OVERLOAD PROTECTION OF THREE-PHASE MOTORS
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Since the early 1960’s, most Reclamation power installations have been designed and constructed utilizing 3-phase overload protection for all 3-phase motors powering auxiliary equipment. Prior to 1960, most 3-phase auxiliary equipment was provided with 2-phase overload protection only.

The accompanying article, reprinted for this volume by permission from plant Engineering Magazine, explains why 3-phase protection is now required by the National Electrical Code. In addition, the article provides a reliable method of determining whether current unbalance in a 3-phase motor is due to unbalanced line voltage or is caused by problems in the motor itself.

While the older 2-phase overload protection is probably adequate for most existing installations, 3-phase protection should be provided for important existing auxiliary equipment (particularly where there has been a history of motor burnout) and whenever existing equipment is being modernized.
The case for three protectors-

Overload Protection of Three-Phase Motors

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THE 1971 EDITION of the National Electrical Code requires that an overload protective device be installed in each phase of a 3-phase motor feeder. In the superseded 1968 edition, protection was mandatory in only two legs of a 3-phase motor feeder—provided that the motor was not installed in an isolated, inaccessible, or unattended location.

The new Code does away with the exception which permitted protection in only two phases for accessible motors, and 3-phase overload protection is now required in all cases for 3-phase motors, an overwhelming majority of industrial electrical motors are installed in areas where the old "minimum of two overload elements" provision applied, and most 3-phase motors in service today have protection in only two legs. However an understanding of why the Code change was necessary bears out in service today have protection in only two legs. However an understanding of why the Code change was necessary bears out

Requirement of protection in each phase of a 3-phase motor is, essentially, a means of minimizing motor burnouts that are caused by unbalanced line voltages or single-phasing. Here's what NEMA Standard MG 1-1433 has to say about the advisability of retrofitting older motor branch circuits to incorporate 3-phase overload protection.

The effect of unbalanced voltages on polyphase induction motors is equivalent to the introduction of 'negative sequence voltage' having a rotation opposite to that occurring with balanced voltages. This negative sequence voltage produces in the air gap a flux rotating against the rotation of the rotor, tending to produce high current. A small negative sequence voltage may produce in the windings currents considerably in excess of those present under balanced voltage conditions.

The voltage unbalance (or negative sequence voltage) in percent may be defined as follows: Per cent voltage unbalance =

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\text{Max. voltage deviation from Avg. voltage} \times 100 \over \text{Average voltage}
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Example: With voltages of 220, 215, and 210, the average is 215, the maximum deviation from the average is 5, and the percent unbalance is

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5 \times 100 = 2.3 \text{ per cent.}
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Voltage unbalance is difficult to detect with a common, industrial-type voltmeter of about two percent accuracy. However, since it is the current (I) that causes heating, the phase currents of the motor can be readily measured with a clamp-on ammeter. A current reading of all three phases should be taken, if currents are balanced, it is practical to presume that the voltages are balanced. If currents are unbalanced, it can be assumed that voltages are unbalanced, or that there is an improper connection inside the motor.

A simple test will determine whether current unbalance is the result of voltage unbalance, or caused by problems in the motor itself. Line leads and motor terminal leads are identified, and a current check is taken of each line lead. Motor terminals are then rotated in such a manner that direction of motor rotation is preserved. Another, current reading is taken of each line. if the high-reading line remains the same as on the first check, then the problem is one of voltage unbalance. If the high-reading line is observed on another line, then the problem is internal to the motor or is in its connections.

If it is determined that the problem is one of voltage unbalance, the next step is to find out what caused the unbalanced condition. These are some of the causes:

1. Unequal loading per phase on the transformer serving the motor;
2. Single phasing, such as would be caused by a blown fuse on the primary of the transformer serving the motor;
3. Unequal transformer tap settings;
4. Unequal transformer impedances (impedances can range from 1.6 to 6 per cent);
5. Capacitor banks with fuse blown or with unequal capacity per phase;
6. Voltage regulators out of step or calibration;
7. Transformer bank connected in configuration that inherently provides poor regulation, such as open delta or T-T connection.

Of these, the most common items are 1 and 2. Item 2 (open phase) can be quite difficult to detect if a high percentage of the load connected to the transformer secondary is rotating equipment, in such cases, the open phase may remain at approximately full potential.

Motor insulation tests (documented in AIEE Specification 510 and IEEE 117) show that 10 per cent increase in insulation temperature over design temperature cuts motor insulation life in half. And, as pointed out in NEMA Standard MG 1-14.33, voltage unbalance of only 3.5 per cent will cause an increase in temperature rise of about 25 per cent.

Examination of the winding of a motor that has failed because of voltage unbalance will reveal a failure pattern typical of single-phasing—a condition diagnosed as the cause of many motor winding failures. If investigation reveals that single-phasing did not occur, the failure is often attributed to a faulty motor.

One electric utility reports that among its customers there were 300 confirmed cases of motor burnouts caused by single phasing or voltage unbalance within a one-year period. Because large industrial plants seldom report motor failures to the utility company, it follows that the reports of failure came from operators of commercial buildings and small plants which do not have their own electric department. Such users usually have a large proportion of single-phase load—such as lighting—in proportion to the balanced 3-phase load drawn by 3-phase motors. Uneven loading is quite likely in such operations. It is probable that the majority of the motors failing in a single-phasing type pattern actually failed because of voltage unbalance.

Even when voltage unbalance is suspected as tile cause of a high motor mortality rate, it is difficult to detect because of its erraticism, in such cases, a 3-phase recording ammeter can be a valuable tool in determining if unbalance is, in fact, the problem.

In the past, two overload protectors were usually considered adequate for most motor applications. Three-phase protection was usually provided only in the following types of situations:

1. Motor is in isolated, inaccessible, or unattended location.
3. Wye-delta or delta-wye transformer supplies the motor.
4. Transformer connections are unknown.
5. Motors are operated in parallel with other motors, which might cause circulating currents or permit sustained operation under single-phasing conditions.
6. Local electrical codes require three overload protective elements.

"With the new National Electrical Code, 3-phase protection will be provided on all new motor installations, and eventually, motor starters with only two protectors will become rare. it is, therefore, advisable to review existing motor circuits in terms of retrofitting them with an additional protector. Its cost is only a fraction of total cost of the motor and control. End

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Simple test determine whether current unbalance or motor problem is cause of voltage unbalance. In (a), line current-readings are taken of each phase. In (b) and (c) motor terminal connections have been rotated in a manner that motor direction of rotation remains unchanged. In (b), the same readings prevail as were read for the test connection in (a), indicating that the problem is caused by unbalanced line voltages. In (c), the highest-reading phase has shifted, indicating that the problem is in the motor connections or the motor.