover, they are also graduated in 'motor amperes': current indicated on the motor plate displayed on the relay. They can also respond to a loss of a phase; this is the differential. This feature prevents the motor from working in a single-phase and complies with standards IEC 60947-4-1 and 60947-6-2.

This type of relay is widely used and is very reliable and cost-effective. It is especially recommended if there is a risk of rotor locking. It does, however, have the disadvantages of impression with regard to the thermal status of the motor and sensitivity to the thermal conditions where it is installed (housing ventilation for instance).

Electronic Overload Relays

These relays have the advantages of electronic systems and build a more detailed thermal image of the motor. These relays use a template with the motor's thermal time constants; the system continuously calculates the motor temperature based on the current passing through it and operating time. These relays therefore protect much closer to the reality and can prevent inadvertent tripping. These relays are less sensitive to the thermal conditions when they are installed.

Apart from the usual functions of overload relays (protection against motor overload, unbalance and lack of phase), electronic overload relays can include options such as:

- PTC probe temperature control
- Protection against locking and overtorques
- Protection against phase inversion
- Protection against insulation faults
- Protection against no-load operation

Positive Temperature Coefficient (PTC) Thermistor Probe Relays

These protection relays control the actual temperature of the motor to be protected. Probes are imbedded into the motor and because they are small, their thermal inertia is very low ensuring a very short response time and hence a very accurate temperature reading. They directly control the temperature of the stator windings so

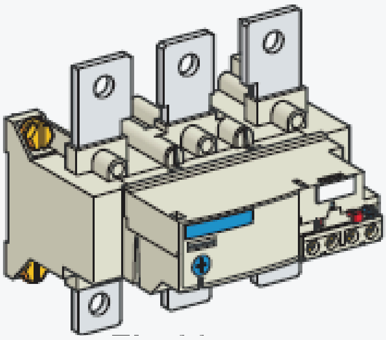

Fig 17: Electronic overload relay (LR9F- Telemecanique)

Fig 18: Electronic device for three thermistor probes

Fig 19: The overtorque relay

can be used to protect motors against: overload, increase in ambient temperature, ventilation circuit faults, too frequent starting processes, inching etc. These normally consist of one or more positive temperature coefficient (PTC) thermistor probes in the windings themselves or at any other point likely to heat (bearings, etc.). These are generally static components with resistance that increases suddenly when the temperature increases a threshold called the Nominal Operating Temperature (NOT).

The choice of PTC probes depends upon the insulation category and motor structure. It is usually made by the motor manufacturer or winding fitter who are the only ones with the requisite skills. PTC probe protection really only applies to high-end equipment with expensive motors or processes.

Overtorque Relays: Extra Protection

These relays ensure protection of the drive chain in the event of rotor locking, mechanical seizing or inching. Unlike most thermal relays, these have no thermal memory. They have a set operating time,i.e., adjustable current threshold and timing. An overtorque relay can be used to protect motors against overload when their starting process is long or very frequent. For example: inching.

Multifunction Relays

Electromechanical or electronic relays protect the motor using the current flowing into the motor. These are perfectly suitable for regular operation. However, they are not able to take into consideration multiple potential problems due to

Solution 1: Relay is embedded into the motor starter (Figure 20-1)
The benefit of this all-in-one solution is a very compact product with a limited number of connections. The upper limit is 32 Amps.

Solution 2: Relay separated from the motor starter. (Figure 20-2)
The benefit is a possible connection to any motor starter.

Solution 3: Relay separated from the starter and offers multiple input/outputs. (Figure 20-3)

This is the most versatile solution.

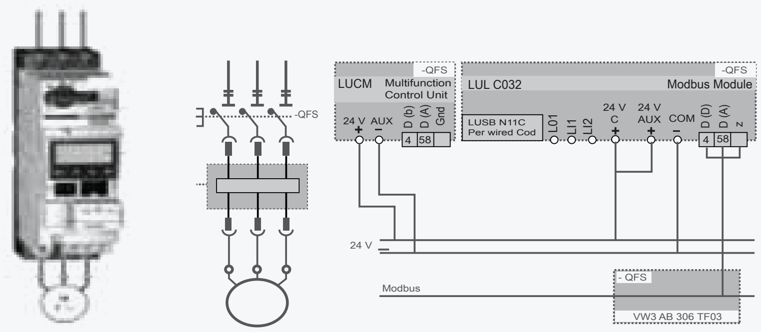

Fig 20-1: Multifunction relay embedded into the motor starter

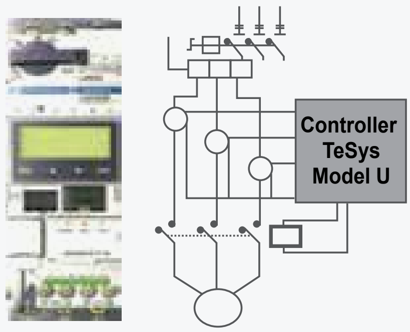

Fig 20-2: Multifunction relay separated from the starter

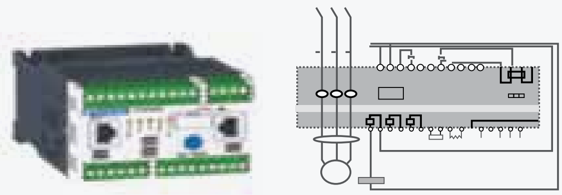
Fig 20-3: Multifunction relay with multiple I/O

voltage temperature or specific application.

These relays have been developed using the following technologies:

- Voltage and current sensors, the latter uses ironless devices (Rogowsky sensors) which are fast and offer an outstanding linearity
- An electronic device combining numerical and analogic technologies. The result is good capacity for treatment and data storage
- Use of field buses to exchange data to and from PLCs and other devices
- Use of accurate motor modelisation algorithms

This new generation of product allows to reduce the design costs of the equipment as programming PLCs has been made simple. Moreover, operation, maintenance cost and downtime are also dramatically cut down.

There are three possible solutions to using Multifunction relays for motor protection:

Motor Circuit Breakers

This device is a thermal and magnetic circuit breaker in the same package which protects the motor against short circuits and overload by rapidly opening the faulty circuit. It is a combination of a magnetic circuit breaker and overload relays and complies with the IEC 60947-2 and 60947-1 standards.

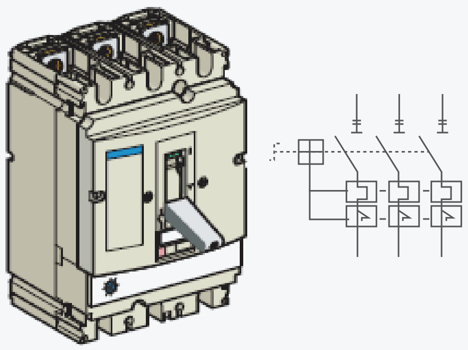

Fig 21: Motor circuit breaker and its graphic symbol

In these circuit breakers, the magnetic devices (protection against short circuits) have a non-adjustable threshold, usually about 10 times the maximum current setting of thermal release units. The thermal elements (protection against overload) are compensated for fluctuations of the ambient temperature. The thermal protection threshold can be adjusted on the front of the unit. Its value must correspond to the rated current of the motor to be protected. In all these circuit breakers, coordination (type II) between the thermal elements and short-circuit protection is built into the device. Moreover, in the open position, the insulation distance (between the contacts) in most of these units is adequate to ensure isolation. These also have a padlocking device.

Conclusion

Any motor failure will have the following cost-contributors: repair/part replacement, removal, installation and loss of production. Overheating of the motor is the most important contributor of motor component failures. Thermal stresses can cause the failure of all major motor parts: stator, rotor, bearings, shaft and frame. As such, motor protection is an essential function for ensuring the continuity of machine operation. The choice of protection device must be made with extreme care. The user would be wise to select devices that include electronic communication features to foresee and prevent any faults. They greatly improve the detection of abnormalities and the speed with which the service is restored.

Author Profile

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Raju Chikkannavar is a specialized Electrical Design Engineer in the field of power generation and distribution with over 10 years of experience in electrical engineering. He is accomplished in working with generator synchronization and load sharing for various generator sets with different types of controllers, motor control centers and numerous power distributions.

Raju holds a Bachelor of Engineering in Electrical and Electronics from Karnataka University, Dharwad.

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