Energy Tips – Motor

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Industrial Technologies Program

Improve Motor Operation at Off-Design Voltages

Motors are designed to operate within +/- 10% of their nameplate rated voltages. When motors operate at conditions of over- or under-voltage, motor efficiency and other performance parameters are degraded.

There are certain standard utilization voltages for motors. These correspond to (but are about 4% lower than) standard service voltages. The 4% difference was established to allow for a reasonable line voltage drop between the transformer secondary and the point of use (see Table 1).

Table 1. Standard Motor Operating Voltages (Volts)

Service Voltage	208	240	480	600	2400	4160
Utilization Voltage	200	230	460	575	2300	4000

Motors sometimes come in multivoltage ratings. The different voltages are accommodated by making different connections in the motor terminal box. For 1:2 ratios like 230/460, the connections change coil groups from parallel to series. For 1:1.73 like 2300/4000, the connections change coil groups from delta (for the lower voltage) to wye (for the higher voltage). There is no difference in performance at the different voltage ratings because the different connection compensates to put exactly the same total current through each winding turn. Tri-voltage motors (208-230/460 V) are designed to produce rated torque at each voltage, but will slip more and operate hotter at 208 volts than at 230 or 460 volts.

What Happens to Motor Performance when Voltage Varies?

With reduced voltage, torque capability is reduced over the whole accelerating range from initial start to stabilization at running speed. This reduces a motor's ability to break loose a stuck load and increases acceleration times. Running speed stabilizes at only a fraction of a percent lower than normal but the breakdown torque is reduced, meaning the motor has less ability to drive through a brief torque overload without stalling. Low voltage caused by high system impedance is exacerbated during starting and acceleration when the current is four to eight times nameplate full-load levels.

Power factor improves with under-voltage. This might be seen as a benefit except the reduction in reactive current is more than nullified by the increase in the total current necessary to deliver the real power at reduced voltage. Higher currents lead to increased resistance and power losses (I^2R), reduced motor efficiency, and possible overheating.

Slip and starting torque vary as the square of the voltage deviation. Slip is the difference between a motor's actual speed and synchronous speed. Synchronous speed is always 7200 RPM divided by the pole count, e.g. 3600 (2-poles), 1800 (4-poles), 1200 (6-poles), 900 RPM (8-poles), etc. The actual synchronous speed is always the lowest possible synchronous speed above the nameplate full-load speed. For example, the synchronous speed for a 1750 RPM motor is 1800 and the slip is 50 RPM. Running this motor at 10% over-voltage would increase the power draw for centrifugal fans and circulating pumps by around 1.5% because their power requirement is sensitive to speed.

Suggested Actions

The best motor performance occurs when power supplied to the motor terminals is close to the nominal utilization voltage. To ensure efficient motor performance, use the following tips to correct for over- or under-voltage and voltage unbalance.

- If voltage does not vary much, but is constantly too high or too low, change to a different main service transformer tap setting. Adjust branch or secondary transformer tap settings as necessary.
- If daily voltage variation occurs at the service entrance, an "auto-tap-changer" transformer is recommended. This can be provided by the customer or the utility.
- If voltage is constant at the service entrance, but varies within the facility due to load variations and distance from the transformer, conductor and/or in-plant transformer losses are excessive. Replace existing conductors with larger ones or add parallel conductors. Replace old, inefficient, or undersized transformers if they are the cause.
- For a single motor attached to a conventional motor starter, low power factor is usually corrected by installing capacitors attached to the load-side terminals of the motor starter. Correcting power factor at the points of use will reduce system current and associated voltage drop.
- When using a motor with an adjustable speed drive (ASD), the drive can compensate for voltage discrepancies as long as the input voltage is within the operating range of the drive. The drive's capacitors correct for low power factor.
- Have your service center rewind motors for the actual utilization voltage. At the same time, they can evaluate the design for other possible ways to improve reliability and efficiency.

Full load efficiency is at maximum between nominal voltage and about 10% over-voltage. However, at reduced load the best efficiency point shifts considerably toward lower voltages.

Sometimes low voltage only occurs at remote areas of a facility where high loads are concentrated. In new construction, or where correction of severe voltage drop is necessary, it may be practical to run medium voltage (>600 to 6600 volts) distribution lines to the remote areas. At medium voltage, even with dramatically reduced conductor cross section, the voltage drop and power losses are usually held to well under 1%. The medium voltage can be transformed down near the points of use, or the equipment can be driven by medium voltage motors. Standard medium voltage motors are available as small as 100 hp.

Resources

U.S. Department of Energy—For additional information on ways to improve motor efficiency by improving the voltage supplied to the motor terminals, refer to the DOE Motor Tip Sheet # 7: *Eliminate Voltage Unbalance*. Find this tip sheet and additional information or resources on motor and motor-driven system efficiency improvement measures on the BestPractices Web site at www.eere.energy.gov/industry/bestpractices, or contact the EERE Information Center at (877) 337-3463.

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