Don't Go Out On a Limb

Every plant professional should be able to check the circuitry used within their plant. Remember to take these precautions when checking the reliability of three-phase motor branch circuits.

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The National Electrical Code (NEC) defines a branch circuit as the conductors between the final overcurrent device that protects the circuit and the loads the circuit is feeding. The branch circuit includes the final overcurrent device (disconnect switch and fuses or circuit breaker), the motor starter and associated control circuits, circuit conductors and the three-phase motor.

The plant professional ought to know how to test newly installed branch circuits and again during startup and while running. The Occupational Safety and Health Administration, in publication NFPA 70E, states that any such measurements are to be made only by qualified persons using voltage-rated tools and proper personal protection equipment suitable for testing live circuits.

New circuits

Before energizing the load, you'll need to check four things: a physical examination, the ambient temperature, insulation integrity and voltage.

During a physical check, look for problems related to shipping and installation. Vibration and jolting can loosen mounts and damage plastic parts. Tighten any screws and lugs. Failure to torque them correctly can result in high resistance, high connection temperatures at loose connections and damaged conductors on overtorqued connections. Many manufacturers provide connector torque specifications.

It's generally accepted that standard three-phase motors have a life of 20,000 hours. Most motor nameplates show a maximum ambient operating temperature of 40°C (104°F). Also, most motors are wound with conductors that have a Class B insulation rating, which is designed for the same temperature. Operating in a temperature 20°F warmer can cut motor life in half. A motor operating in an ambient temperature of 140°F might have a life of only 5,000 hours.

The solution for many temperature problems is to use a motor with Class F insulation, which is rated for an additional 25°C above that of Class B. This means the surrounding ambient temperature could be raised and additional 25°C without decreasing insulation life (Figure 1). Don't forget other items that may be affected by temperature, such as lubricants and motor control equipment. Several motor starter manufacturers offer starter coils having Class H insulation, which is rated for an additional 40°F rise above Class F.

Insulation testing
Check the insulation before startup and before restoring power after a motor burnout. This requires a megger, a testing device providing a high-voltage, low-current DC output. It simulates the peak voltage of the AC supply, which is 1.4 times the voltage measured on a multimeter. Be sure to review the megger's instruction manual before using it. If a variable-frequency drive is used as a controller, contact the manufacturer for guidance before making this measurement.

Disconnect the power and any electronic devices, including electronic overload protection, proximity switches and the like. Measure the conductor resistances of the short circuit protection device from the load side conductor to ground. This evaluates the wiring between the load side of the protective device and the line side of the motor starter. Close the starter contacts manually and retest. This measurement prevents damaging the insulation on the moveable contact carriers.

Check each leg of the motor starter overload protector load side conductors to ground to verify the integrity of the insulation between the load side of the motor starter and the motor itself. The readings are usually 100 megohms or more. A reading below 2 megohms suggests an incipient problem. Recheck periodically to monitor insulation degradation. A reading of 100,000 ohms or less signifies dangerous leakage to ground.

The NEC dictates that short-circuit protection should be able to clear a fault without extensive damage to the circuit's components. This is interpreted as confining the damage to the branch circuit, which explains the need to check insulation integrity after each motor fault.

High and low voltage
Use a multimeter to check for high and low voltage on each phase at the line side of the disconnect switch or circuit breaker. The voltage should be within the motor's nameplate tolerances, which is 10% for standard NEMA designs.

This test checks the highest branch circuit voltage, which is reduced by conductor resistance on its way to the motor. The lowest voltage won't be found by checking at the control panel. It can only be measured at the motor when it is starting. Inadequate voltage at the disconnect may prevent the motor from starting (Figure 2). Possible problems related to low voltage include:

- An increase in full load current after starting.
- A decrease in starting current and dramatic decrease in starting torque.
- A large increase in running current and a large decrease in running torque.
- Reduced power factor, which is a measure of energy used for producing the magnetic fields that enable the motor to do work, but doesn't directly contribute to horsepower. The power factor reduces system capacity and reduces voltage.

Possible problems related to high voltage include:

- Increase in starting and full load current.
- Possible stator and rotor overheating.

Unbalanced voltage
Unequal phase voltages and unbalanced currents can overheat motors. NEMA standard MG1-14.35 defines percent unbalance as the maximum deviation from average voltage divided by the average voltage. For example, if the three readings are 460 V, 470 V and 490 V, the average is 473 V. In this case, the maximum deviation is 17 V (490 V â€“ 473 V), which corresponds to 3.6% unbalance (17 V/473 V).

An unbalanced voltage condition can be caused by four things. First, heavy loads on one phase can reduce the voltage on that phase. If this is the case, try rebalancing the loads.

Second, unbalanced voltages result in unbalanced currents. The power company or the transformer that supplies power to the branch might cause the unbalance or there might be a motor problem. Testing for unbalance requires making current measurements while the motor is running.

To determine if the supply or the motor is the unbalance source, rotate the leads at the motor. Suppose the incoming power lines are L1, L2 and L3 and the motor connections are T1, T2 and T3. With L1 connected to T1, L2 connected to T2 and L3 connected to T3, record the three currents. With power off, rotate the leads -- L1 to T2, L2 to T3 and L3 to T1. Power up and record the currents again. If the high-current phase stays with L1, L2 or L3, the incoming power is the problem. If it stays with T1, T2 or T3, the motor has a problem.

A third problem source is the power factor correction capacitor, a device sometimes used to raise system voltages. A bad capacitor can result in reduced phase voltage.

Finally, the culprit can be harmonic distortion, a degradation of the supply voltage's sine wave. A likely culprit is any device that changes AC to DC, typically a variable-frequency drive. They feed odd harmonics back onto the AC line. The amount of harmonics generated depends on the amount of power that the converter uses and the ability of the AC supply to absorb them.

If the motor's phase unbalance can't be corrected, the only option remaining is to reduce the load. Figure 3 shows suggested reductions needed for increased motor life. For example, a 5% voltage unbalance calls for a load reduction of 75%.

Startup and running
This is when two tests are needed: voltage and current. Checking voltage drop is straightforward. Measure the voltage drop at the motor when starting. The NEC says that a motor should operate with "a reasonable efficiency" if the drop at the load is no more than 5%. The current checks on starting and while running, on the other hand, are more involved.

When starting, the current shouldn't be greater than the motor's high-end tolerance. Some reasons for high starting currents are overload, which is caused by changes in load or motor horsepower, and using high-efficiency motors, which usually have higher starting currents compared with medium-efficiency motors.

High starting current means stronger magnetic fields. Be sure your branch circuit components can withstand them. Older branch circuit components, such as the disconnect switch or circuit breaker, starter and fuse clips, might be damaged by the greater magnetic forces.

The highest currents occur when the motor is first actuated, the so-called locked rotor amperage. Calculate the locked rotor current by substituting into the following formula:

LRA = (1,000 x hp x K) / (1.732 x V)

Where LRA = lock rotor amps
hp = motor horsepower
K = KVA/hp
V = motor voltage

Table 1 shows letters corresponding to different values of locked rotor KVA, one of which will be found on a motor's nameplate. For example, most medium efficiency motors use the letter G, which corresponds to 5.6 to 6.29 KVA/hp. If the motor in question is a 10-hp 3-ph unit operating at 480 volts, the starting current should fall within a range of:

LRA = (1,000 x 10 x K) / (1.732 x 480)
= 12.03 x K
= 67 amps to 76 amps

Running current

While operating, a low motor current could mean that the unit lost its load. No-load current in a three-phase motor can be as little as 30% to 40% of the full load current. High currents, by contrast, make themselves obvious by tripping the overloads. When this happens, first check to see if the load has increased. Someone might be trying to get more work out of the motor.

Next, ensure that the size of the overload heater is correct. Then, check for frequent starts and stops. Rapid start/stop cycling generates heat in the motor at a rate proportional to the square of the current. Although it's beyond the scope of this article, data tables in NEMA MG 1-1998 detail the maximum number of motor starts per hour, which helps determine maximum motor life.

A formula for finding motor winding temperature by measuring resistance isn't as good as an embedded thermocouple, but can provide an indication. Two measurements are needed: one made with the motor off for at least three hours at its normal ambient temperature, and another just after the motor has tripped its overload contact. The ambient temperature should remain constant. Use an ohmmeter accurate to two decimal places because there's not much difference between the hot and cold resistance. The formula for the temperature rise by resistance method is:

T[-]h[-] = [(R[-]h[-] / R[-]c[-]) x (K + T[-]c[-])] â€“ K

Where:
T[-]h[-] = hot temperature (°C)
T[-]c[-] = cold temperature (°C)
R[-]h[-] = hot resistance (ohms)
R[-]c[-] = cold resistance (ohms)
K = 234.5 (a constant for copper)

Finally, check for single phasing. A three-phase motor can't start if it lost a phase, but it can continue to operate with about a 70% overload on the remaining phase. If the motor starter has a manual reset, a single phasing condition will be obvious after the motor has cooled and has tried to restart. If the motor has an automatic reset overload protector, as is found on air-conditioning and refrigeration compressors, the motor will burn itself up, unless it has an overload alarm.