



**FLUKE®**

# **REDUCE COSTS BY FIXING ELECTRICAL AND MOTOR PROBLEMS IN FACTORIES**

A complete outline of maintenance procedures

*Keeping your World up and Running.®*



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# Reduce costs by fixing electrical and motor problems in factories

Virtually all energy waste ends up as heat, and the higher the temperature the greater the waste and the greater the chance of equipment failures. New electrical components begin to deteriorate as soon as they are installed – with fatigue, age, vibration and environmental conditions helping loosen and corrode electrical connections. Simple faults can bring down an entire production line. Even simply replacing a fuse can take half an hour. Lost production alone can in some industries cost as much as US \$1,000 per minute, and elsewhere failure in even a relatively small component can mean losing a whole production batch.

Motors making billions of revolutions over their lifetime are particularly susceptible. There are several main reasons for overheating: poor cooling, too many stops/starts, overload and overvoltage, and poor power quality – particularly unbalance and distortion. Even a small voltage unbalance can cause excessive motor current, which eventually returns on the low-resistance neutral connector of your power system, and that can itself increase the risk of fire.

## Best practice maintenance

All these problems can be detected early by a regular [predictive maintenance](#) round. Detecting and correcting failing connections avoids shutdowns, dangerous machine conditions and fires. Visual inspection is not enough, though. Thermal analysis shows operating temperatures, and therefore energy waste if those are above design values. That energy waste has a cause and, where this is not immediately obvious, other instruments can track it down.

Maintenance is all about best practice (with the most important aspect being safety, see our [application note](#)).



The exact order of actions will depend on what equipment and instruments you have, but we outline the procedures in the rough order you will need them. First comes the data gathering and then deciding your plan of attack. With experience, you can decide on normal operating temperature ranges with an upper limit as an “alarm”. Prioritize repairs first by safety risk, criticality of the equipment, and temperature rise. After you’ve done the repairs you check they’ve worked and that all the updated information is in the system.

## Content of the white paper

[Section 1](#) of this white paper covers the overall order to tackle things. A thermal imager ([1.1](#)) is the best general-purpose front-line maintenance instrument. Collecting thermal signatures of equipment with imagers during installation and service also gives a baseline to check for later overheating and to check that repairs have been successful. After the thermal inspection, an insulation resistance meter (megohmmeter, [1.2](#)) can instantly check insulation quality of your windings. A vibration analyzer ([1.3](#)) can pinpoint motor faults. A power quality analyzer ([1.4](#)) can show harmonics and other power quality problems. A handheld scope can show the key signals, and any intractable problems are likely to be intermittent with an energy logger serving as a final catch-all ([1.5](#)).

The actual maintenance routines depend on what equipment you have in the factory. [Section 2](#) covers how to trace the most common electrical ([2.1](#)) and motor (electro-mechanical, [2.2](#)) faults. Motors are particularly important because there are so many of them in an average factory, and they drive a huge amount of equipment like fans, pumps and compressors. Equipment like transformers, vats and tanks also need inspecting ([2.3](#)).

[Section 3](#) covers maintenance and energy waste ([3.1](#)), and how to deal with faults that have no obvious causes ([3.2](#)). At the end of the white paper, we’ve collected some references ([Section 4](#)) and a glossary ([Section 5](#)). Separate panels give the key requirements for the instruments.





### **Instruments – choose with care**

Readings need to be accurate and repeatable, and instruments must be safe, reliable and robust. Initial capital costs are less important than how much an instrument will save over its lifetime. Quality and robustness are worth paying extra for. And yes with Fluke's reputation for reliability "we would say that wouldn't we", but if you drop an instrument and it alters subsequent readings that will send you looking for faults that aren't there or, worse, not send you looking for faults that are there.

## **1. What to look for and what you will need**

### **1.1 The thermal imager as a front-line tool**

Good system design and commissioning is critical, since faults like under-sized conductors and components and loose connections can often cause later failures. Motors should not be run above the design temperature or other maximum ratings. Every increase of 10 °C on a motor's windings above its design operating temperature cuts the life of its windings' insulation by 50%, even if the overheating is only temporary.

[Thermal imagers](#) don't eliminate the need for conventional inspection and testing to check for electrical safety – that should be done every five years or less. And bear in mind that a device's temperature—even its relative temperature—may not always be the best indicator of how close it is to failure. Other factors include changes in ambient temperatures and mechanical or electrical loads, visual indications, the criticality of components, histories of similar components and measurements from other tests. Thermography is best as part of a comprehensive condition monitoring and predictive maintenance program.

### **Go for a structured approach**

Predictive maintenance should give time to schedule repairs before you get failures. Particularly if the technician doing the inspecting will not be doing the repairs, documentation needs to be complete, with both thermal and digital images of all key equipment. Past experience of plant personnel is helpful, with any recent changes to electrical systems that might be causing problems.

Servicers need to know the basic operation and heat flow characteristics of machinery, and understand heat related

failure mechanisms. They should observe the machinery during startup, operation and cool down. When inspecting, the system should preferably be under "worst case" or peak loads, but at least 40% loading (according to NFPA 70B). Check the motor operating temperatures and currents on the nameplate. If you have to inspect with low loads, then note all temperature differences, even if only small.

Wherever possible, enclosures should be opened to show the circuits (but only by authorized and qualified personnel using the appropriate Personal Protective Equipment – see our [fire-risk application note](#) and our [safety video](#), particularly the testimony starting at 11:45). If that is not possible, look for slightly raised surface temperatures of cabinets, since they usually mean much higher temperatures inside.

Look for hot spots and different temperatures in similar units operating under similar conditions. Be aware, though, that winds or air currents can sometimes reduce surface temperatures and mask issues. Shiny connections and contacts can reflect infrared energy from nearby objects, which can interfere with temperature measurement. Dirty equipment can also interfere with accuracy.

Unbalanced loads, overloads, bad or undersized connections, and harmonic imbalance can all create a similar pattern – you need to measure the electrical load to diagnose the problem. A cool circuit or leg might similarly signal a failed component.

### What to look for – thermal imagers

Unless you will be inspecting small, complicated components or have very heat sensitive applications, you very likely do not need the top models. High resolution screens and images look nicer and are more impressive, but they add to the price. You will however need enough accuracy, adjustable emissivity (to allow for how well the object under view emits the heat), and level control and span control. Thermal imagers also need sharp auto-focusing (out of focus images can be up to 20°C in error.) with auto-blending of infra-red and visual images to pinpoint the exact problem. Voice annotation frees you from having to take written notes.

For basic imagers, the user manual and some form of interactive training will often be enough. Medium to high end imagers are more complicated and should include at least two days of good in-person training. Software should let you document your measurements easily. Check whether software is included in the price, whether future updates are free of charge, and whether you have to buy licenses for multiple team members.

Basic instrument specs of course need to be good enough to show faults. The Fluke Ti400 for example measures -20 °C to +1200 °C with an accuracy of 2° or 2% depending on temperature and thermal sensitivity of  $\leq 0.05$  °C. It has a 320 x 240 detector and 640x480 display.



*Fluke Ti400 Thermal Camera*

### Imminent failure is a red alert

Treat imminent failure of any piece of critical equipment as a red alert. NETA (InterNational Electrical Testing Association) guidelines recommend immediate repairs of components unexpectedly 40 °C or more above ambient, and similar components under similar conditions where temperature differences exceed 15 °C (27 °F). Thermal mirrors (like a clean 3-mm aluminum sheet) can show temperatures of hard to reach equipment like motors or gearboxes mounted on the top of a machine. This will show comparative readings rather than true temperature readings, though.

Thermal-analysis based predictive maintenance saves downtime and money. Many faults involve positive feedback effects that quickly lead to failures: overheated components for example further reducing the insulation resistance of wires, contamination further corroding connections, and vibrating components further loosening connections.

When a piece of equipment fails the first impulse is to get a production line up and running again, but you still need to try to find what caused the failure. Visual inspection

should look for clues like discoloration or charring, and you'll need to work from what measurements you can take. Without thermal analysis, you have much less to go on, though. It can highlight many potential problems, and even though infrared cameras only measure the exterior surface temperature, that indicates the internal temperature. Other instruments are often needed to determine the precise cause of failure.

### 1.2 Measuring insulation resistance

For new installations, [insulation testers](#) are invaluable for proof tests of wiring errors and insulation damage. The tester generates a known dc voltage of say 1 kV and measures the leakage current from the conductor through the insulation to calculate the resistance. It detects potentially catastrophic phase-to-phase or phase-to-ground faults on start-up. An initial insulation resistance value of sometimes 1,000 MΩ plus at start of life can drop rapidly with over-temperature (Figure 1), and it should be regularly checked.

Before doing ANY insulation resistance testing, you **MUST** isolate any electronic controls and other devices from the circuit under test.

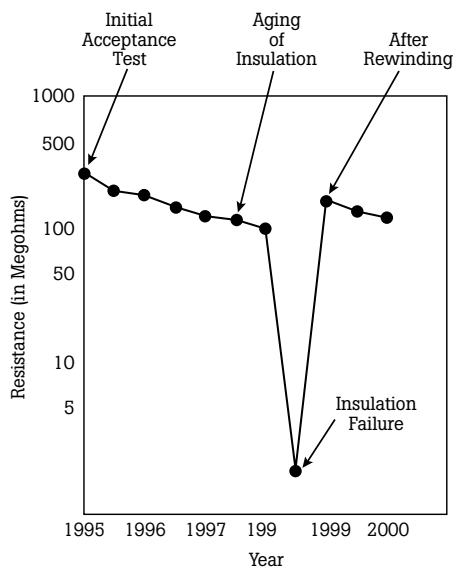
### What to look for – Insulation resistance meters

Some larger motors have in-built insulation meters. Alternatively, an insulation resistance tester with combined multimeter can perform most tests you need to troubleshoot and maintain cables, switchgear, generators and motors. Insulation multimeters take basic supply measurements and contact temperatures. An extra safety feature is to detect live circuits; another is to automatically discharge the residual voltage after the test.

The Fluke 1587 performs insulation tests up to 1 kV and adds an RMS digital multimeter. It combines them with capacitance, diode and continuity tests and temperature measurements. There is a low-pass filter for work on VSDs.



Fluke 1587 Insulation Multimeter



**Figure 1:** Every six months, measure resistance of each winding to ground and record the reading.

Be careful when interpreting readings that are different – these may be down to differences in temperature and humidity because resistance decreases as temperature and humidity increase. Insulation resistance doubles for every 10 °C decrease in temperature, so measure both temperature (with the thermal imager) and humidity.

### 1.3 Vibration analysis for bearings and misalignment

Vibration analysis is a key element of predictive maintenance. [Vibration analyzers](#) should show the vibration spectrum of the three axes (preferably simultaneously), at each end of the motor and equipment being driven. Three sweeps are needed with single-axis instruments, since some faults produce vibration in a single axis only. Vibration equipment is relatively expensive and should not miss faults because the operator does not have time to do a thorough analysis.

### What to look for - vibration meters

Vibration meters should cover a wide frequency range (up to 20 kHz will cover most applications). Accuracy of measured frequency is particularly important because it is the frequency that will suggest a fault cause. Readings from probes can depend on how hard they are pressed and at which angle, and the meter should compensate for this. Different severity levels (like good, satisfactory, unsatisfactory, unacceptable) help prioritize repairs.

Entry-level instruments like Fluke's 805 measure overall vibration as well as specific variables like bearing condition and temperature. More advanced, the 810 asks for basic machine information. It then identifies the root cause, its location, and how severe it is. It identifies and locates bearing faults, misalignment, unbalance and looseness. Repair recommendations advise technicians on corrective action. A laser tachometer measures accurate machine running speeds.



Fluke 805 Vibration Meter



The individual frequencies in a motor's vibration signature are often multiples of the rotation speed and often themselves point to defective bearings, bent shafts or loose components. Check the multiples of the rotation speed – not the nameplate speed but the actual running speed, which can be lower. That is important because high frequencies can divide down to be the exact number of stator slots or rotor bars.

Vibration at rotating frequency often points to rotor problems. Bent shafts and poor couplings often appear at double the rotating frequency. Higher multiples can depend on the number of balls in a bearing, and the number of stator slots, rotor bars or fan blades. You therefore need to know exactly how many of each there are. The diameter of the ball bearings, and the circumference of the inner and outer races will also affect the frequency, depending on where the fault is. Any sizeable change in amplitude over the previous maintenance reading should be investigated.

#### 1.4 Analyzing power quality

Mains pollution can cause intermittent lock-ups and resets, corrupted data, premature equipment failure, and overheating of components for no apparent cause. Two major causes of power quality problems are unbalance and harmonic distortion.

##### Unbalance

Even a small voltage unbalance can cause connections to deteriorate. Unbalance can be caused by power delivery problems, low voltage on one leg, or an insulation resistance breakdown inside the motor windings. A motor rotating with imbalance will have lower efficiency and shorter lifetime. It can draw excessive current and deliver lower torque (with associated mechanical stress).

Unbalance voltages can also cause malfunctions in single-phase loads whose voltage is lower or (particularly to be avoided) higher than the load's rated voltage. Unbalance effects can be especially severe when equipment is improperly installed or has failed, or where photovoltaic solar systems are connected to a single phase. The loss due to unbalance current can be reduced by more efficient grouping of the loads or by adding compensation components.

##### Harmonics and transients

Applying a sine-wave voltage to a non-linear load (where the value changes with the voltage applied to it) produces a current that contains harmonic components. The most widespread example of a non-linear load is the rectifier circuit. This is widely used in switched-mode power supplies, variable-speed motor drives, LED and compact fluorescent lights and many other electronic devices.

Transient voltages from lightning strikes, switching motors on and off, and VSD (variable speed drive) operation can be very rapid and many times higher than the line voltage. VSDs are particularly prone to induce magnetic fields and hence currents from stator to shaft and bearings with resultant stresses. This really needs to be addressed at design, by for example matching drive output and motor, and using ceramic bearings, insulated housing, and brushes to ground the shaft. Conductive grease can help, though, as can filtering the VSD output. Harmonic losses can be reduced by either avoiding generating them or by using passive or active filtering.

Harmonics and/or unbalance can also cause neutral currents, which can be cured by filtering the harmonics and balancing the loads. Circuits containing capacitance and inductance can additionally have one or more resonant frequencies, which can trip an electrical power system.

#### What to look for – power quality analyzers

[Power quality meters](#) should ideally capture voltage, current and frequency of signals simultaneously. They should capture voltage sags, transients and inrush current. And they should measure power, harmonics and possibly the efficiency of inverters. Power quality meters will also repay by reducing energy losses and helping to avoid utility penalty charges from breaching power-factor limits.

The Fluke 430 Series II power quality analyzer performs electrical load analysis, and power quality logging and analysis according to EN 50160. It separates out the losses you are suffering, and estimates how much each is costing.



Fluke 435 II Power Quality and Energy Analyzer

### 1.5 Finding hidden faults with oscilloscopes and loggers

Some faults will need you to see the signals, noise or other disturbances that lead up to them. A handheld scope will show you signal amplitude, time, shape and disturbance or distortion characteristics. Inspecting input signals, output feedback loops or safety interlocks simultaneously can find problems like voltage and current overload, signal timings and synchronization issues, attenuation/input impedance mismatch and signal fluctuation and drift.

Handheld scopes can check for harmonics, transients and loads at the three-phase power input. They can troubleshoot dc to ac converters for faulty IGBT gates

or filter circuits, and test Pulse Width Modulation (PWM) outputs for reflections and transients or voltage unbalance.

#### Intermittent faults

Intermittent faults can be caused by dust, dirt, corrosion, or bad or broken wiring and connections. Line outages, sags, or starting and stopping a motor can also cause problems. Energy loggers can capture these and other disturbances, and show when and where energy is being consumed. You can compare multiple data points over time and build a picture of energy usage.

A multimeter with a clamp (clamp meter) can be used instead of a power quality analyzer as a “first line tool” to check current balance and loading on each phase.

#### What to look for – handheld oscilloscopes and energy loggers

**Handheld scopes** can have many of the features of bench scopes. They have two or four channels along with automatic measurements and features like **auto-trigger**, **single shot** and **pulse width** triggering. A deep **memory** will allow you to examine very small parts of the waveform in detail.

The Fluke 4-channel 190 Series works up to 500 MHz with 10,000 samples per channel. It combines a high performance oscilloscope, multimeter and paperless recorder in one instrument with the highest safety category. It can examine trends for 22 days, so there is some crossover with energy loggers.

**Energy loggers** should have **high sample rate** and **large memory**, and you should be able to store a number of separate logging sessions. They should measure three-phase voltages, currents and power factors – with software to transfer measurements easily.

Fluke’s 1730 has an energy analyzer software package for performing energy surveys and load studies. It can also discover hidden operational waste such lighting, air conditioning and other large loads that could be switched off when not in use.



Fluke 1730 Three-Phase Energy Logger





## 2. Tracking down problems

### 2.1 General electrical circuits

Thermal analysis should examine substations, electrical power distribution, three-phase systems, overhead transmission lines, cable runs, thyristor banks, circuit breakers, switches, fuses, wiring and connections.

Overheating generally comes from high resistance or excessive current flow. Thermal analysis can identify broken or undersized wires, defective insulation, faulty (corroded, too loose or over tightened) connections and electrical unbalance among phases.

Current through high resistance is typically caused by poor switch, plug, fuse or connector contacts. Heat at both ends of the contact suggests overload or undersized components (check the conductor rating and the actual load with a clamp meter) or phase imbalance (use a power quality analyzer). Heat at one end suggests a high contact resistance at the hot end. Excessive current flow can come from overloading or multi-phase imbalance. Where you discover higher temperatures, follow that circuit and examine associated branches and loads. Overheating connections should be disassembled, cleaned, repaired and reassembled.

### 2.2 Motors and associated equipment

Most motor failures are caused by poor installation or a combination of stresses acting on the bearings, windings, rotor and shaft. Excess friction from misalignment, bearings, imbalance, and looseness overworks the motor, consuming excessive power. Irrespective of the cause, many faults end up giving off heat or increasing vibration so thermal analysis and vibration analysis are the best place to start (thermography is better and faster than vibration analysis for smaller, low-speed motors and bearings like those on conveyors, or those that are in physically inaccessible or unsafe locations).

A Pareto chart of motor failures would show the top 60% from overheating (mainly of bearings and then stator windings), and 30% from stator winding insulation failure. The two causes are related, with overheating

quickly degrading insulation. The motor is however only one part of the system. The actual fault may lie in power supply, motor controls, mounting base, drive equipment or the process itself. Key motor components include bus bars, controllers, starters, contactors, relays, fuses, breakers, disconnects, feeders, and transformers.

### The general approach

The [general order](#) is a visual inspection followed by a check of the control contacts. Then measure the insulation resistance of line and load circuits to ground, and the winding insulation resistance phase to phase and phase to ground. In general, line voltage should be within 10% of the nameplate rating. Neutral-to-ground voltage tells you how heavily your system is loaded and helps you track harmonic current. Neutral-to-ground voltage higher than 3% of line-to-line voltage should trigger further investigation. Loads do however change during normal operation. A phase can suddenly be 5% lower on one leg if a large single-phase load comes online.

Voltage drops across the fuses and switches can also show up as unbalance at the motor and excess heat at the root trouble spot. Neither feeder nor branch circuits should be loaded to the maximum limit. The most common solution to overloading is to redistribute loads among the circuits, or to manage when loads come on during start up.

### Bearings need special attention

Their relatively small size makes **bearings** vulnerable to wear and damage. Too little lubrication, too much lubrication, contamination, defective seats, rotor misalignment and currents through the shaft and bearings can all reduce bearing lifetimes.

Lubrication should be checked against guidelines for amount and frequency of application. Higher bearing temperatures will heat the casing, and this can sometimes be seen on a thermal image, while individual bearing problems will show up with vibration analysis.



### **Winding insulation faults can be particularly expensive**

Although bearing failures are the most common, **winding insulation** failures are much more expensive and time consuming to replace or have repaired (and so result in additional expensive downtime). The fault location can often be narrowed down by whether a thermal imager shows heat on one, two or all three phases. Heat on one phase can mean that the winding is shorted to the motor casing, on two phases suggests a shorted winding, and on three phases could show a bad bearing or partially applied brake.

Mechanical overload is the most common cause of stator winding failures. Mechanical loads should be no greater than the power rating. Motors have commonly been operated at 1.15 service factor (higher than rated horsepower), but this should only be for intermittent overload rather than continuous operation. Run continuously, even that service factor can raise winding temperatures by 20 °C.

### **Watch for overcurrent**

Most important in preventing electrical overload is to keep current values low. Overcurrent is however often unpredictable and sudden. The procedure when checking for a motor trip is generally first to compare the full-load current from the nameplate against the percentage of full-load current at which the overload relay trips. Measure the full-load current through each phase with a clamp meter at the overload relay.

The stator current doesn't always indicate the right cause of a fault, however. It isn't only the value of current that causes overload, it is the losses and they depend on the voltage too. Motors are sometimes run at overvoltage in an attempt to reduce the heat generated. This actually doesn't reduce the heat that much, and can mask possible fault causes. A small overcurrent may not look like a problem, but an overvoltage too can increase the overload to failure levels. High motor currents can come from many other causes including undervoltage, phase issues, too many motor stops and starts, and ground faults.

### **Environmental overload**

Environmental overload can be caused by poor cooling. Dirt can block cooling fans (which should therefore have backup ventilation), ducts and filters. With inadequate airflow, if possible shut off the motor and clean the air intake grills. Schedule a thorough cleaning during the next planned plant shutdown. Inspect temperatures of switchgear, disconnect and connection box and confirm any unbalance using a multimeter, clamp meter or power quality analyzer. Lubricate or replace overheating bearings.

Open casing motors should not be used in dirty environments and it can be worth replacing a failed unit with a totally enclosed motor. Other cooling problems can come from motors working at high air temperatures and at high altitudes.

Moisture – particularly when chemicals are present – can corrode the motor rotor, shaft, bearings and insulation. That can in turn cause vibration, and can cause failures by affecting motor alignment.

### **Rotor failures**

**Rotor** failures can come from the cast rotor end ring, overheated rotor bars, and broken and loose rotor bars. **Shafts** can suffer from rotational bending, impact failure and cracking. The effects of misalignment increase by the cube of the misalignment. Vibration analysis will confirm a misaligned shaft, which can be corrected using laser alignment.

## **2.3 Other equipment**

**Transformers** can have relatively high operating temperatures, and maintenance should refer to relevant standards like NFPA Standard 70B (see also Fluke's [Transformer Application Note](#)). Look at surface temperatures plus the temperature of external connections, cooling tubes, fans and pumps, and bushing connections. Look, too, for unbalance and overloading.

Uneven temperature profiles of **belts and pulleys** can indicate misalignment.



Thermal inspection can also give useful information on **tanks** and their contents, particularly uninsulated metal tanks and heat exchangers like steam radiators (see our [Tanks and Vessels Application Note](#)). It can usefully study heat loss in furnaces and ovens, and process freezers.

### 3 Finding energy savings

#### 3.1 General inspection

Alongside maintaining equipment to prevent faults, the maintenance department is best placed to reduce energy consumption (energy efficient equipment needs to be specified at the design stage, with maintenance then keeping it in peak condition).

Even if thermal images don't show possible failures, they can be interesting for improving energy efficiency – so saving money and CO2 emissions. Heat from poor, missing or damp insulation can easily be retained. Flanges and valves are often left uninsulated but can have a large surface area. They should have insulation jackets that can be fastened, and then unfastened for maintenance.

#### A first study

A first study should identify how much a system is specified to consume, determine how much it is currently consuming, and identify wasteful practices (either in the hours and type of operation, or in the equipment and system itself). Waste generally comes from changes in operation, in maintenance, or in equipment and controls.

You can check that equipment continues to work efficiently without even visiting the factory by tracking energy consumption. Manual, semi-automatic or automatic readings from energy meters connected to the major pieces of equipment can show if waste develops. You can allow for differences in production levels (in buildings, you can similarly allow for differences in outdoor temperatures using degree day values). You should calculate (three-sigma) control limits that will reliably detect energy waste. Energy consumption going above control limits suggest that new equipment has been added, or that a fault has developed.

#### 3.2 Deeper study of systems highlighted

If the initial study suggests waste but no immediate cause, a targeted data gathering can help. It can be worth logging kW, kWh and power factor over time at the main service entrances and key loads. How much power is consumed at what time of day and with how much waste? Even just a couple minutes of peak usage can increase the utility rate for a couple of hours, days, or even weeks. Loads are commonly left on after hours or unnecessarily run at peak rate time of day. Rescheduling loads may allow a company to take advantage of times of day when power is cheaper. Check how far below "1" the cos phi is, and check the utility invoices to see if there's a penalty for poor cos phi.

Leaks in compressed air lines are wasteful. Measure pressure at compressor and point of use to determine the amount of drop. Ultrasound scan of lines can identify the source. Failed steam traps and insufficient insulation waste steam, causing overproduction to maintain necessary supply. Thermally scan pipes and traps to identify insulation gaps and blockages. Keeping a power log at the boiler can help calculate baseline consumption.

At startup, stagger equipment with large electrical power consumption at least 15 minutes apart to avoid peak demand charges. Install VSDs on large motors and replace existing bad motors with high-efficiency models. Sensors and controls can turn systems off when they are not needed.

#### Attacking structural waste

Everything so far has been aimed at reducing 'avoidable waste' through good maintenance. When upgrading equipment, companies need to reduce 'structural waste' for their next equipment generation, which means routinely using 'real' costs (including the price of energy) when making their decisions. Old equipment can consume so much more power than new high-efficiency models that early replacement may be justified in reduced kWh consumption alone. With energy efficiency, the repayment time or [Return on Investment](#) is the critical measure.

Examining **HVAC systems and building insulation** is a [topic](#) in itself, and that alone can repay initial capital costs of a thermal imager within a few months.





## 4. References

### ANSI

- [Preventive Maintenance Standards](#)

### CENELEC Standards Inspections

- [Inspection and maintenance](#)

### EPRI Electric Power Research Institute:

- [Best Practice Guideline for Maintenance Planning and Scheduling](#)
- [Guideline on Proactive Maintenance](#)
- [Electric Motor Predictive and Preventive Maintenance Guide](#)

### European Committee for Standardization

- [European Standard EN 13306 – Maintenance](#)

### European Directives

- [Council Directive 89/391](#) – “Framework Directive” general principles concerning the prevention and protection of workers against occupational accidents and diseases
- [Directive 2009/104/EC](#) – use of work equipment
- [Directive 2006/42/EC](#) on machinery

### IEC

- [IEC 61000-4-30](#): Power Quality Measurement Methods, EN50160 Power Quality Standard
- Electrical Code in the US: NEC Article 250.  
Link: [http://212.175.131.171/IEC/iec61000-4-30%7Bed1.0%7Den\\_d.pdf](http://212.175.131.171/IEC/iec61000-4-30%7Bed1.0%7Den_d.pdf)

### Infraspection Institute

- [Standard for Infrared Inspection of Electrical Systems & Rotating Equipment](#)

### Institution of Engineering and Technology

- [IET Wiring Regulations 17th Edition \(BS 7671:2008 incorporating amendment number 1:2011\)](#)

- [Code of practice for in-service inspection and testing of electrical equipment.](#)

### Legislation.gov.uk

- [The Electricity at Work Regulations 1989](#)

### National Fire Protection Association

- [NFPA 70B Recommended Practice for Electrical Equipment Maintenance](#)

### NEMA

- [Specifications for motors NEMA MG1](#)

### UK Health & Safety Executive

- [Keeping electrical switchgear safe](#)

### UK Department of Health

- [O6-03: Electrical safety guidance for high voltage systems](#)

### See also

- [International Electrotechnical Commission system for certification to standards relating to equipment for use in explosive atmospheres \(IECEx system\)](#)
- [NETA InternNational Electrical Testing Association](#)
- [OSHA maintenance](#)
- [UK Health and Safety Executive Electrical standards and approved codes of practice. \(Electrical and Power, Electrical Appliances, Electromagnetic Compatibility, Flammable Atmospheres, Machinery\)](#)
- [Fluke's Thermal Imaging and other specialist application information.](#)

## 5. Glossary (other terms are defined in our [electrical glossary](#))

**Accuracy:** the difference between a reading and the true value for a quantity measured under reference conditions.

**Clamp meter:** a multimeter with two jaws that open to allow them to clamp around an electrical conductor.

**Cos phi:** the effective fundamental power in a circuit (measured in Watts) is the product of voltage, current, and displacement power factor (DPF) or  $\cos\phi$  (the cosine of the phase angle between current and voltage).  $\text{Watts} = E \cdot I \cdot \cos(\phi)$ .

*Note: in Europe, the Power Factor is equivalent to the Total Power Factor in the US.*

**Emissivity:** how effectively a material's surface radiates IR energy.

**Span control (thermal imagers):** used to adjust an image to distinguish between small differences in temperature.

**Inrush current:** the initial surge of current the moment a load (resistance or impedance) is energized until the nominal state is reached.

**Level control (thermal imagers):** used to adjust the measurement window within the total temperature measurement scale.

**Power quality:** a voltage supply and system design that enable electric power users to use electric energy from the distribution system successfully, without interference or interruption.

**Pulse Width Modulation (PWM):** a technique that controls a motor's rotational speed by the width and fundamental frequency of the pulsed output voltage.

**Repeatability:** the difference between measurements taken by an instrument on the same piece of equipment item under the same conditions.

**Rotor bars:** the conducting aluminium or copper rods in a rotor that carry the rotor current.

**Thermal signatures:** the range of surface temperatures that appear in a thermal image.

**Thyristor:** a high-power electrical current switch.

**Unbalance:** any difference in amplitude, phase angle and/or harmonic content of currents, voltages or impedances in the individual phases of a three-phase supply.

**Variable speed drives:** control systems that adjust the speed and torque of motors depending on the load requirements, making them more efficient than fixed-speed drives.

**Vibration signature:** the range of frequencies found from a vibration analysis sweep.