AC Motor Protection

An Online Continuing Education Course for Engineers

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AC Motor Protection

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There is a wide range of AC motors since they can be used in numerous applications. AC motors need to be protected, but protection selection usually does not depend on the motor and load type. This selection is based on the fundamental AC motor operation processes. There are crucial differences between the protection of induction motors and synchronous motors. Motor operation characteristics have to be particularly considered when applying selected protection. This approach is more important for the motors than for any other power system element. For example, the starting and stalling currents/times have to be known and taken into account when using overload protection. Also the thermal withstand of the AC motor has to be precisely defined under balanced and unbalanced loading conditions. The conditions for which AC motor protection is needed can be separated into two main groups: imposed external conditions and internal short circuits. Table 1 gives information on most likely issues that call for AC motor protection.

Table 1. Typical causes of motor faults

External failures	Internal failures
Reverse phase sequence	Bearing faults
Under-voltages	Winding failures
Single phasing	Overloads
Unbalanced supplies	

Modern Relay Motor Protection Technology

Modern numerical motor relay protection technology must be sufficient to meet protection requirements of any one of the vast range of motor designs. Many motors designs do not tolerate overloads. A motor protection relay providing sufficient protection will have the following set of characteristics:

Induction and Synchronous Motors

- extended start relay protection
- loss-of-load relay protection
- number of starts limitation
- stalling relay protection

- short circuit relay protection
- thermal relay protection
- earth fault relay protection
- negative sequence current detection
- winding RTD measurement/trip
- under-voltage relay protection
- auxiliary supply supervision

Synchronous Motors in Particular

- loss of supply relay protection
- out-of-step relay protection

Also, protection relays may provide options such as circuit breaker condition monitoring assessment that can be used for maintenance needs. Manufacturers may also provide protection relays that use a smaller number of functions in situations when less sophisticated relay protection is warranted (e.g., low rating asynchronous motors). The following paragraphs comment on possible motor fault types.

Thermal (Overload) Relay Protection

The majority of winding faults are either indirectly or directly triggered by overloading (prolonged or cyclic). Also, winding faults can be caused by an operation on an unbalanced supply voltage or single phasing. These effects cause excessive heating which deteriorates winding insulation and effectively creates electrical faults. The universally adopted rule is that insulation life is halved for each 10ºC rise in temperature above the rated value. This rule is affected by the length of time spent at the higher temperature. As electric motors have a great heat storage capacity, it means that occasional short duration overloads may not adversely impact the motor. Nevertheless, prolonged overloads of only several percents may end in premature aging and insulation fault. Next, the motor thermal withstand capacity is impacted by winding heating prior to a fault. Hence, it is crucial that the protection relay features consider extremes of zero and full-load pre-fault. These are known as the 'Cold' and 'Hot' conditions, respectively. Different motor designs, various usages, a variety of different abnormal working conditions and resulting fault modes result in a complex thermal formula. Therefore, it is not possible to create a universal mathematical model that is precise. Nevertheless, it is possible to make an approximate mathematical model. This model assumes that the motor is a homogeneous machine, producing and dissipating heat at a rate proportional to temperature rise. This rule known as the motor 'thermal replica' is used for overload relay protection. The temperature *T* at any instant can be presented with:

$$T = T_{max}\left(1 - e^{-\frac{t}{\tau}}\right)$$

Where

T_{max} - Maximum/final steady state temperature

τ - heating time constant

Temperature rise is directly proportional to the current squared:

$$T = KI_R^2\left(1 - e^{-\frac{t}{\tau}}\right)$$

Where

I_R- the current which, if continuously transferred, generates temperature T_{max} in the motor. Hence, it can be demonstrated that, for any overload current I, the allowable time t for this current to run is:

$$t = \tau \log_e\left[\frac{1}{\left\{1 - \left(\frac{I_R}{I}\right)^2\right\}}\right]$$

Typically, motor supply can comprise both positive and negative sequence components. Both current components produce motor heating. Hence, motor thermal replica should consider both components. Common equation for the resulting current is:

$$I_{eq} = \sqrt{(I_1^2 + KI_2^2)}$$

where
$I_1 -$ positive sequence current
$I_2 -$ negative sequence current
K - negative sequence rotor resistance / positive sequence rotor resistance at nominal speed.

A common value of K is 3. Eventually, the motor thermal replica has to consider the fact that the motor will cool down during light load periods. It also has to consider the motor's initial state. The motor has a cooling time constant,τ_r, that specifies the motor cooling rate. Therefore, the final motor thermal model can be defined as:

$$t = \tau \log_e \frac{(K^2 - A^2)}{(K^2 - 1)}$$

Where

$\tau -$ motor heating time constant

$$K = \frac{I_{eq}}{I_{th}}$$

$A^2 -$ initial motor state (cold or hot)

$I_{th} -$ thermal setting current

Above equation considers motor 'cold' and 'hot' features as described in IEC 60255. Particular protection relays may use a dual curve feature for the motor heating time constant. In that case, two motor heating time constants are needed. Switching between the two constants starts at a pre-defined motor current. This method may be utilized to get enhanced tripping performance during motor starting with the star-delta starter. During motor starting, the motor windings transfer full line current. However, in the 'run' condition, they transfer only 57% of the current detected by the protection relay. Also, when the motor is disconnected from the network, the motor heating time constant τ is equal to the motor cooling time constant τ_r. Since the protection relay should be perfectly matched to the protected motor and capable for sustained overload protection, a great range of protection relay adjustments is desirable. Common protection relay setting curves are presented in Figure 1.

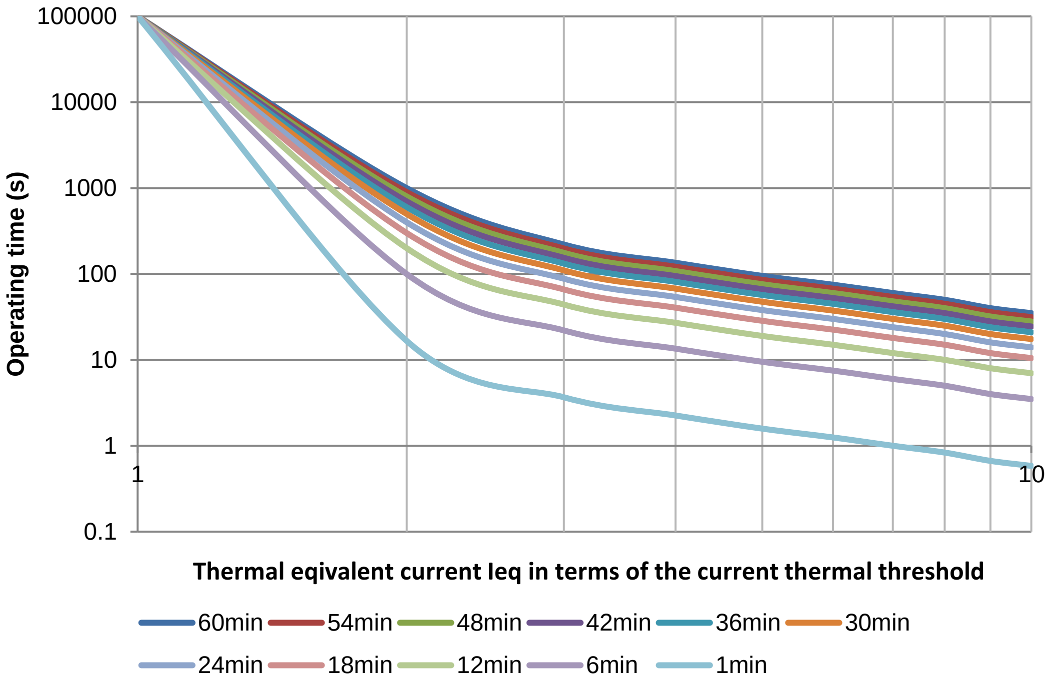


Figure 1. Thermal overload curves from cold – initial thermal state 0%

Start/Stall Motor Protection

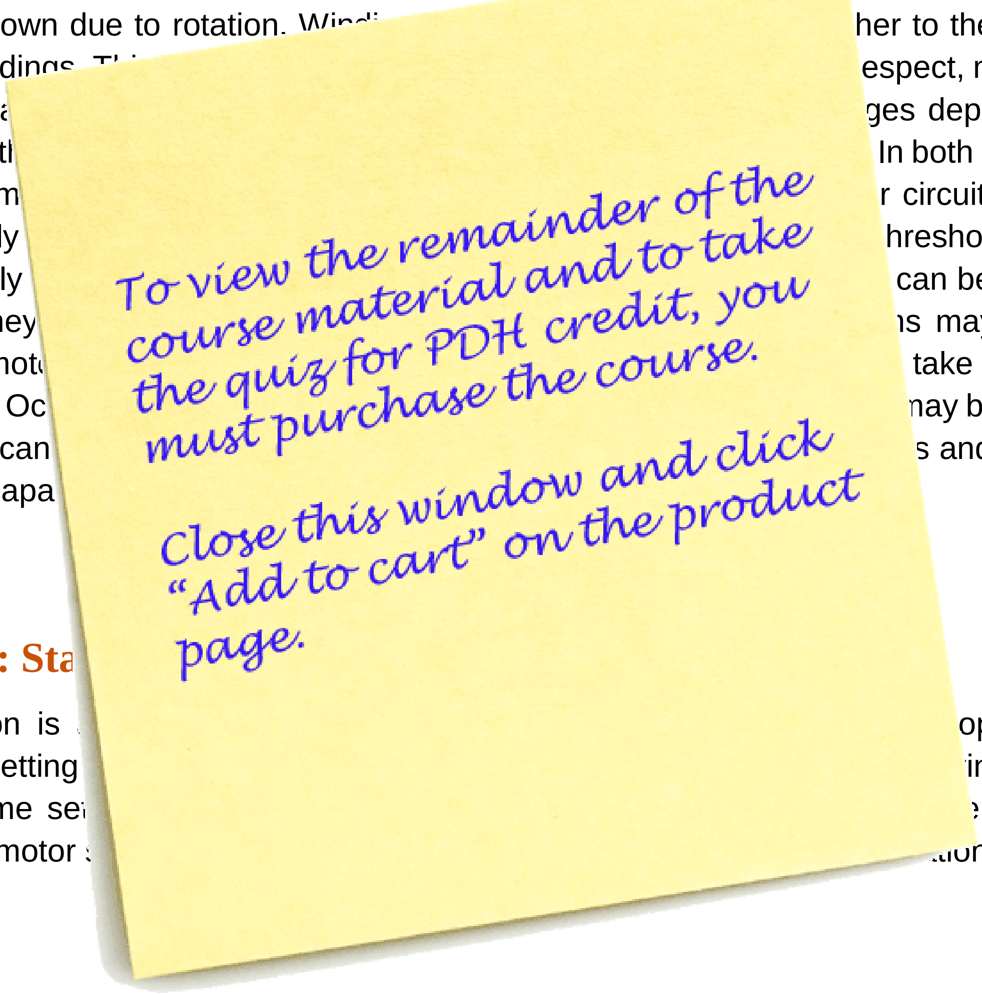
Once a motor starts, it takes a current greater than full load rating current. This lasts throughout the period that the motor needs to run up to speed. Even though motor starting current decays as motor speeds up, in protection practice, it is normal to assume that the motor current stays constant throughout the starting period. The starting current varies depending on the motor design and starting method. For direct-on-line (DOL) started motors, the nominal starting current can be 4-8 times of full-load current. Nevertheless, when a star-delta starter is used, the line current will be only $1/\sqrt{3}$ of the DOL starting current. In the case motor stalls whilst running, or fails to start, due to great load, the motor will take a current equal to its locked rotor current. Hence, it is not possible to recognize stall condition and a healthy start solely on the basis of the taken current. Discrimination between the two conditions has to be made based on the duration of the taken current. For motors where the starting time is lower than the motor safe stall time, relay protection can be easily made. Nevertheless, in situations, where motors are used to power high inertia loads, the stall withstand time can be lower than the starting time. In these situations, extra methods have to be given to allow discrimination between the two conditions.

Prolonged Start Time/Locked Rotor Protection

A motor may fail to speed up for a number of different reasons:

- loss of a supply phase
- excessive load torque
- insufficient supply voltage
- mechanical issues

A huge current will be taken from the supply and create high temperatures within the
motor. This situation gets even worse since the mot ng, so it cannot be
cooled down due to rotation. Windi her to the stator or
rotor windings. Thi espect, motors are
differentia ges depending on
whether th In both situations,
starting m r circuit breaker).
Optionally hreshold value –
commonly can be detected
only if they ns may exist for
certain mot take these into
account. Oc may be needed,
and this can s and the built-
in logic capa



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Case 1: Sta

Protection is option. The
current setting ing current.
Relay time se r than the
allowed motor tion principle.