Pacific Gas and
Electric Company

Open-phase Protection Issues for Motors

The result of single phasing in a power system is most pronounced with three-phase induction motors. Most three-phase motors will continue to operate with power from only two phases, but will result in overheating and failure if not protected. Most of the commonly used protective devices, such as conventional circuit breakers or thermal overload relays for motors, are not designed for detecting single phasing conditions.

For lightly loaded three-phase motors, say 70% of normal full-load amperes, the phase current will increase by the square root of three under secondary single-phase conditions. This will result in a current draw of approximately 20% more than the nameplate full load current. If the overloads are sized at 125% of the motor nameplate, circulating currents can still damage the motor. This is why it is recommended that motor overload protection be based upon the actual running current of the motor under its given loading, rather than the nameplate current rating.

The most common fault on the utility system is a single phase-to-ground fault. It is over twice as likely to be a single-phase outage as a three-phase outage. Normal events are outages caused by weather conditions, third party contacts, utility equipment failure, etc. These normal events are inherent to an electrical utility system.

PG&E's description of service Rule 2, available on the web, explains the customer's responsibility for protecting their equipment.

Rule 2, paragraph E.3.c.

> "It shall be the applicant's responsibility to equip his three-phase motor installations with appropriate protective devices, or use motors with inherent features, to completely disconnect each such motor from its power supply, giving particular consideration to the following:
>
> c. Open-phase protection to prevent damage due to overheating in the event of loss of voltage on one phase."

Not only does Electric Rule 2 require the customer to protect his electrical equipment, but the National Electrical Code (NEC) requires over-current protection on all three phases and recommends that the current limiting protection be set at no more than 125% of the full load current of the motor. As you see above however, protecting to 125% of nameplate may not be adequate.

There are four strategies to use for a customer:

a) The customer can employ a circuit breaker with a built-in shunt trip overload relays that are adjustable to 125% of full load current with a time delay to allow for start-up. The most important application issue to keep in mind is the type of sensing used with the relay as both voltage and current sensing is offered. While voltage sensing is less expensive it is not as accurate because motor back-EMF (reverse current) can mask the loss of phase. This type of breaker is more expensive than a conventional overcurrent relay breaker.

b) The customer can employ a Phase Failure Relay with his motor controller or tie it in series with the undervoltage trip of the breaker, if his breaker has this extra cost option. This relay looks at phase sequence, unbalance and undervoltage. This relay is the fastest trip but can cause nuisance tripping.

c) The customer can employ dual element fuses. This is the least expensive. The key element is proper sizing and two elements that allow for a time delay for start-up. The only disadvantage to this method is the customer must have spare fuses. The built-in time delay allows for momentary sags in voltage while not causing nuisance tripping.

d) The customer can specify a higher standard motor that has inherently higher heat resistance and better insulation. A major cause of motor failure is overheating the insulation. Therefore, improving the insulation value lengthens the time before failure. The simplest improvement is to specify a service factor of 1.15 instead of 1.0. Instead of the typical class B insulation, specify a higher rating. These are extra cost options.

Some customers use an inexpensive solution, commonly referred generically as a “motor saver.” Many times this inexpensive solution leads to nuisance tripping caused by normal utility events, not just lost of phase conditions. At least two manufacturers have a higher cost model that provides for adjustable trip delay settings, auto restart and diagnostics.

Background:

Some historical data on motor failure suggest the following causes for motor failure; the majority are directly related to insulation breakdown from heat:

Overloads	30%
Contaminants	19%
Single-phasing	14%
Bearing failure	13%
Old age	10%
Rotor failure	5%
Miscellaneous	9%
Total	100%

Allowing a motor to reach and operate at a temperature 10°C above its maximum temperature rating will reduce the motor’s expected life by 50%. Operating at 10°C above this, the motor’s life will be reduced again by 50%. This reduction of the expected life of the motor repeats itself for every 10°C. This is sometimes referred to as the “half life” rule.

Although there is no industry standard that defines the **life of an electric motor**, it is generally considered to be 20 years.

The term, **temperature “rise,”** means that the heat produced in the motor windings (copper losses), friction of the bearings, rotor and stator losses (core losses), will continue to increase until the heat dissipation equals the heat being generated.

For example, a continuous duty, 40°C rise motor will stabilize its temperature at 40°C above ambient (surrounding) temperature. The National Electrical Manufacturers Association (NEMA) standard also assumes a typical ambient temperature of 40°C. If the ambient temperature is well above this typical value, then the insulation will start to break down sooner.

Standard motors are designed so the temperature rise produced within the motor, when delivering its rated horsepower, and added to the industry standard of maximum of 40°C ambient temperature rating, will not exceed the safe winding insulation temperature limit. The original motor manufacturer has control over the basic design and insulation materials used. This is a very important consideration when a motor is re-wound also.

Classes of Insulation

The following shows the maximum operating temperatures for different classes of insulation:

Class A Insulation	105°C
Class B Insulation	130°C
Class F Insulation	155°C
Class H Insulation	180°C

The significance of these classes of insulation is that for the higher H rating, a superior insulation class is employed that will withstand much higher sustained temperatures before the insulation breaks down. Of course, there are extra costs involved and they require special order specifications. Typically, you will find higher rating insulation being used for severe duty locations, such as for boiler motors and hot water pumps. If you have a location that is not hot but has high voltage unbalance, you could specify a higher insulation class motor and get a longer life.

The term, "**Service Factor**" (SF) for an electric motor, is defined as "a multiplier which, when applied to the rated horsepower, indicates a permissible horsepower loading which may be carried under the conditions specified for the Service Factor of the motor."

"Conditions" include such things as operating the motor at rated voltage and rated frequency.

Example: A 10 HP motor with a 1.0 SF can produce 10 HP of work without exceeding its temperature rise requirements. A 10 HP motor with a 1.15 SF can produce 11.5 HP of work without exceeding its temperature rise requirements. Motors with a SF of 1.15 have better quality insulation, will have a longer service life and cost more. They will also be capable of withstanding longer periods or greater magnitudes of current imbalance before failure.

Overloads, with the resulting overcurrents, if allowed to continue, will cause heat build-up within the motor. The outcome will be the eventual failure of the motor's insulation. As stated earlier, for all practical purposes, insulation life is cut in half for every 10°C increase over the motor's rated temperature.

Voltage Unbalance

When the voltage between all three phases is equal (balanced), current values will normally be the same in each phase winding of a motor.

The NEMA standard MG-1 for electric motors and generators recommends that the maximum voltage unbalance be limited to 1%.

When the voltages between the three phases (AB, BC, CA) are not equal (unbalanced), the current increases dramatically in the motor windings, and if allowed to continue, the motor will be damaged.

It is possible, to a limited extent, to operate a motor when the voltage between phases is unbalanced. To do this, the load must be reduced.

Voltage Unbalance in Percent	Derate Motor to These Percentage of the Motor's Rating *
1%	98%
2%	95%
3%	88%
4%	82%
5%	75%

This is a general "rule of thumb," for specific motors consult the motor manufacturer.

Some Causes of Unbalanced Voltage Conditions

- Unequal single-phase loads. This is why many consulting engineers specify that loading of panelboards be balanced to +/-10% between all three phases.
- Open delta connections.
- Transformer connections open - causing a single-phase condition.
- Tap settings on transformer(s) not proper.
- Transformer impedances (Z) of single-phase transformers connected into a "bank" not the same.
- Power factor correction capacitors not the same or off the line.

Note: It should be noted that PG&E's Electric Rule 2 states that a customer's phase load current shall be balanced to within no more than 10% unbalance.

Insulation Life

The effect of voltage unbalance on the insulation life of a typical T-frame motor having Class B insulation, running in a 40°C ambient, loaded to 100%, is as follows:

Voltage Unbalance	Insulation Life	
	Service Factor 1.0	Service Factor 1.15
0%	1.00	2.27
1%	0.90	2.10
2%	0.64	1.58
3%	-----	0.98
4%	-----	0.51

Typical voltage unbalance at the motor terminals is going to be between 1 and 3%. Therefore, to get a reasonable motor life, a user should specify a Service Factor of 1.15. Older, larger U-frame motors, because of their ability to dissipate heat, could withstand overload conditions for longer periods of time than the newer, smaller T-frame motors. End users have pressured motor manufacturers to reduce the size and weight of motors. The result is shorter life.

The National Electrical Code (NEC) 1999

In the NEC, Table 430-37 requires three overload protective devices, one in each phase, for the protection of all three-phase motors. Prior to the 1971 NEC, three-phase motors were considered to be protected from overload (overcurrent) by two overload protective devices. These devices could be in the form of properly sized time-delay, dual-element fuses, or overload heaters and relays (melting alloy type, bimetallic type, magnetic type, and solid-state type). While this was an improvement it will not protect the customer's motors from failure due to single phasing without additional measures. Article 430 is only designed to protect the motor from overload or failure to start overcurrent.

According to NEC article 430-32, continuous duty motors of more than one horsepower have the option for overload protection if they are larger than 1500 horsepower of using embedded temperature detectors that cause current to the motor to be interrupted when the motor attains a temperature rise greater than marked on the nameplate in an ambient of 40°C. This strategy is actually the best but it is the most expensive.

The NEC has always been a compromise between safety and the desire to maximize manufacturing production. In cases where it assumes an industrial customer has qualified personnel, it will allow a hazardous condition to exist if special steps are taken. For example, *Article 430-44 - Orderly shutdown*, states that *if immediate automatic shutdown of a motor by a motor overload protective device(s) would introduce additional or increased hazard(s) to a person(s), and continued motor operation is necessary for safe shutdown of equipment or process, a motor overload sensing devices(s) conforming with the provisions of Part C of this article shall be permitted to be connected to a supervised alarm instead of causing immediate interruption of the motor circuit, so that corrective action or an orderly shutdown can be initiated.*

References:

NFPA 70, National Electrical Code (NEC), 1999 edition.

National Electrical Manufacturers Association (NEMA), Motor and Generator MG 1-1987, section on selection and application.