Safety Considerations for AC Motor Thermal Protection

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Abstract — In this author's experience, it is not uncommon for industrial operators to experience a motor trip due to thermal overload and then immediately restart the motor to resume operations. Often times, restarting a recently overloaded motor involves actively bypassing the protective relay's start inhibit function. Given that the cost of replacing an electric motor can be less costly than the opportunity cost of process downtime, the procedure of bypassing motor protection is often defended on economic grounds.

This paper reviews the thermal properties of a motor and the concept of thermal modelling in a protective relay. This paper details the consequences of exceeding the motor's thermal damage limits, with an emphasis on motors employed in classified hazardous locations. Methods of preventing operators from bypassing start inhibit are explored.

Index Terms —Motor protection, thermal overload, hazardous areas, thermal inhibit emergency restart

I. Thermal Properties of a Induction Motor

The purpose of an electric motor is to convert electrical energy to mechanical energy. Because the laws of physics do not allow a perfectly efficient machine, any motor in operation will produce losses in the form of heat. Motors are designed to dissipate this heat at a faster rate that it accumulates, provided the motor is operated under rated conditions. Overloading a motor and operating a motor at a reduced frequency using a variable frequency drives are two examples of conditions that may result in excessive heating.

The thermal limits of a motor are defined by its manufacturing specifications. For example, NEMA MG-1 defines thermal insulation Class F, a common specification in medium voltage motors in North America, with a maximum stator winding temperature of 190 degrees Celsius, assuming an ambient temperature of 40°C[1].

When motor temperature exceeds its thermal rating, the motor does not necessarily fail instantly. Depending on the severity of thermal stress, the motor may continue to operate without a noticeable detriment to the continuity of load. For any 10°C rise above insulation class rating, the motor's life is reduced by 50%[1].

II. Application of Motors in Hazardous Locations

A. Hazardous Area Classifications

Defined by the National Electric Code (NEC), a Class I hazardous location is one that contains a combustible gas or vapor. A Class II contains combustible dust, and Class III pertains to combustible fibers. Per NEC, the hazardous location is further classified by likelihood of the presence of those combustible materials. A Class I, Division 1 classification implies that combustibles are present under normal operating conditions or under normal maintenance operations or if equipment can fail in such a way that the electrical equipment will become an ignition source. A Class I, Division 2 classification implies that combustible gases and vapors may be present, but it is less likely than a Class I, Division 1 area [2].

In Class I, Division I areas where combustible gases or vapors are almost certain, it is best to avoid the installation of electric equipment altogether, but where it is necessary, hermetically sealed motor enclosures are required. In Class I, Division II areas, open motors are allowed provided their design does not include arc-inducing components such as contactors or brushes[3].

B. Ignition of Combustibles

For a gas or vapor to combust, two conditions must be present: sufficient heat and oxygen. Heat can be supplied by an ignition source such as an arc or spark, which can normally exceed 2000 °C. Excluding the extreme temperature of an arc or spark, a gas/atmosphere mixture can spontaneously combust when it reaches its autoignition temperature.

In the context of an industrial motor application, motor insulation does not need to break down, and stator voltage does not need to arc in order to ignite a combustible. A hot spot in the windings or bearing temperature can exceed autoignition temperature. Table 1 shows some examples of gases whose autoignition temperature is below or near the NEMA Class F insulation thermal limit.

Gas	%LEL	%UFL	AIT (°C)	Class F Thermal Limit (°C)
Acetaldehyde	4	60	175	190
Acrolein	2.8	31	235	190
Carbon Disulfide	1.3	50	90	190
Crotonaldehyde	2.1	15.5	232	190
Diethyl Ether	1.7	48	160	190
Diethylene Glycol Monobutyl Ether	0.9	24.6	204	190
Dioxane	2	22	180	190
Isobutyraldehyde	1.6	10.6	196	190
Kerosene	0.7	5.0	210	190
Monomethyl Hydrazine	2.5	92	194	190
Nonane	0.8	2.9	205	190
n-Octane	1.0	6.5	206	190
Propionaldehyde	2.6	17	207	190
Propyl Ether	1.3	7.0	215	190
Propyl Nitrate	2.0	100	175	190

Table 1: Examples of Gases with Autoignition Temperatures Near NEMA Class F Thermal Insulation Limits

III. THERMAL PROTECTION

A. OVERLOAD PROTECTION

The function of a thermal overload relay is to mimic the ebb and flow of heat accumulation and dissipation within the motor and trip the motor offline before the motor exceeds its thermal limits. Bimetallic overloads mimic motor heat by bending at a certain rate according to the temperature, and eutectic style relays have a solder-like material that melts at a certain temperature. Each is specified to roughly match the thermal capabilities of the motor. Digital relays apply an algorithm to mathematically model the heat of a motor.

An overload device trips in anticipation that the motor will soon eclipse its thermal insulation rating. This does not mean that the overload device prevents the motor from exceeding its thermal insulation rating. If an overload relay is reset or bypassed before the motor's heat can dissipate to a level that will allow a successful start, the motor windings, specifically the rotor, will exceed its thermal limits despite the overload trip.

B. START INHIBIT

A motor can only start a certain number of times in succession before exceeding its thermal limits. For all NEMA rated motors, the motor is capable of successively accelerating twice, allowing for time to coast to rest between starts. This is provided that all other conditions such as load torque, voltage and frequency applied, etc are within the design ratings of the machine. Furthermore, a NEMA motor will be capable of making one successive start on the condition that its temperature is not above normal operating temperature. This is commonly referred to as a "2 Cold/1 Hot" motor. It is not uncommon for a motor to be rated "3 cold/2 hot". Essentially, a 2 Cold/1 Hot motor uses no more than 50% of its thermal capacity on startup, and a 3 Cold/2Hot motor uses no more than 33% of its thermal capacity on startup, as shown in Figure 1.

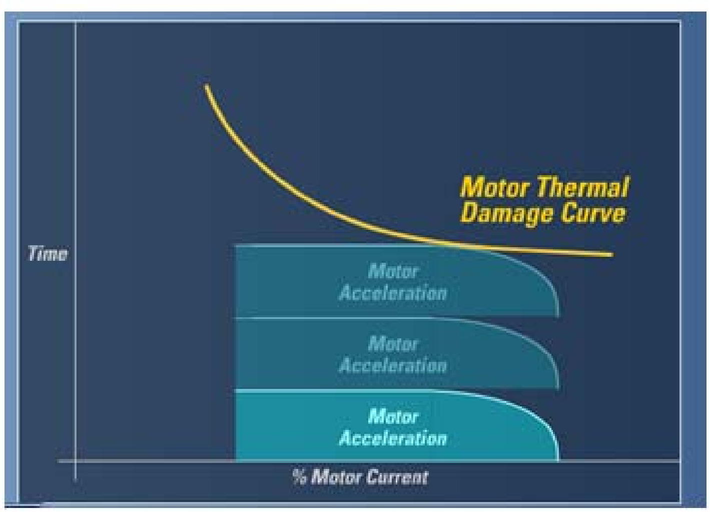

Figure 1: Representation of a 3 Cold/2 Hot motor.

A common function of a digital motor protection relay is to prevent a motor from starting when there is insufficient thermal capacity available to do so[4]. This function is called Start Inhibit or Start Blocking. The example shown in Figure 2 uses the analogy of a beaker to represent the thermal capacity of a motor. This example motor could be considered a 2 Cold/1 Hot motor because thermal capacity on startup exceeds 33% but is less than 50%. The relay prevents the motor from overheating on a subsequent start by requiring the temperature of the motor to be no greater than 60% of its total thermal capacity.

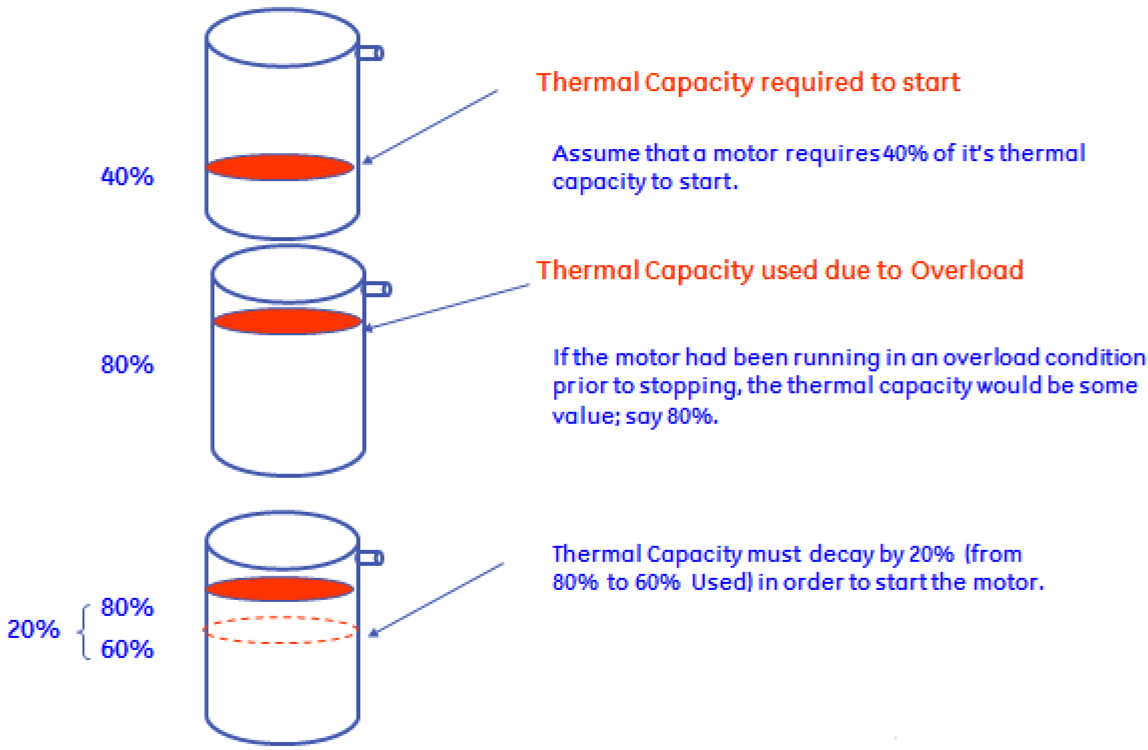

Figure 2: Thermal Inhibit of a 2 Cold/1 Hot Motor

Unlike the overload protective function which is reactive with respect to restarts, the start inhibit function is proactive. Unless it is bypassed, a properly configured start inhibit function will prevent a motor's winding temperature from exceeding autoignition temperatures.

C. Bypassing the Protection

It is common for digital relays to have an emergency restart function which temporarily disables any motor protection that may ordinarily prevent the motor from starting. The purpose of this function is for rare occurrences when immediate safety considerations override the concern of motor life or exceeding its rated temperature. An example of a justified emergency restart might be starting a fan whose purpose is to clear a temporarily occupied space of asphyxiating gas.

With bimetallic overloads, a reset could only be accomplished by physically pressing the reset or by jumpering the contactor circuit so that the contactor remained closed regardless of the overload device's state. With some digital relays, an emergency restart is accomplished by digital input, which can be wired to a control switch, PLC contact, or physically jumpered[4].

Of course, the decision to bypass motor protection to make an emergency restart must be made very carefully by qualified personnel considering all implications. Some factors to consider include:

- Economic loss due to motor insulation degradation
- Additional risk of downtime due to a faulted motor
- Potential safety hazard due to exceeding autoignition temperature in a hazardous location.

IV. Securing the Protective system

Critical motors should be secured to prevent unqualified personnel to bypass carefully engineered protective systems. A critical motor is any motor that should not be overloaded or excessively started due to economic or safety concerns.

Non-critical motors can be allowed to be pushed beyond rated capability for the sake of short-term economic decisions or simple convenience.

A. Physical barriers

Any motor control system can be bypassed with a jumper. It is essential to physically restrict access to motor control circuits with a lock and key. This can either be done by restricting keyed entry into the control room or local locks on the motor control center as shown in Figure 3.

Figure 3: Lock and Key on MCC Door

B. Password Access

If a relay only relies on a physical control switch or a jumper to activate the emergency restart, a password is not applicable. However, if the relay's emergency restart is actuated by a PLC contact or a SCADA command, a password can be implemented at the PLC/SCADA device.

If the emergency restart is actuated by a relay pushbutton or any other relay command, it may be possible to implement password access at the relay level.

i. Role-Based Access Control (RBAC)

RBAC is a method of restricting user access that is commonplace among computer networks and is now commercially available in digital relays. It is a permissions-based system where users are assigned a password to access the relay but may be restricted to some functions based on the predetermined permissions level. For example, some users may be classified as "Operators" with the ability to read event records, reset alarms and target messages but cannot change relay setpoints. Other users may be classified as "Administrators" who are unrestricted with regard to any relay function[5].

ii. Remote Authentication Dial-In User Service (RADIUS)

RADIUS is a protocol used to manage user-access to computer networks that is now commercially available in digital relays. It is a client/server protocol where the relay is the client, and the server is a network computer that is running RADIUS host server software, which is available both commercially and as freeware. The relay user enters a user name and password, and the RADIUS server applies an authentication scheme and responds with an acceptance or rejection message.

The National Energy Regulatory Commission (NERC) has required under the Critical Infrastructure Protection Standard NERC CIP-004-3a:

"The Responsible Entity shall revoke such access to Critical Cyber Assets within 24 hours for personnel terminated for cause and within seven calendar days for personnel who no longer require such access to Critical Cyber Assets."

Although most industrial plant operators are not governed by NERC, the concept of strict relay access is still sound advice. Using RADIUS gives management the ability to revoke password access from a single individual by deleting their permissions from a server, as opposed to changing every password on every relay in the installed base.

C. Accountability and Alarming

Even if someone is trained as a qualified individual, that person still may violate the rules and operating procedures. If someone jumpers an emergency restart digital input to reset a thermal trip, there is limited information to track down the offending party. At best, a relay might give a time-stamped event record that the emergency restart took place. If a PLC or SCADA system was used to initiate an emergency restart, the PLC or SCADA system could be programmed to provide more forensics information.

i. Syslog

Preferably, the digital relay is equipped with a comprehensive event logging system that includes not only a time-stamp but also a user-name, MAC address, and summary of changes that were made. If it is determined that a qualified person is in violation of safe operating practice, that person can be recommended for additional training, and/or access can be revoked.

Syslog is once again a concept from the computer networking sphere that has been adopted in protective relaying.

ii. Simple Alarm

In order to maintain integrity of the precisely engineered motor protection system, any settings change should trigger an alarm to alert a qualified person to validate the change.

V. Conclusions

For motors installed in areas with combustible gases or vapors whose autoignition temperature is near the motor's insulation temperature rating, it is essential to safety to prevent that machine from overheating. Motor protection relays can help prevent such overheating from occurring by properly applying standard thermal protection, which includes the start inhibit function. To ensure that unqualified personnel do not bypass this essential protection, it is recommended to apply both physical locks and password-protected user access. Where possible, advanced user-authentication techniques can be helpful to manage a large group of users and/or a large installed base of relays.

VI. References

[1] *NEMA MG-1 Motors and Generators, Revision 3,* NEMA Standard, 2002.

[2] *NEMA MG-2 Safety Standard and Guide for Selection Installation and Use of Electric Motors and Generators,* NEMA Standard, 2014.

[3] *Recommended Practice for the Classification of Flammable Liquids, Gases or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas,* NFPA Standard 497, 2004.

[4] GE Document, *469 Motor Management Relay- Instruction Manual*, 2015.

[5] GE Document, *869 Motor Protection System- Instruction Manual*, 2015.

VII. Biography

Matt Proctor is currently a Technical Application Engineer at GE Multilin and has been with GE Multilin for over 6 years. Matt earned Bachelor of Science in electrical engineering from Louisiana State University in Baton Rouge, LA in 2001 and an MBA from LSU in 2005. He has been working in the electrical power field in various capacities since 1997. He specializes in power system studies and protection and control relay applications.