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Project Report ECE 586
Motor Protection

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Contents

1. Introduction

An electric motor uses electrical energy to produce mechanical energy. The reverse process that of using mechanical energy to produce electrical energy is accomplished by a generators or dynamo. Electric motors are found in household appliances such as fans, refrigerators, washing machines, pool pumps, floor vacuums, and fan-forced ovens. There are several types of motors but we would limit our discussion to AC induction motors to explain the techniques used in the field of motor protection. For small size motors most of the time protection is present inside the motor structure so our focus would be on the large size induction motors. A typical AC motor consists of two parts, an outside stationary stator having coils supplied with AC current to produce a rotating magnetic field, and an inside rotor attached to the output shaft.

The induction motor can be analyzed by means of convenient circuit models. The circuit models of positive and negative sequences are shown in the following figure. The resistance and inductance on the left side of the figure, R_t and X_t, represent the The venin equivalent impedance parameters of the power system supplying the motor. The voltages are V_{a1} and V_{a2} for the positive and negative sequence networks, respectively.V_{m1} and V_{m2} are the terminal voltages applied to the two sequence networks. R_s and X_s are stator resistance and impedance of the motor.

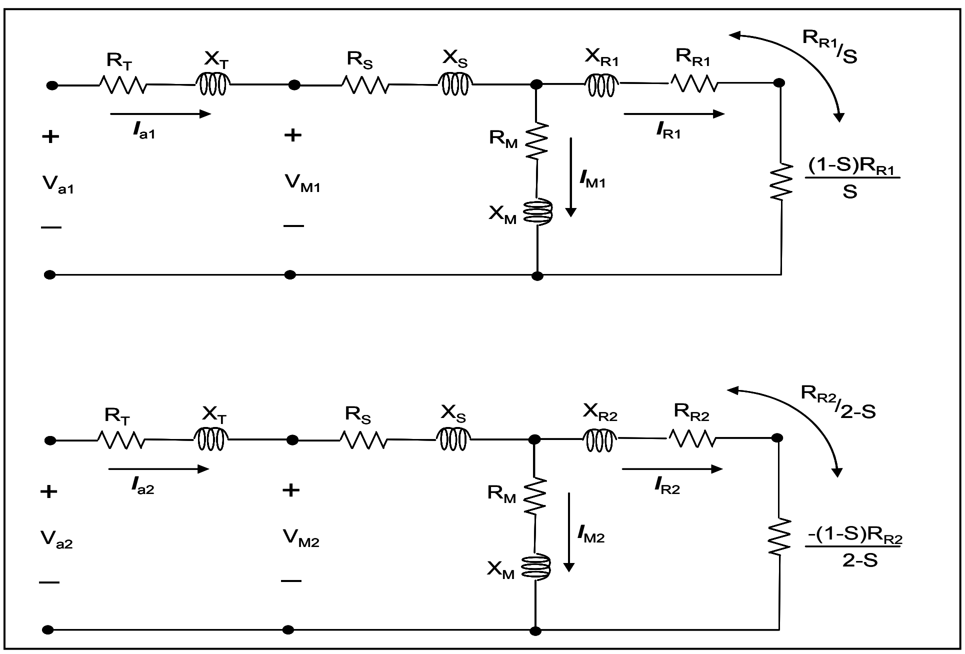


Fig 1: Positive and Negative Sequence Networks of Induction Motor

All motors need protection, but fortunately, the most fundamental principles, affecting the choice of protection are independent of type of motor and type of load connected. We can divide the faults occurring in motors as external faults (Unbalanced supplies, under voltages, single phasing etc) and internal faults (bearing failures, winding failures overloads).

The most common problems of motors, which need protection, are listed below:

1. Thermal / Overload protection
2. Extended start protection
3. Stalling protection
4. Number of starts limitation
5. Short circuit protection
6. Ground fault protection
7. Winding RTD measurement/trip
8. Negative sequence current detection
9. Under voltage protection
10. Loss-of-load protection
11. Out-of-step protection
12. Loss of supply protection
13. Auxiliary supply supervision

There are many ways to provide these various protective functions, but we will discuss only most common of these.

2. Thermal Protection

One of the most difficult problems in motor protection is to provide protection against overheating of the motor. This problem is more complicated for large motors. The motor windings and core have thermal capacitance that is capable of storing heat, and heat will flow from the sources through the surrounding materials .In steady state, the heat is removed from the motor by convention. During the starting of the motor, we can assume that all of the heat is stored in the motor metals and the starting current causes an increase in the temperature of these metals.

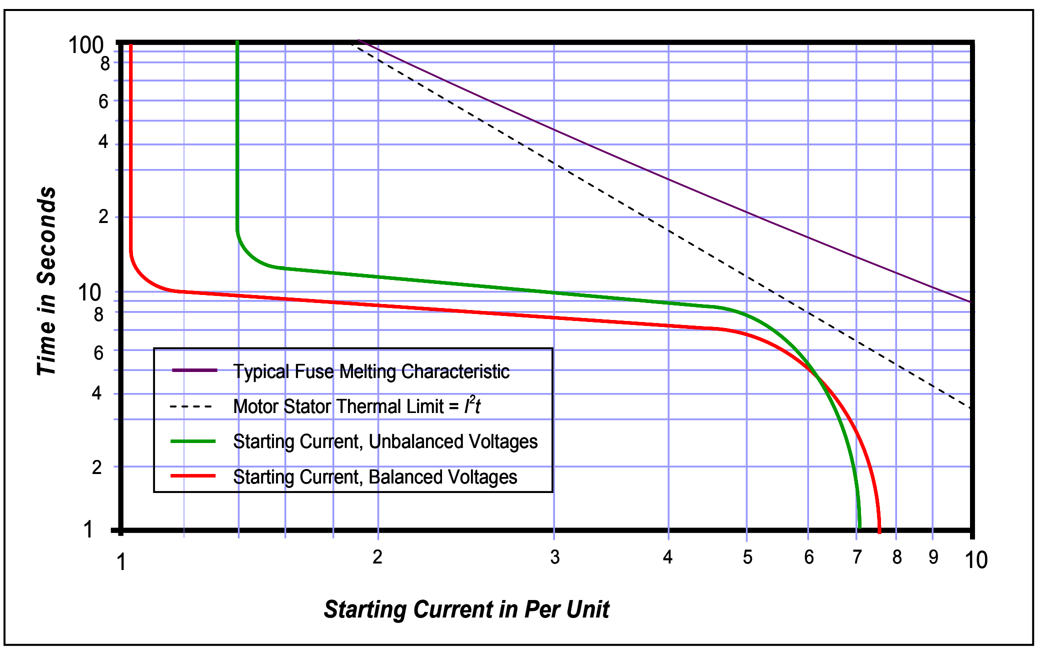
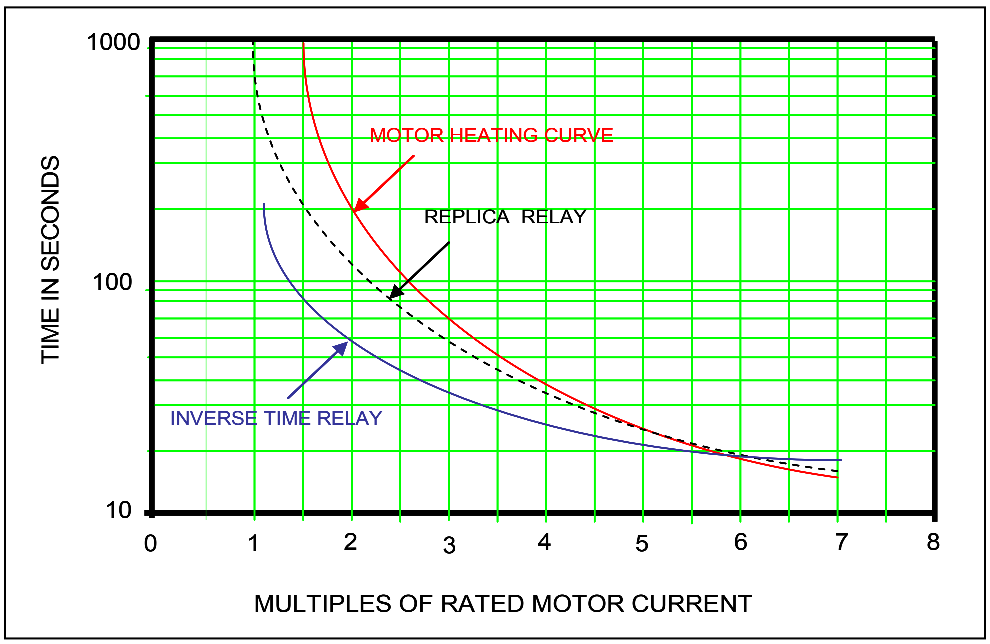


Fig 2: Motor Starting Current and the Thermal Limit

Over current protection is provided to prevent the motor from overheating beyond design limits. Overloading causes winding failures. These failures could be prolonged or cyclic. Replica type thermal overload relays are often used for overload protection. The problem associated with the use of these relays is that thermal capability of the motor is often not known accurately. Also it is difficult to define damage, loss of life, and safe zones of operation.

Replica type relay characteristic protects the motor against long term overloads, but coordination for short term overload is not satisfactory. This issue is resolved by the use of overcurrent relay. If there is extreme variation in load then this solution is not suitable. It can result in to premature tripping. We can solve this problem by measuring the stator temperature directly using embedded exploring coils placed in the stator slots. This type of thermal relay use exploring coils, that are connected in one leg of a Wheatstone Bridge circuit. This solution is also effective in protecting the motor against blocked ventilation, against which current operated relays are not effective. The characteristic approach is illustrated in fig 3.



. *Fig 3: Comparison of Motor Thermal Characteristic and Overcurret Characteristic*

3. Phase Fault Protection

Phase faults rarely occur in motors. The reason is that all faults become ground faults in very short interval of time and we can use ground relay to clear these faults. But still it is a common practice to provide protection against phase faults. This protection involves the use of over current relays for smaller motors and phase winding differential relays for larger motors. The reason for the use of differential relays is that they are more sensitive and faster than over current relays. Moreover, differential relays will not operate during starting as compared to the over current relays.

The pickup setting of phase over current relays should be about four times rated current, but it should have time delay in order to stop its operation during starting. Also the instantaneous phase over current relays must be set well above locked rotor current.
Sometimes it is possible to provide adequate phase fault protection by using over current and instantaneous relays in two phases of the motor, and the third phase is used for thermal overload relays.

4. Negative Phase Sequence Protection

Negative phase sequence current is generated from any unbalanced voltage condition, such as unbalanced loading, loss of a single phase, or single phase faults. The actual value of the negative sequence current depends on the degree of unbalance in the supply voltage and the ratio of the negative to the positive sequence impedance of the machine. Modern protection relays have a negative sequence current measurement capability, in order to provide such protection. The level of negative sequence unbalance depends largely upon the type of fault. For loss of a single phase at start, the negative sequence current will be 50% of the normal starting current.

A typical setting for negative sequence current protection must take into account the fact that the motor circuit protected by the relay may not be the source of the negative sequence current. Time should be allowed to clear the source of the negative sequence current without introducing risk of overheating to the motor being considered. So two stage tripping characteristic is used.

5. Ground Fault Protection

As we mentioned that almost all motor faults are developed into ground faults very quickly, so it is very important to provide ground fault protection. It is common practice to have wye connection with ungrounded neutral in induction motors. We can detect ground faults by using instantaneous relays. The pickup is set at about 20% of full load current with a time dial of 1.0.There is a chance of false tripping due to unequal saturation of the current transformer on motor starting. It can be solved by using a lower relay tap settings, so that all transformers saturate uniformly. This problem can also be solved by placing a resistor in series with the ground relay .The value of the resistor is calculated as

$$R_{stab} = \frac{I_{st}}{I_0}(R_{ct} + kR_l + R_r)$$

Where:
I_{st} = starting current referred to CT secondary
I_0 = relay ground fault setting (A)
R_{stab}=stability resistor value (ohm)
R_{ct} = d.c resistance of CT secondary (ohms)
R_l = CT single lead resistance (ohms)
K = CT correction factor (=1 for star pt at CT =2 for star pt at relay)
R_r = relay input resistance (ohms)

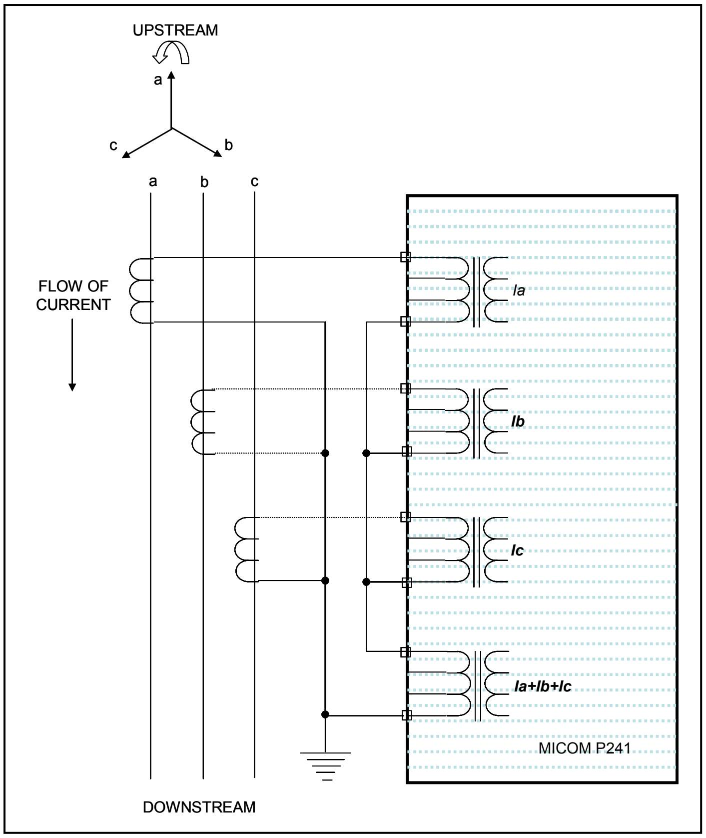


Fig 4: Residual CT Connection for Ground Fault Protection

The effect of stability resistor is to increase the effective setting of the relay under these conditions and hence delay tripping. In the presence of stability resistor, the tripping characteristic should be instantaneous. The time delay used will have to be found by trial and error.

Co-ordination with other devices should also be considered. Usually we use fuse contactor to supply power to motor. The fuse is not capable of breaking fault current beyond a certain value, which will normally be below the maximum system fault current. When the trip command will be issued from relay to open the fuse contactor, care must be taken to ensure that it does not occur until the fuse has had time to operate. Fig 5a explains incorrect grading of the relay with the fuse. Fig 5b explains the correct grading. It is achieved by intentional definite time delay in the relay.

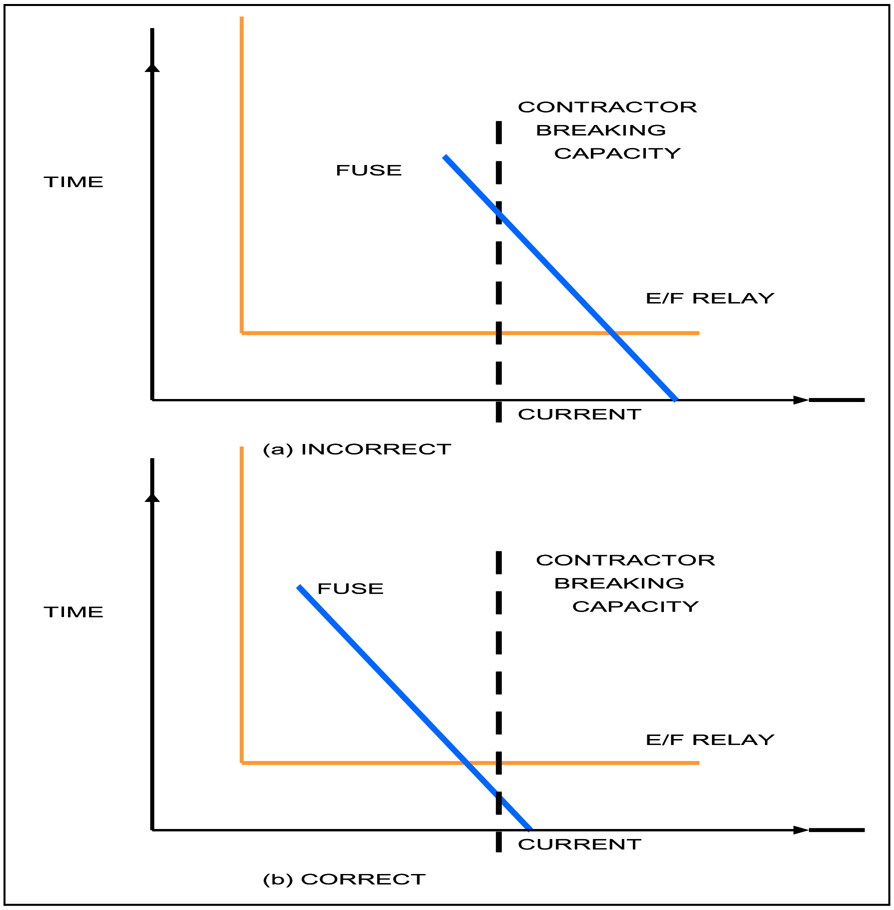


Fig 5: Application of the Core CT.

If a more sensitive relay setting is required, we can use a core balance CT. This is a ring type CT, through which all phases of the supply to the motor are passed, plus the neutral on a four wire system. The turn ratio of the CT is no longer related to the normal line current expected to flow, so provide flexibility to choose pickup current. Magnetizing current requirements are also reduced, due to the use of single CT core to be magnetized instead of three.

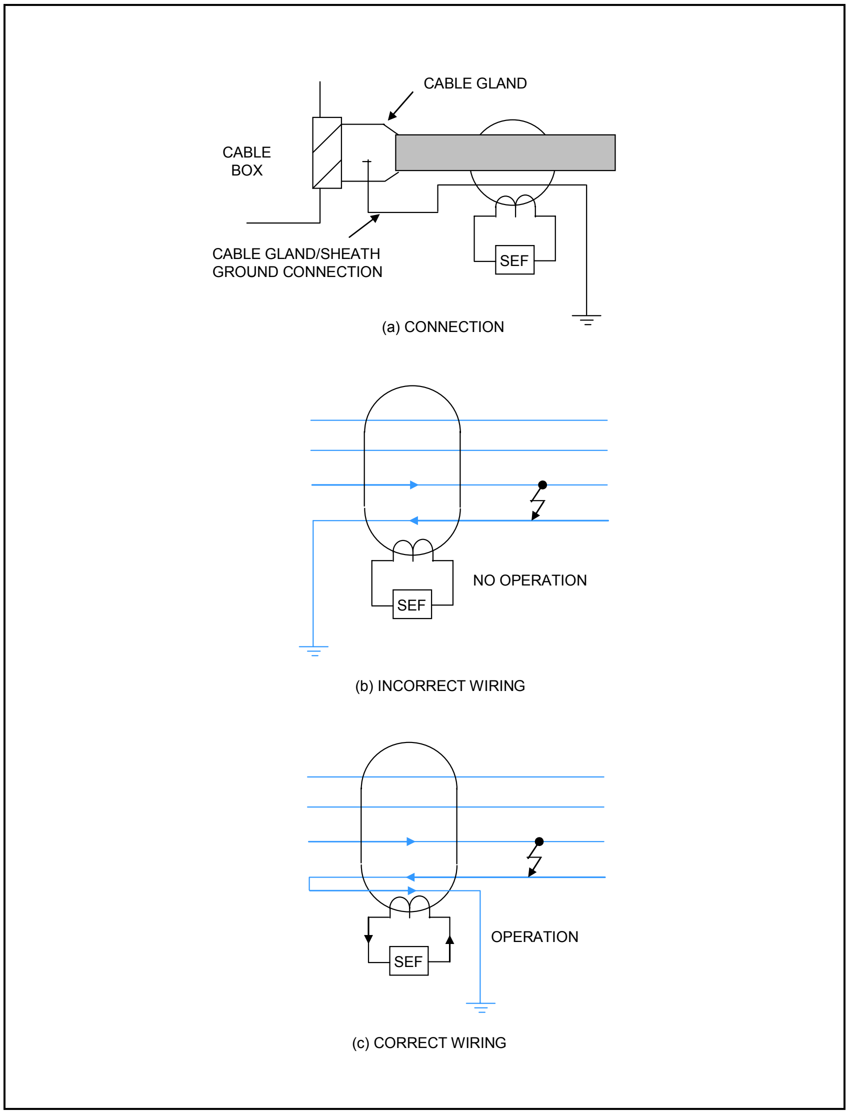


Fig 6: Application of Core Balance CT

6. Excessive Start Time/ Locked Rotor Protection

This protection is used to deal with excessive overheating of motor. The overheating could be caused by the motor limitation to accelerate large mechanical loads or motor stalls while running. A typical induction motor can carry locked rotor current safely for 20 seconds. If the motor starting is fully accomplished in about 10 seconds, this leaves a good margin for time discrimination in setting an overcurrent relay delay time. However, if the load inertia is great, such as large fan, the motor starting time may be close to the thermal capability of the motor and other means must be used to detect the need for tripping.

A motor may fail to accelerate from rest for a number of reasons like loss of a supply phase, mechanical problems, low supply voltage, excessive load torque etc. A large current will be drawn from the supply, and cause extremely high temperatures to be generated within the motor. This is made worse by the fact that the motor is not rotating, and hence no cooling due to rotation is available. Winding damage will occur very quickly – either to the stator or rotor windings depending on the thermal limitations of the particular design (motors are said to be stator or rotor limited in this respect).

The method of protection varies depending on whether the starting time is less than or greater than the safe stall time. In both cases, initiation of the start may be sensed by detection of the closure of the switch in the motor feeder and optionally current rising above a starting current threshold value – typically 200% of motor rated current. For the case of both conditions being sensed, they may have to occur within a narrow aperture of time for a start to be recognized. Special requirements may exist for certain types of motors installed in hazardous areas and the setting of the relay must take these into account. Sometimes a permissive interlock for machine pressurization may be required, and this can be conveniently achieved by use of a relay digital input and the in-built logic capabilities.

If the start time is less than safe stall time, then protection is provided by use of definite time over current characteristic. The current setting is greater than full load current but less than the starting current of the machine. The time setting should be a little longer than the start time, but less than the permitted safe starting time of the motor. It is explained in the following figure.

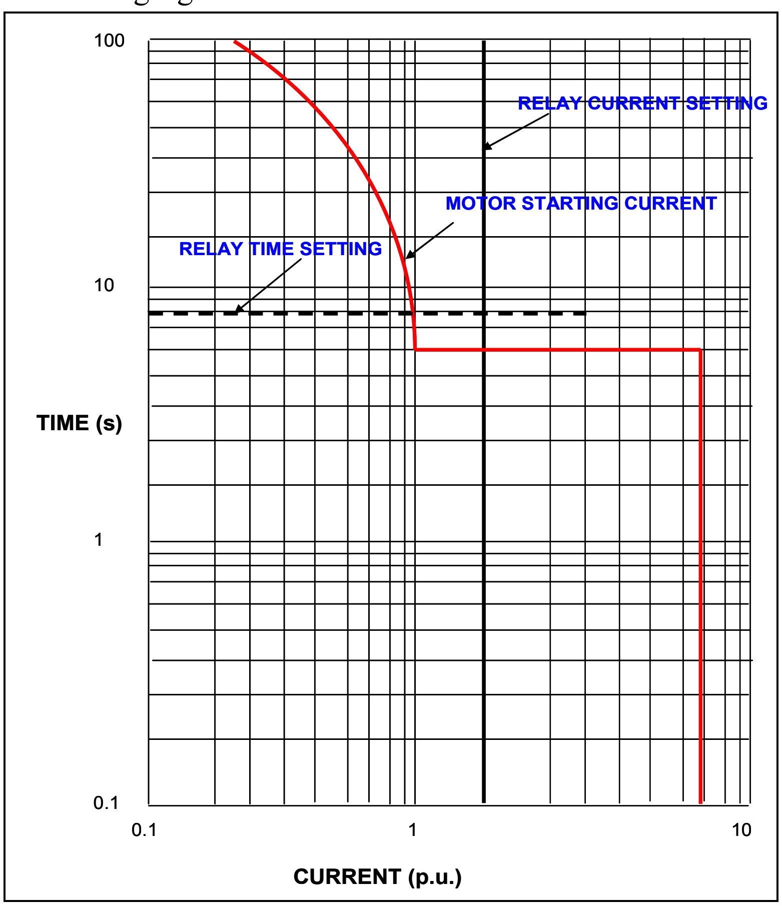


Fig 7: Motor start Protection start time<safe stall time

If start time is greater than or equal to the safe stall time, a speed sensing switch is safe. This time can be longer than the safe stall time, as there is both a decrease in current drawn by the motor during the start and the rotor fans begin to improve cooling of the machine as it accelerates. If a start is sensed by the relay through monitoring current and/or start device closure, but the speed switch does not operate, the relay element uses the safe stall time setting to trip the motor before damage can occur. Fig 7a illustrates the principle of operation for a successful start and fig 7b for unsuccessful start.

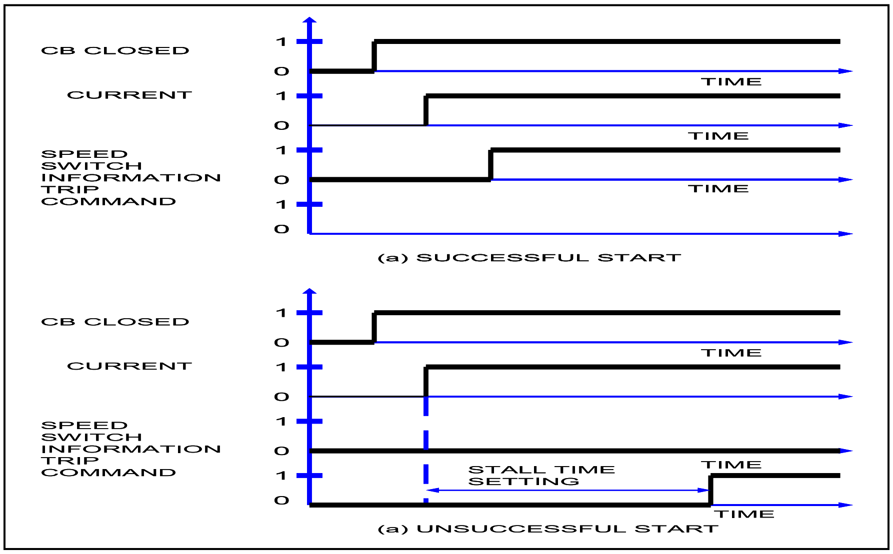


Fig 8: Motor Start Protection Start Time>Safe Stall Time

7. Under Voltage Protection

Under voltage usually causes a drop in speed as shown in fig 8

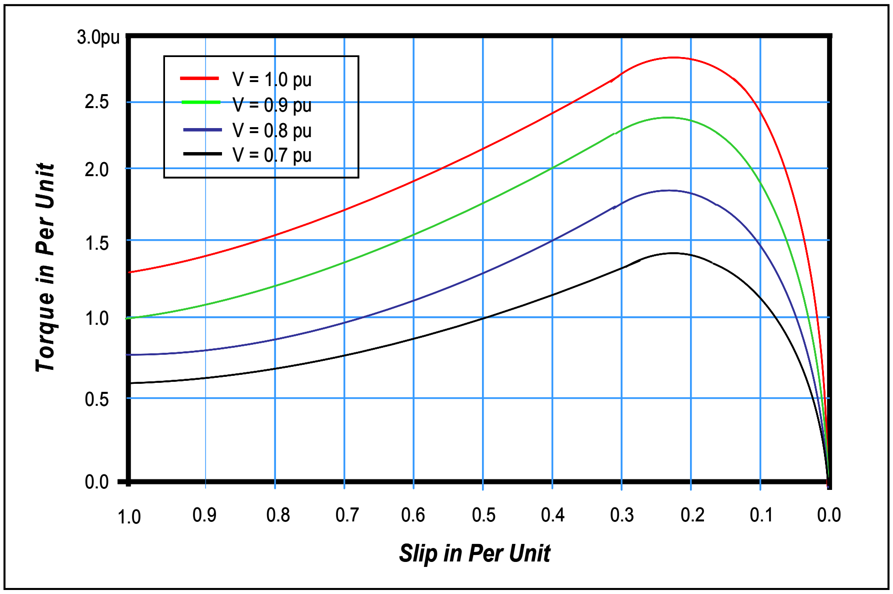


Fig 9: Effect of Low Voltage on Induction Motor Torque

Motor would stall if subjected to prolong under voltage conditions. Transient under voltage would allow a motor to recover when the voltage is restored, unless the supply is weak. Most of the motor have inherent under voltage protection. Where a specific under voltage trip is required, a definite time under voltage element is used. An interlock with the motor starter is required to block relay operation when the starting device is open, otherwise a start will never be permitted. The setting for voltage and time delay settings depend on system and motor.

8. Stall Protection

When a motor stalls while running or is unable to start because of excessive load, it will draw a current from the supply equivalent to the locked rotor current. We should disconnect it as quickly as possible. A stall condition is detected by a rise in current above the motor starting current threshold and tripping will occur if this condition persists for greater than the setting of the stall timer. An instantaneous relay element provides protection. In some system staling and re-acceleration current seems to be confused, so stall protection would be expected to operate and defeat the objective of the re-acceleration scheme.

9. Short Circuit Protection

Short circuit faults can be protected by the same instantaneous relay used for ground faults, because the stator windings, are completely enclosed in ground metal, the fault would very quickly involve earth, which would operate the instantaneous earth fault protection. A single definite time over current relay element is all that is required for this purpose. It is set to about 125% of motor starting current. Differential protection may be provided on larger HV motors fed via circuit breakers to protect against phase –phase and phase-ground faults particularly where the power system is resistance- ground. Damage to the motor in case of a fault occurring is minimized as the differential protection can be made quite sensitive so fault is detected at its early stages.

10. Conclusion

Motor protection was the topic of this report. As mentioned earlier there are many type, size and variety of functional motors used in the power industry. Same is the case with the protection of motors. It is hard to cover all aspects of protection in one report but I tried to summarize most important aspects of it. In short Motor is very important part of the power system as well as our daily life, so its protection is a critical issue. We get introduction to the new and improved techniques of protection every year but the basic mythology is still same. The most remarkable improvement is the invention of computer relays in contrast to the conventional electromechanical relays, which made protection complications simple and easy to implement. Also New simulation tools helped to improve the protection of motor along with other power devices.