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Predictive maintenance (PdM) techniques are commonly used on motors and drives. But how often is the power to the equipment inspected? Adding basic power quality measurements to equipment maintenance procedures can head off unexpected failures in both the equipment and the power system.

## **Cost savings**

Insurance claims data in the NFPA 70B maintenance standard show that roughly half of the cost associated with electrical failures could be prevented by regular maintenance. A study published in IEEE 493-1997 says that a poorly maintained system can attribute 49 percent of its failures to lack of maintenance.

To determine the cost of a failure, it helps to consider three key categories:

- · Lost income (gross margin) due to downtime
- Cost of labor to troubleshoot, patch, clean up, repair, and restart

• Cost of damaged equipment and materials, including repairs, replacements, and scrapped material.

# Integrating power quality into PdM

Unlike a comprehensive electrical system survey, predictive maintenance power quality focuses on a small set of measurements that can predict power distribution or critical load failures. By checking the power quality at critical loads, the effect of the electrical system up to the load can be seen. Predictive maintenance inspection routes probably already include motors, generators, pumps, A/C units, fans, gearboxes, or chillers on site.

Voltage stability, harmonic distortion, and unbalance are good indicators of load and distribution system health and can be taken and recorded quickly with little incremental labor. Current measurements can identify changes in the way the load is drawing. All of these measurements

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can be taken without halting operations and generate numbers that can easily be entered into maintenance software and plotted over time.

For each measurement point or piece of equipment, determine what limit should trigger corrective action. Limits should be set well below the point of failure, and as time goes on limits may be tightened or loosened by analyzing historical data. The appropriate limits depend somewhat on the ability of the loads to deal with power variation. But for most equipment, the maintenance team can devise a set of house limits based on industry standards and experience.

# Voltage

Good voltage level and stability are fundamental requirements for reliable equipment operation.

• Running loads at overly high or low voltages causes reliability problems and failures. Verify that line voltage is within 10 percent of the nameplate rating.

• As connections in the system deteriorate, the rising impedance will cause insulation resistance drops in voltage. Added loads, especially those with high inrush, also will cause voltage decline over time. The loads farthest from the service entrance or transformer will show the lowest voltage.

• Neutral to ground voltage indicates how heavily the system is loaded and helps track harmonic current. Neutral to ground voltage higher than 3 percent should trigger further investigation.

# Voltage sag count

Taking a single voltage reading tells only part of the story. How is the voltage changing during an hour? During a day? Sags, swells, and transients are short-term variations in voltage. The voltage sag (or dip) is the most common and troublesome variety.

Voltage sags are momentary reductions in rms voltage from 1 cycle to 2 minutes. Loads may be added without notifying plant management, and these loads may draw down system voltage, especially if they draw high inrush currents. Also, as electrical systems age, the impedance of

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the system may increase, making the system more prone to voltage sags.

Sags indicate that a system is having trouble responding to load requirements; significant sags can interrupt production. Voltage sags can cause spurious resets on electronic equipment such as computers or controllers, and a sag on one phase can cause the other two to overcompensate, potentially tripping the circuit.

Sags have several dimensions: depth, duration, and time of day. Utilities use a special index to track the number of sags that occur over a period of time. To gauge the depth of the sags, they count how often voltage drops below various thresholds.

The longer and larger the voltage variations, the more likely equipment is to malfunction. For example, the Information Technology Industry Council (ITIC) curve specifies that 120 V computer equipment should be able to run as long as voltage does not drop below 96 V for more than 10 seconds or below 84 V for more than 0.5 sec.

The main cost factors of voltage sag are lost income due to computer reset, control system reset, variable frequency drive (VFD) trip, and shortened life of a backup power system's uninterruptible power system (UPS) due to frequent cycling.

For example, assume a voltage sag causes a VFD on a conveyor system to trip offline at least once a year. No income is permanently lost, but 10 hourly workers have to work 4 hr to make shipments at \$30/hr, which includes overtime. Added labor = 10 people X 4 hr X \$30/hr = \$1200 annually

Motors, VFDs, UPSs, panels, or power distribution units (PDU) serving computer equipment or industrial controls should be checked for voltage sag.

How much voltage sag can be tolerated? Most loads will operate at 90 percent of nominal voltage. The ITIC curve suggests that single-phase computer equipment loads should be able to ride through drops to 80 percent of nominal for 10 sec and 70 percent of nominal for 0.5 sec.

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### Increasing current

Current measurements that trend upward are a key indicator of a problem or degradation in the load. While equipment is running, monitor phase, neutral, and ground current over time. Make sure none of the currents are increasing significantly, verify that they are less than the nameplate rating, and keep an eye out for high neutral current, which can indicate harmonics and unbalance.

As insulation deteriorates it begins to leak. Loads will draw slightly higher current as they age and they may send some of this leakage current into the grounding system. Faults within the equipment also may cause high ground current. The best way to check insulation is by periodically checking equipment with an insulation tester. But equipment also can be checked while it is in service by monitoring all of the currents (phase, neutral, and ground) to make sure none of these is increasing significantly over time.

Excessive phase currents can further damage insulation and overheat the load, resulting in a shortened life of the load. Overcurrent will cause protection devices to trip, resulting in unscheduled downtime. Excessive ground current can create unsafe voltages on metal chassis, cabinets, and conduit.

Any critical load, but especially motors, VFDs, and transformers, should be checked for increasing phase current.

Costs come from premature motor failure and lost income due to overcurrent protection devices tripping. As an example, assume the failure of a pump motor each year costs \$7000 to replace and causes a \$2,500,000/yr continuous process to be shut down for 10 hr. Assume it takes two people 6 hr to clean and restart the process at \$50/hr each.

Lost income = 10 hr X (\$2,500,000/(365 days/yr X 24 hr/day)) = \$2853

Motor replacement = \$7000 Clean and restart = \$600 Total cost = \$10,453 annually Written by MT Staff Sunday, 01 May 2005 00:00

The nameplate rating of the load should never be exceeded. If the phase current being drawn by a load is tracked over months or years, a change in the current should be evident.

### Voltage unbalance

In a three-phase system, significant differences in phase voltage indicate a problem with the system or a defect in a load. Voltage unbalance can cause three-phase motors and other three-phase loads to experience poor performance or premature failure because of mechanical stresses in motors due to lower-than-normal torque output, higher-than-normal current in motors and three-phase rectifiers, and unbalance current will flow in neutral conductors in three-phase wye systems.

Unbalance is tracked in percentages. The negative sequence voltage (Vneg) and zero sequence voltage (Vzero) together identify any voltage asymmetry between phases. Using a power quality analyzer to do the math, high percentages indicate high unbalance. European Union power quality standard EN50160 requires Vneg to be less than 2 percent.

The major costs resulting from voltage unbalance are associated with motor replacement (labor and equipment) and lost income due to circuit protection trips.

For example, assume the cost to replace a 50 hp motor each year is \$5000 including labor. Assume 4 hr of downtime per year with income loss of \$6000/hr.

Total cost: \$5000 + (4 X \$6000) = \$29,000 annually

The EN50160 standard requires voltage unbalance, as a ratio of negative to positive sequence components, to be less than 2 percent at the point of common coupling. NEMA specs call for less than 5 percent for motor loads. Consult user manuals for other equipment.

## Voltage harmonic distortion

Harmonic distortion is a normal consequence of a power system supplying electronic loads

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such as computers, business machines, electronic lighting ballasts, and control systems. Adding or removing loads from the system changes the amount of distortion, so it is a good idea to regularly check harmonics.

Harmonics cause heating and reduced life in motor windings and transformers, excessive neutral current, increased susceptibility to voltage sags, and reduced transformer efficiency.

As current harmonics interact with impedance, they are converted into voltage harmonics. Total harmonic distortion (THD) is a sum of the contributions of all harmonics. Tracking voltage THD over time will help determine if distortion is changing. For voltage harmonics, IEEE 519 recommends less than 5 percent THD.

Harmonic distortion can cause:

- High current to flow in neutral conductors.
- Motors and transformers to run hot, shortening their lives.
- Increased susceptibility to voltage sags, potentially causing spurious resets.
- Reduced efficiency of transformer or a larger unit is required to accommodate harmonics.

• Audible noise.

The major costs of harmonic distortion are associated with shortened life of motors and transformers. If the equipment is part of production systems, income may be affected as well.

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For example, assume the cost to replace a 100 kVA transformer is \$7000 including labor each year. Assume 8 hr of downtime each year with income loss of \$6000/hr.

Total cost: \$7000 + (8 X \$6000) = \$55,000 annually

Motors, transformers, and neutral conductors serving electronic loads should be checked for harmonics. Voltage distortion should be investigated if it is more than 5 percent on any phase. Some current distortion is normal on any part of the system serving electronic loads. Monitor current levels and temperature at transformers to be sure they are not overstressed. Neutral current should not exceed the capacity of the neutral conductor.

These measurements can help uncover hidden costs, protect equipment from damaging conditions, reduce unscheduled downtime, and improve systems performance.

Information supplied by <u>Wade Thompson</u>, power quality specialist, <u>Fluke Corp</u>., P.O. Box 9090, Everett, WA 98206; (800) 443-5853

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