Energy Tips – Motor Systems

Suggested Actions

- Regularly monitor voltages at the motor terminals to verify that voltage unbalance is maintained below 1%.
- Check your electrical system single-line diagrams to verify that single-phase loads are uniformly distributed.
- Install ground fault indicators as required and perform annual thermographic inspections. Another indicator that voltage unbalance may be a problem is 120 Hz vibration. A finding of 120 Hz vibration should prompt an immediate check of voltage balance.

Resources

National Electrical Manufacturers Association (NEMA)—Visit www.nema.org for additional information on voltage imbalance.

U.S. Department of Energy—DOE's *MotorMaster+* and *MotorMaster+ International* software tools help you make motor comparisons and selection on a broad range of motors.

Visit the BestPractices Web site at www.eere.energy.gov/industry/bestpractices to access these and many other industrial energy efficiency resources and training.

Eliminate Voltage Unbalance

Voltage unbalance degrades the performance and shortens the life of a three-phase motor. Voltage unbalance at the motor stator terminals causes phase current unbalance far out of proportion to the voltage unbalance. Unbalanced currents lead to torque pulsations, increased vibrations and mechanical stresses, increased losses, and motor overheating, which results in a shorter winding insulation life.

Voltage unbalance is defined by the National Electrical Manufacturers Association (NEMA) as 100 times the absolute value of the maximum deviation of the line voltage from the average voltage on a three-phase system, divided by the average voltage. For example, if the measured line voltages are 462, 463, and 455 volts, the average is 460 volts. The voltage unbalance is:

$$\frac{(460 - 455)}{460} \times 100 = 1.1\%$$

It is recommended that the voltage unbalances at the motor terminals not exceed 1%. Unbalances over 1% require derating of the motor per Figure 20-2 of NEMA MG-1-2003, Revision 1-2004, and will void most manufacturers' warranties. Common causes of voltage unbalance include:

- Faulty operation of power factor correction equipment.
- Unbalanced or unstable utility supply.
- Unbalanced transformer bank supplying a three-phase load that is too large for the bank.
- Unevenly distributed single-phase loads on the same power system.
- Unidentified single-phase to ground faults.
- An open circuit on the distribution system primary.

The efficiency of a rewound, 1800-RPM, 100-hp motor is given as a function of voltage unbalance and motor load in the table. The general trend of efficiency reduction with increased voltage unbalance is observed for all motors at all load conditions.

Motor Efficiency* Under Conditions of Voltage Unbalance

Motor Load % of Full	Motor Efficiency, %		
	Voltage Unbalance		
	Nominal	1%	2.5%
100	94.4	94.4	93.0
75	95.2	95.1	93.9
50	96.1	95.5	94.1

* Results vary depending upon motor design, speed, full-load efficiency, and horsepower rating. Typically, electric motors have peak efficiency near 75% load, but the above motor tested in the lab showed otherwise.

Voltage unbalance is probably the leading power quality problem that results in motor overheating and premature motor failure. If unbalanced voltages are detected, a thorough investigation should be undertaken to determine the cause. Energy and dollar savings occur when corrective actions are taken.

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Example

Assume that the motor tested as shown in the above table was fully loaded and operated for 8,000 hours per year, with an unbalanced voltage of 2.5%. With energy priced at $0.05/kWh, the annual energy and dollar savings, after corrective actions are taken, are:

Annual Energy Savings = 100 hp x 0.746 kW/hp x 8,000 hrs/yr x (100/93 – 100/94.4) = **9,517 kWh**

Annual Dollar Savings = 9,517 kWh x $0.05/kWh = **$476**

Overall savings may be much larger because an unbalanced supply voltage may power numerous motors.

Further Considerations

Voltage unbalance causes extremely high current unbalance. The magnitude of current unbalance may be 6 to 10 times as large as the voltage unbalance. For the 100-hp motor in this example, line currents (at full-load with 2.5% voltage unbalance) were unbalanced by 27.7%.

A motor will run hotter when operating on a power supply with voltage unbalance. The additional temperature rise is estimated with the following equation: Percent additional temperature rise = 2 x (% voltage unbalance $)^2$. For example, a motor with a 100°C temperature rise would experience a temperature increase of 8°C when operated under conditions of 2% voltage unbalance. Winding insulation life is reduced by one-half for each 10°C increase in operating temperature.

References

Information in this tip sheet is extracted from *NEMA Standards Publication MG-1-2003, Motors and Generators, 2003*.

About DOE's Industrial Technologies Program

The Industrial Technologies Program, through partnerships with industry, government, and non-governmental organizations, develops and delivers advanced energy efficiency, renewable energy, and pollution prevention technologies for industrial applications. The Industrial Technologies Program is part of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy.

The Industrial Technologies Program encourages industry-wide efforts to boost resource productivity through a strategy called Industries of the Future (IOF). IOF focuses on the following eight energy and resource intensive industries:

- Aluminum
- Forest Products
- Metal Casting
- Petroleum
- Chemicals
- Glass
- Mining
- Steel

The Industrial Technologies Program and its BestPractices activities offer a wide variety of resources to industrial partners that cover motor, steam, compressed air, and process heating systems. For example, BestPractices software can help you decide whether to replace or rewind motors (MotorMaster+), assess the efficiency of pumping systems (PSAT), compressed air systems (AirMaster+), steam systems (Steam Scoping Tool), or determine optimal insulation thickness for pipes and pressure vessels (3E Plus). Training is available to help you or your staff learn how to use these software programs and learn more about industrial systems. Workshops are held around the country on topics such as "Capturing the Value of Steam Efficiency," "Fundamentals and Advanced Management of Compressed Air Systems," and "Motor System Management." Available technical publications range from case studies and tip sheets to sourcebooks and market assessments. The Energy Matters newsletter, for example, provides timely articles and information on comprehensive energy systems for industry. You can access these resources and more by visiting the BestPractices Web site at **www.eere.energy.gov/ industry/bestpractices** or by contacting the EERE Information Center at **877-337-3463** or via email at **www.eere.energy.gov/informationcenter/.**

BestPractices is part of the Industrial Technologies Program Industries of the Future strategy, which helps the country's most energy-intensive industries improve their competitiveness. BestPractices brings together emerging technologies and best energy-management practices to help companies begin improving energy efficiency, environmental performance, and productivity right now.

BestPractices emphasizes plant systems, where significant efficiency improvements and savings can be achieved. Industry gains easy access to near-term and long-term solutions for improving the performance of motor, steam, compressed air, and process heating systems. In addition, the Industrial Assessment Centers provide comprehensive industrial energy evaluations to small- and medium-size manufacturers.

FOR ADDITIONAL INFORMATION, PLEASE CONTACT:

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