SEMINAR SERIES

Measurement best practices for troubleshooting motors and drives

The right tools for troubleshooting drives and motors

VFD fault codes – Tripping, DC bus, and input power

- Is the error due to issues with motor or load?
- Is the error due to line power quality issues?
- Is the drive faulty?

The MDA-550 will verify incoming power and power quality vs DC bus.

Motor insulation breakdown or bearing failures ?

- Is the insulation deteriorating due to mechanical load or electrical issues?
- Is the motor running at elevated temperatures due to overload or electrical issues?
- Is the bearing failing due to peak reflective voltages exceeding winding insulation?
- Will electrical issues cause repeat failures?

The MDA-550 will verify electrical signal quality and the Fluke-438 will measure the mechanical load.

CHESS CONTROLS

The right tools for troubleshooting drives and motors

MDA-550 Motor Drive Analyzer
- Displays *Input Power* conditions that cause drive failures, harmonics that disrupt sensitive control equipment.
- Displays *Drive Output* PWM Waveforms and cabling issues that cause motor failures.
- Finds arc flash-overs across bearing races causing *Motor Bearing Failures.*

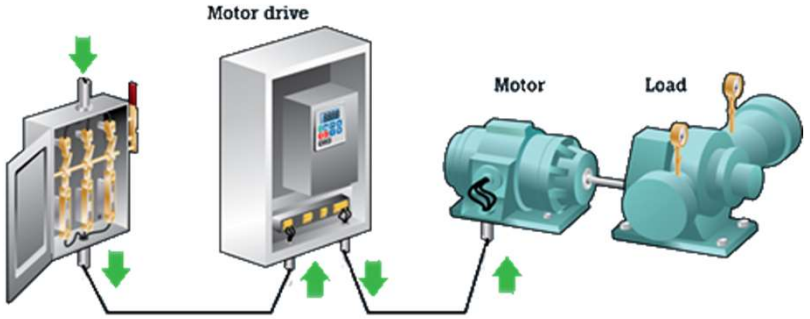
438-II PQ & Motor Analyzer
- Analyzes *VFD Input Power Quality* which leads to extended equipment failures.
- Calculates and analyzes *Motor Overload* which reduces lifespan while *underload* wastes operating expense $'s.

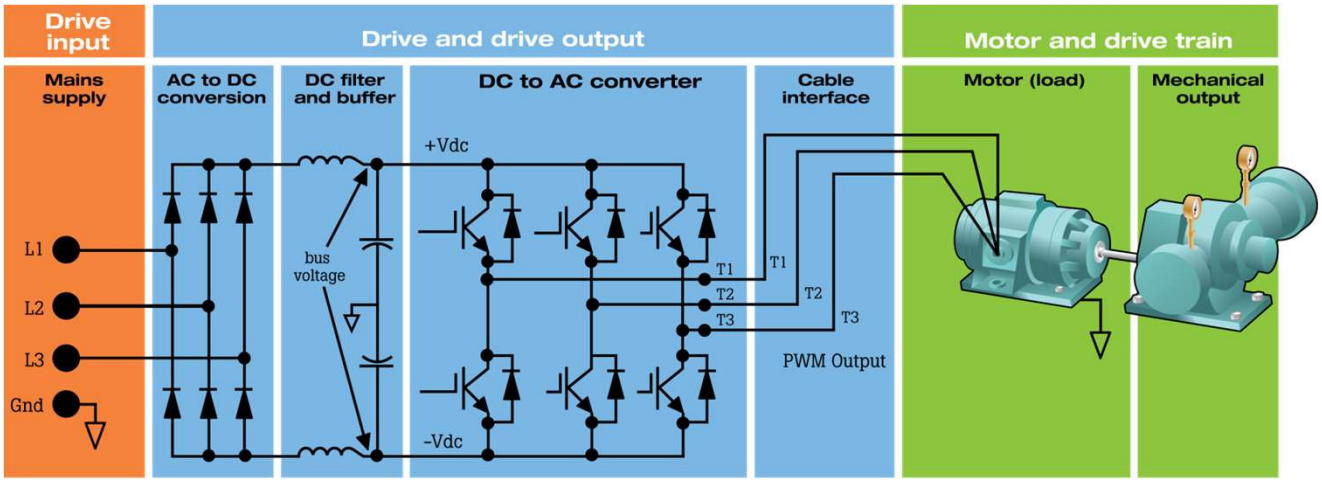
Ti 480 Pro Thermal Imager
- Identifies heat manifested from *Overloads and Bad Connections* causing intermittent & permanent failures.

1587 FC Insulation Resistance Tester
- Stress tests and analyzes *Degrading Insulation Resistance* identifying pending motor failure.

810 Vibration Tester
- Identities *Excessive Vibration* leading to premature wear and failure.

830 Laser Alignment
- Accurately calculates *Misalignment* causing excessive vibration, bearing and seal failures.





Problems

• Nominal supply voltage, current and frequency • Voltage and current unbalance • Transients • Harmonics • Power factor	• DC Bus • Voltage unbalance • Current unbalance • Sigma Current and PE Current • Output reflections • Disturbances • Harmonics • Volt to Hertz ratio • Diagnostic shutdown	• Motor overload • Single phasing • Bearing failures • Misalignment • Mechanical imbalance • Looseness • Insulation breakdown • Shaft voltage and bearing current

Three phase systems in Cat III environments

Do

- Confirm the test instrument is rated for the use. — *drives are typically considered CAT III*
- Use proper PPE—*always.*

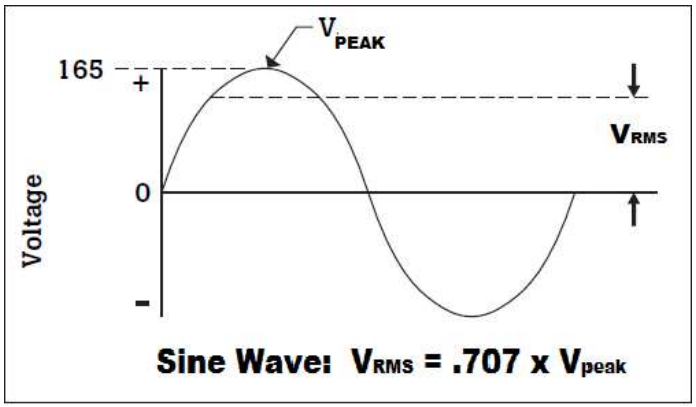
Avoid

- Combining CAT III instruments with lower rated accessories.
- Short circuiting floating differential test points with a common ground non-isolated multichannel input device.
- Holding the meter during testing.

Prop it up or hang it up.

True RMS vs “Average Responding”

- When measuring “AC” Voltage or Current, the “RMS” value is displayed.
- RMS = Root Mean Squared
- “True-RMS” meters use an equation that works for any waveform.
- “Average Responding” meters use an equation that works for sine waves.



Comparison of True-RMS and “Average Responding Meters on various waveforms:

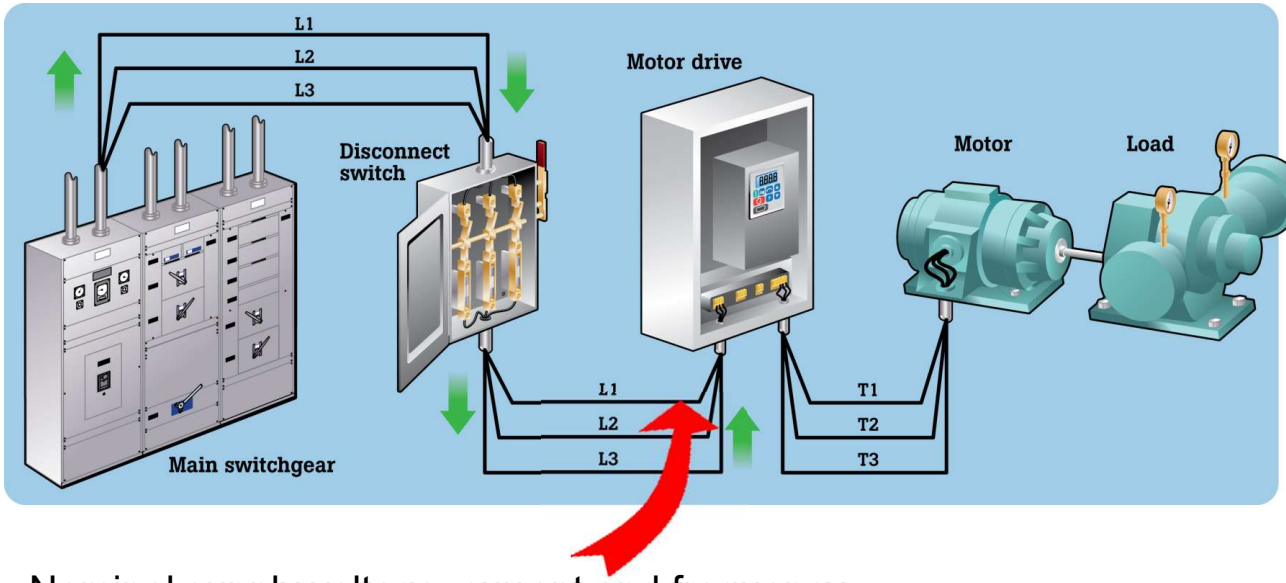
Multimeter type	Response to sine wave	Response to square wave	Response to single phase diode rectifier	Response to 3 Δ phase diode rectifier
Average responding	Correct	10 % high	40 % low	5 % to 30 % low
True-rms	Correct	Correct	Correct	Correct

SEMINAR SERIES

Measurement best practices for troubleshooting motors and drives

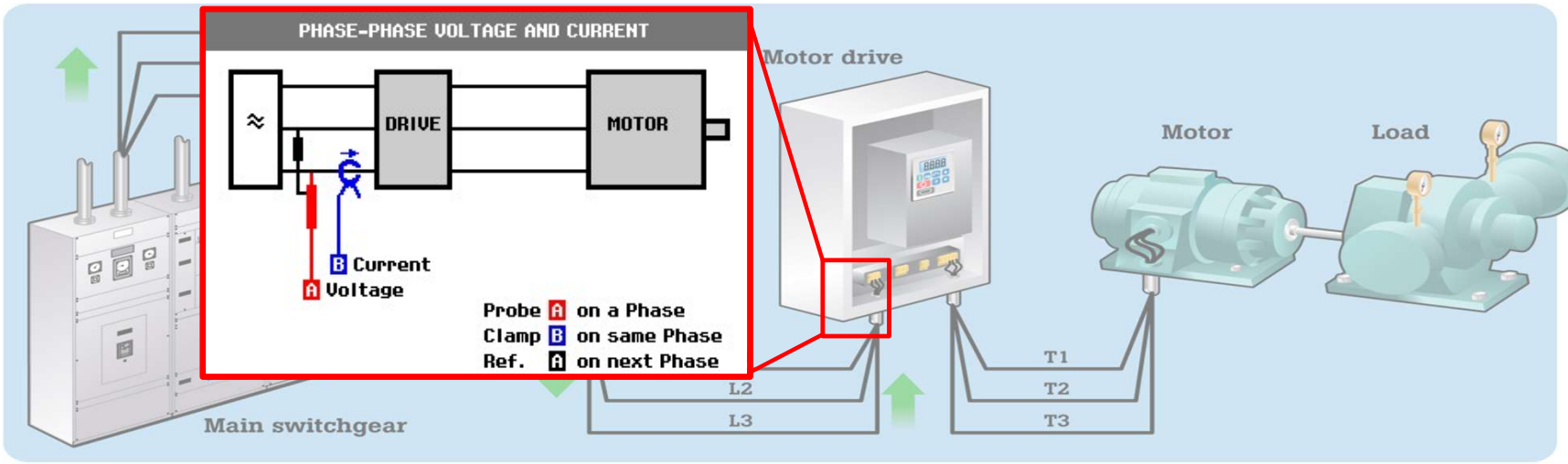
Input Measurements

Introduction to input measurements



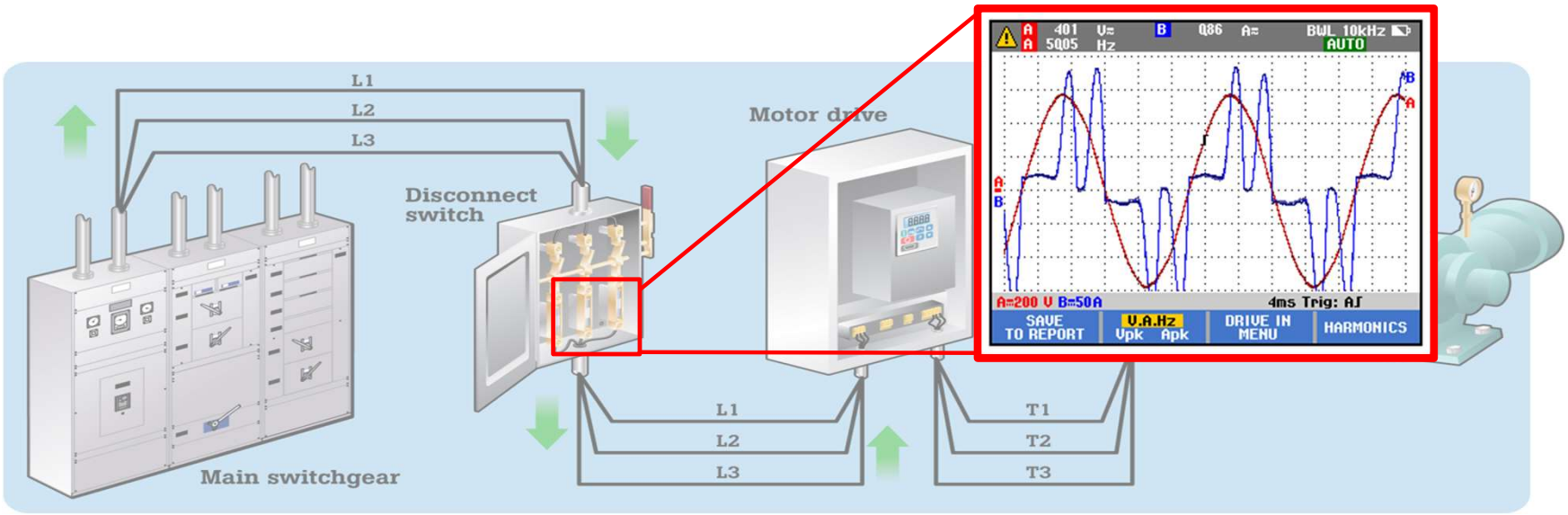
- Nominal supply voltage, current and frequency
- Excessive heat
- Voltage and current unbalance
- Harmonics

Measuring nominal supply voltage, current, and frequency



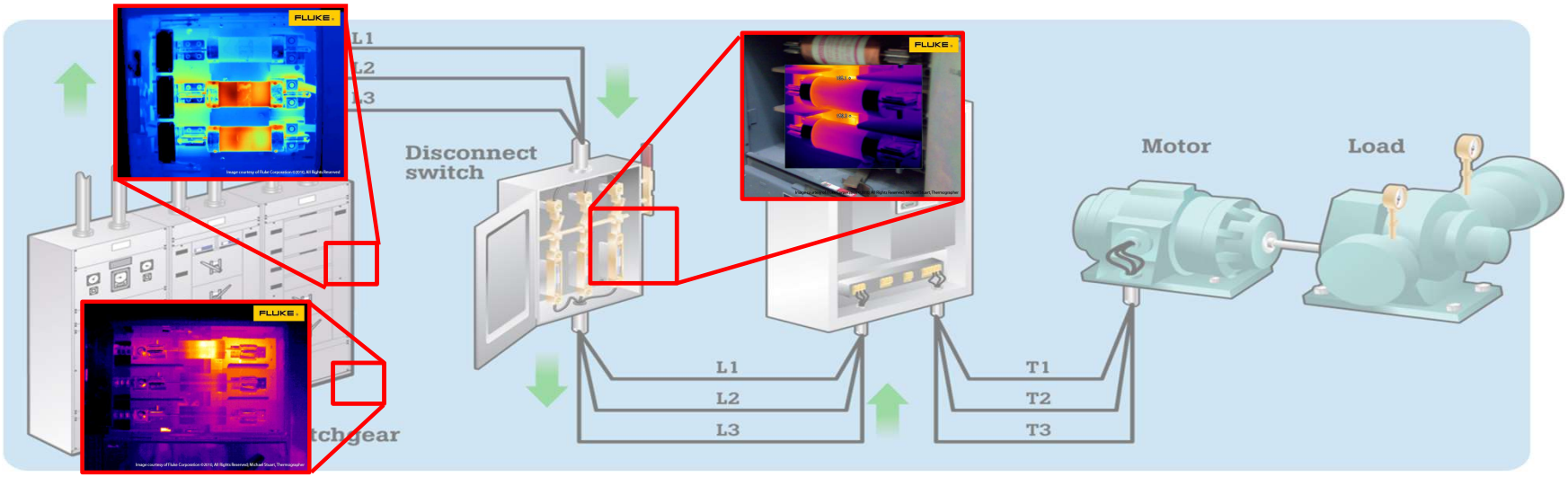
- Use a dedicated motor drive analyzer or power quality analyzer connected to the drive input.
- First measure at the input side of the drive then if needed at the service entrance.

Interpreting nominal supply voltage, current, and frequency



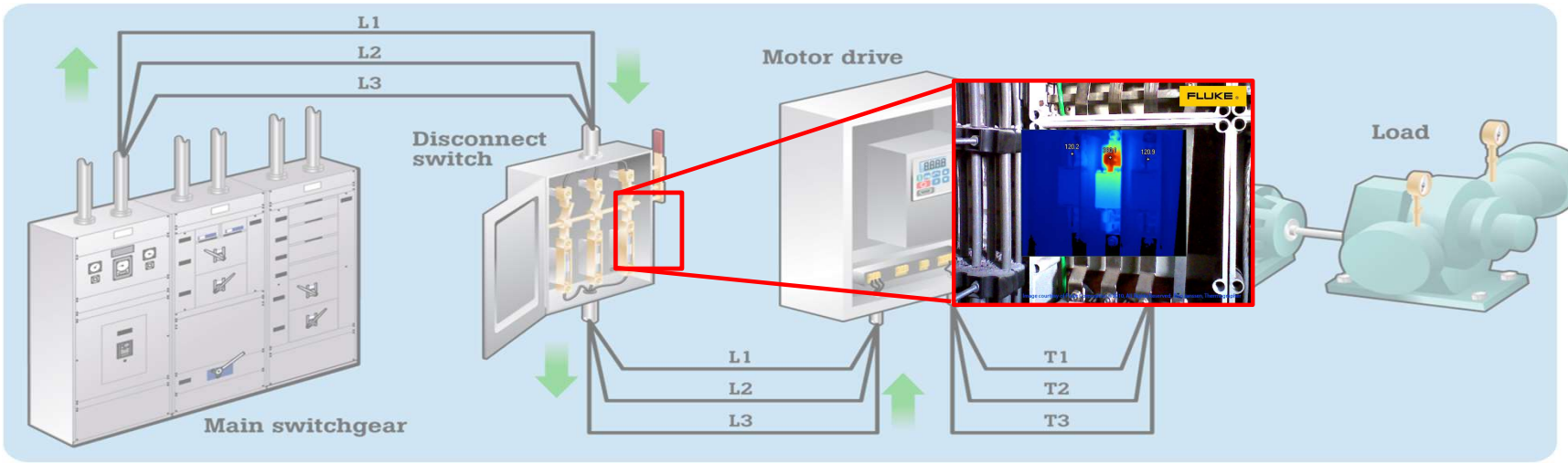
- A measurement of more than 10% out of range means there is potentially a supply voltage problem during the measurement period.
- Attach a power quality analyzer for long-term troubleshooting.
- Next, check for unbalance.

Key thermal signatures of components in the motor drive input



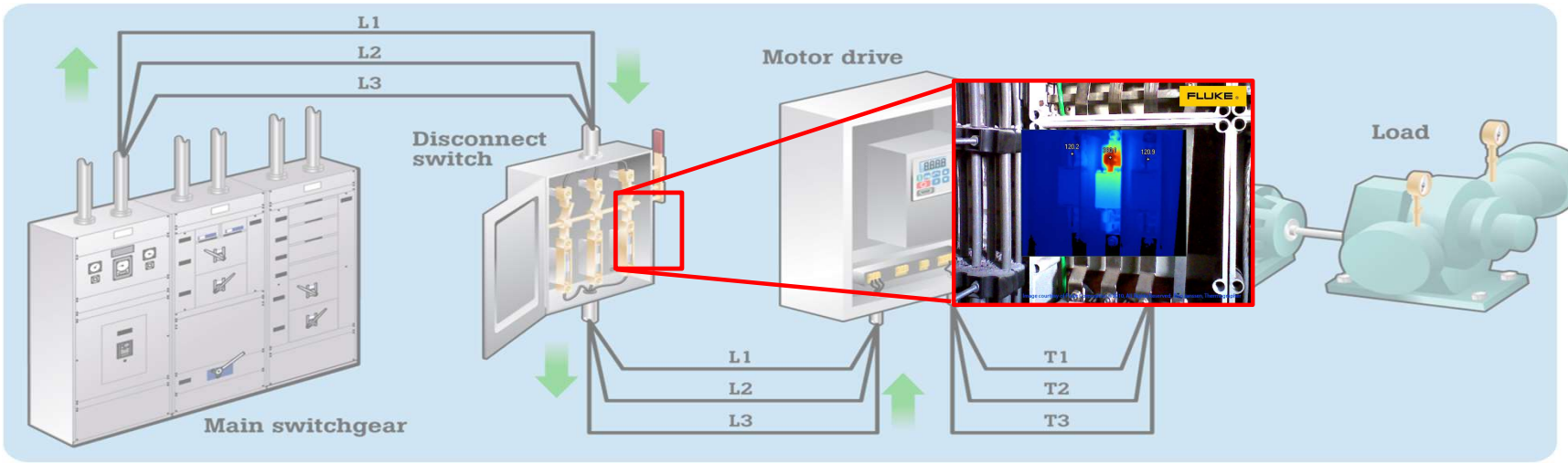
- A thermal signature indicates the apparent heat emitted from the surface of an object.
- Thermal signatures can highlight temperature hotspots or deviations from normal operating conditions.

Measuring the thermal signatures in the motor drive input



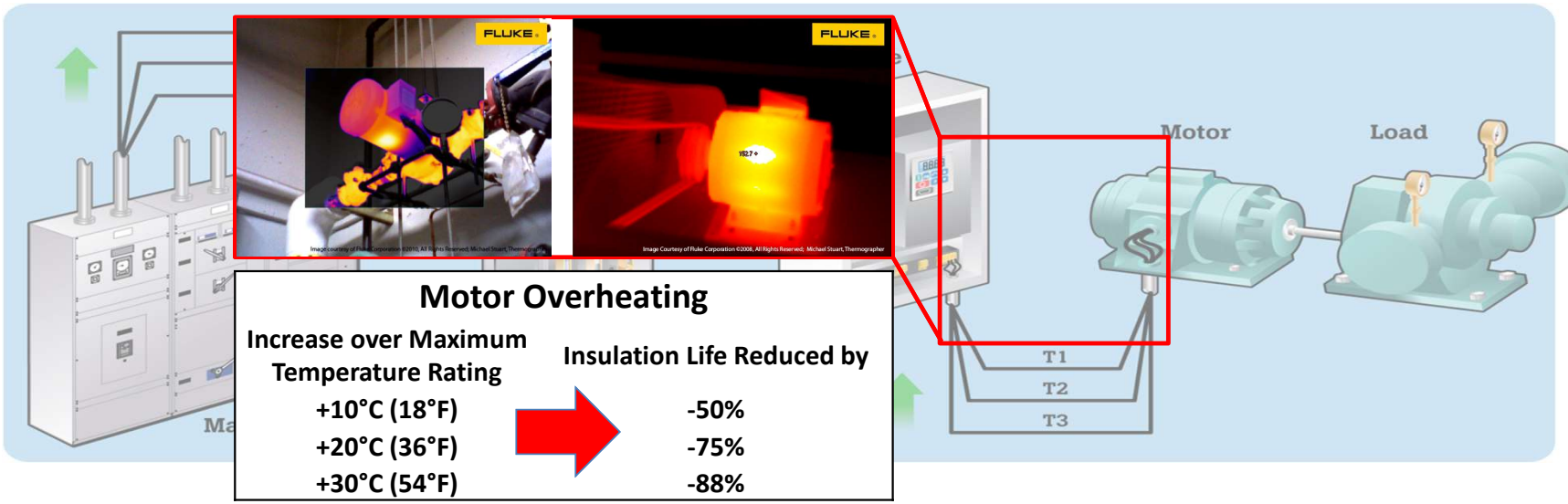
- Use a thermal imager to scan the component and look for irregular and non-uniform thermal patterns or anomalies.
- Be aware that different makes and models of equipment may have different baseline thermal signatures. Try to compare like components or equipment under similar load conditions.

Interpreting the thermal signatures in the motor drive input



- Much of thermography is comparative work.
- Comparing the thermal signature of the object of interest to a similar object under similar load conditions often makes it easier to detect problems.

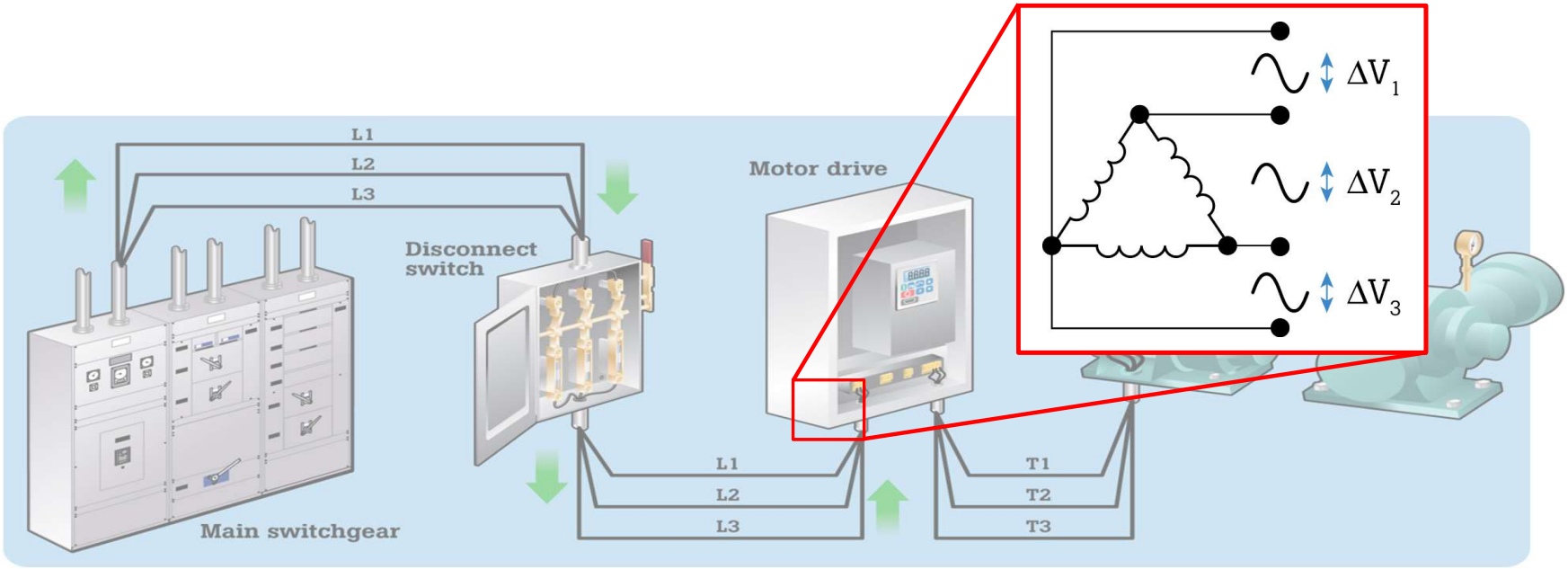
Interpreting the thermal signatures of key components in the motor drive output



- High resistance connections, phase imbalance and current overload contribute to variations in thermal signatures.
- Motor overheating can be caused by winding insulation and cooling problems.

What are voltage and current unbalance?

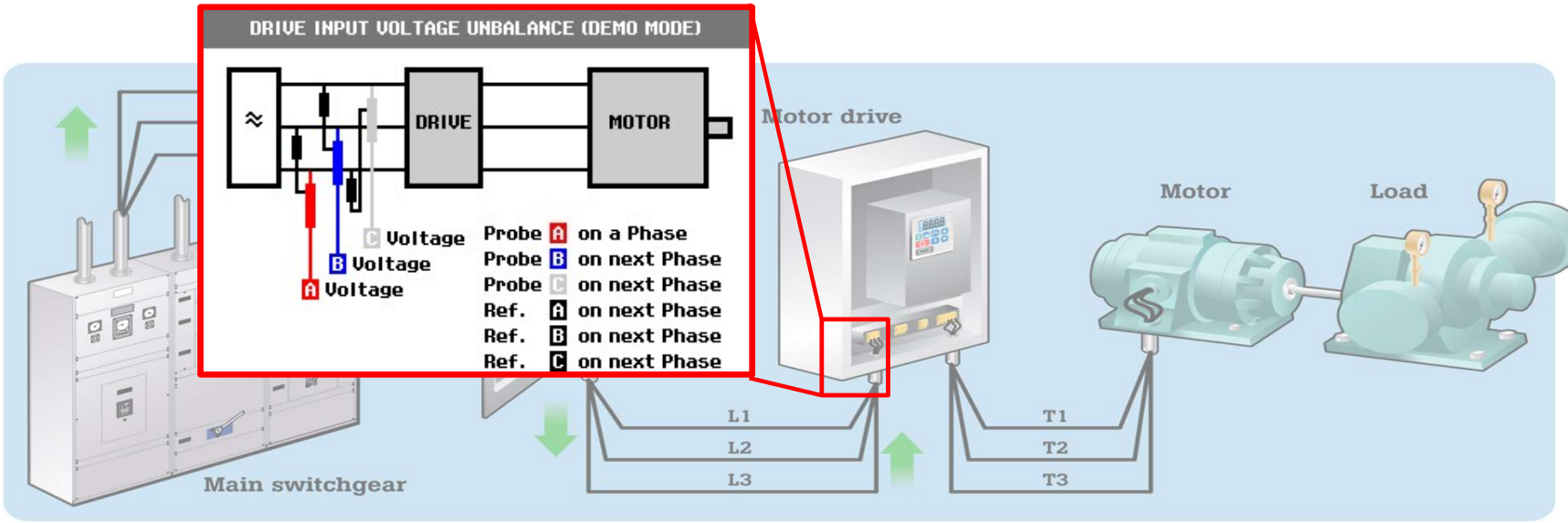
Advanced topic



- Occurs when three phase voltages or current differ in magnitude.
- 2 to 3 % voltage unbalance has the potential to cause drive problems

Measuring unbalance

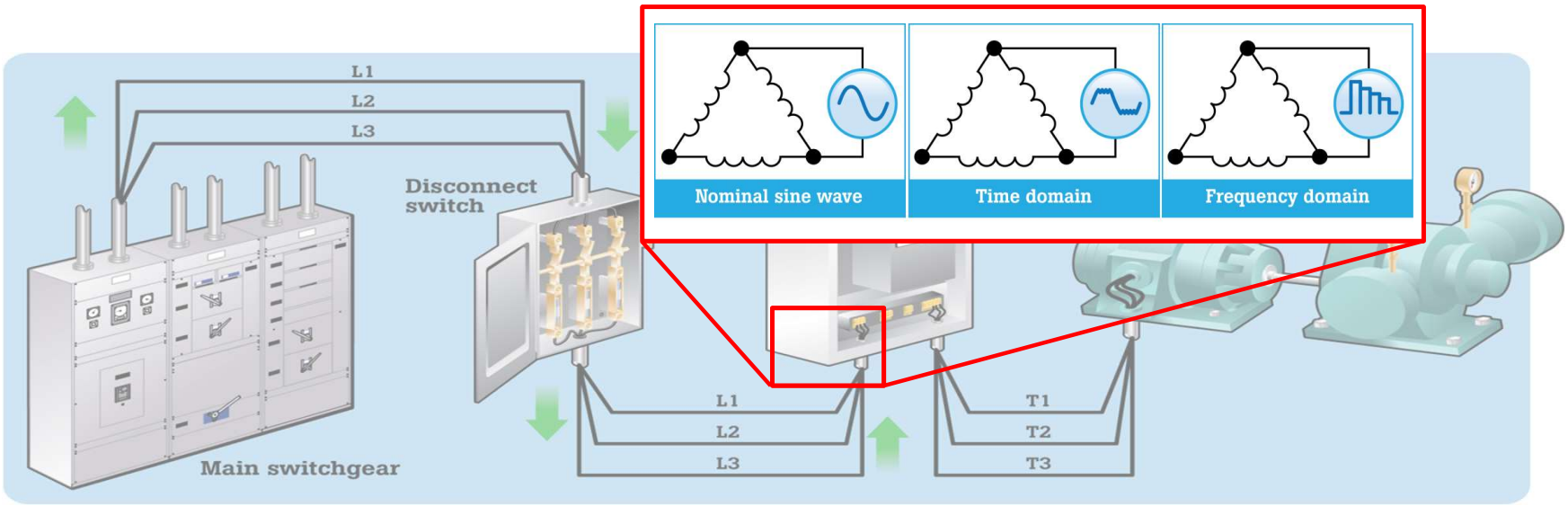
Advanced topic



- Use a dedicated motor drive analyzer or three phase power quality analyzer properly connected to the motor drive input supply.
- Measure three phases simultaneously to assess any impact of load changes

What are harmonics?

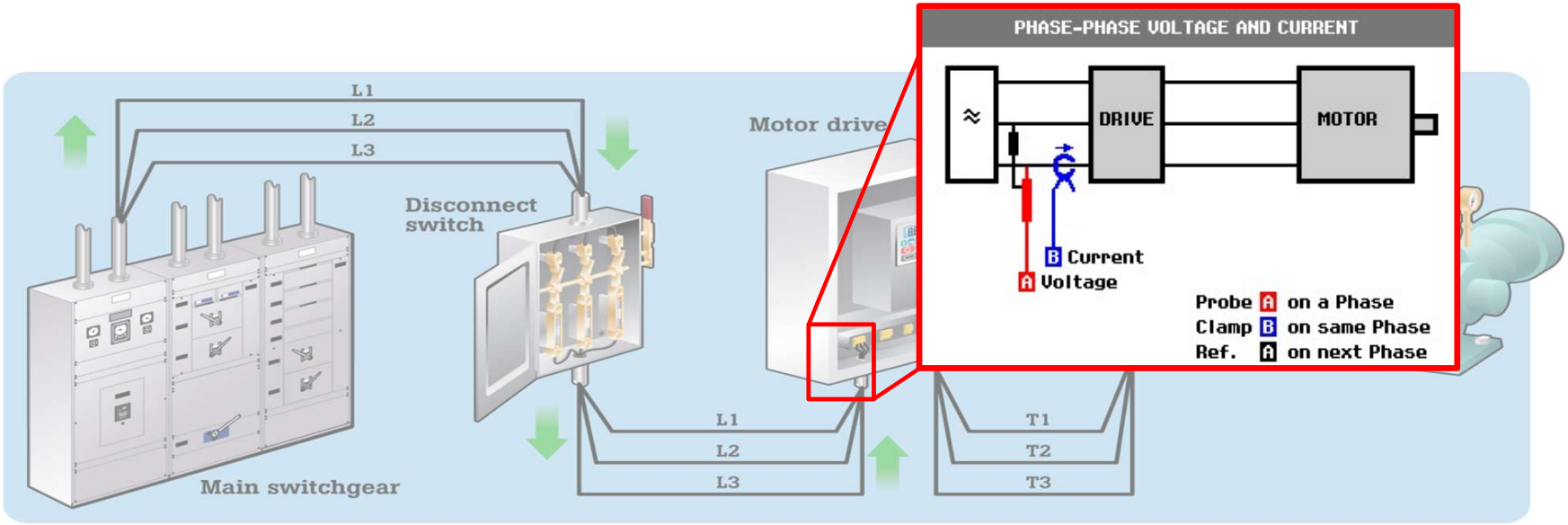
Advanced topic



- Harmonics are multiple frequency components of the fundamental waveform.
- E.g., a third harmonic of 60Hz is 180Hz. The fifth harmonic of 60Hz is 300Hz.

Measuring harmonics

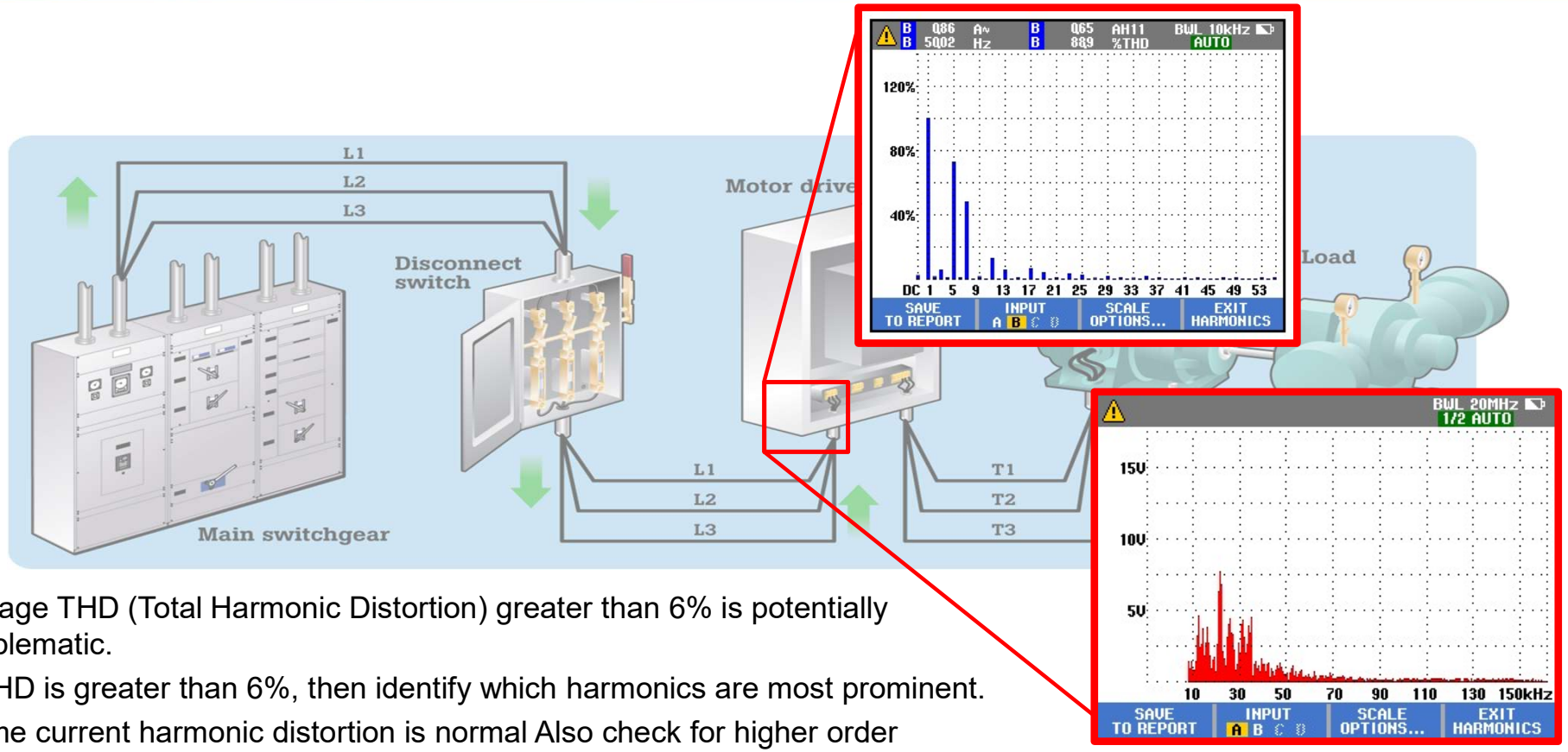
Advanced topic



- Use a power quality analyzer to measure harmonics.
- Measure both the voltage and current harmonics.

Interpreting harmonics

Advanced topic



- Voltage THD (Total Harmonic Distortion) greater than 6% is potentially problematic.
- If THD is greater than 6%, then identify which harmonics are most prominent.
- Some current harmonic distortion is normal Also check for higher order frequency harmonics

Input measurements – Summary

Check input power first:

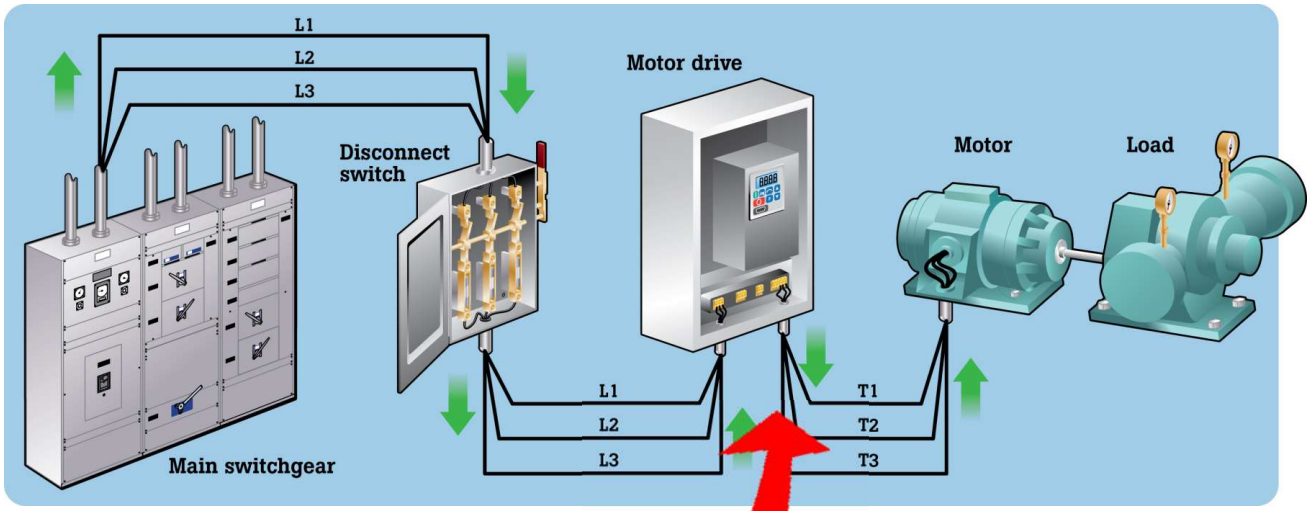
1. Rule out issues that might affect the motor drive or breaker circuits.
   - Save time and lead to a faster problem resolution
   - Identify over or under voltage conditions to avoid nuisance tripping of drive fault circuits and eventual damage to the motor drive itself
2. Ask yourself how much time did you spend trying to fix these kind of problems in the past?
3. How much time/money do you think you can save by using the a thermal imager or a 435 PQ analyzer?

SEMINAR SERIES

Measurement best practices for troubleshooting motors and drives

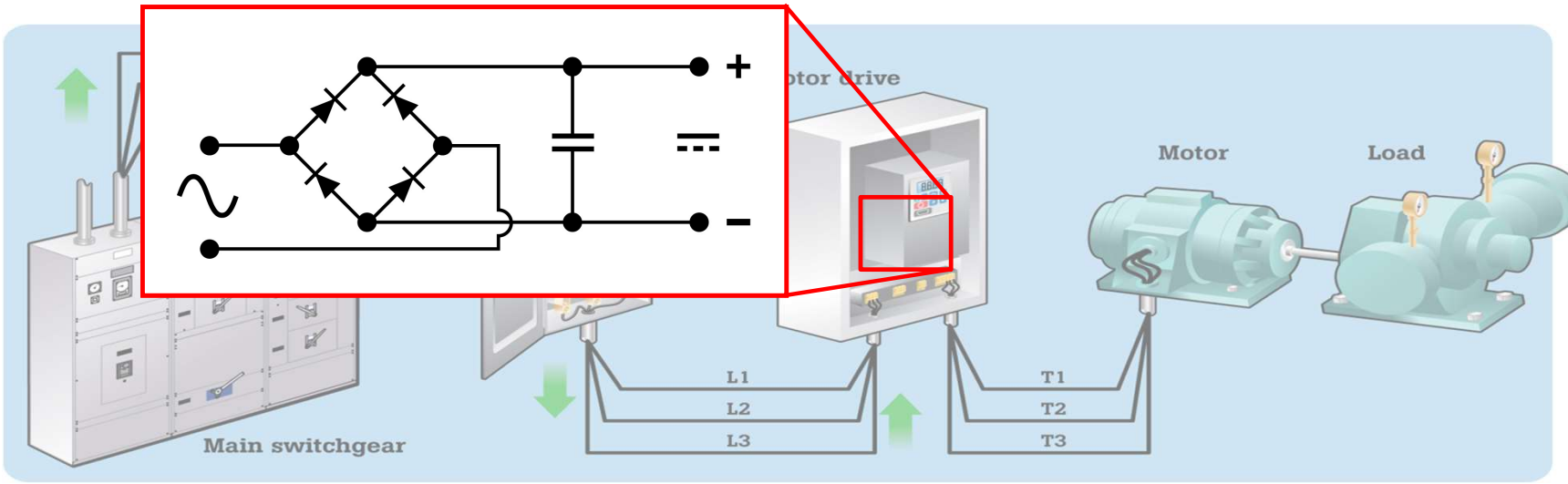
Drive and Drive Output Measurements

Introduction to drive output measurements



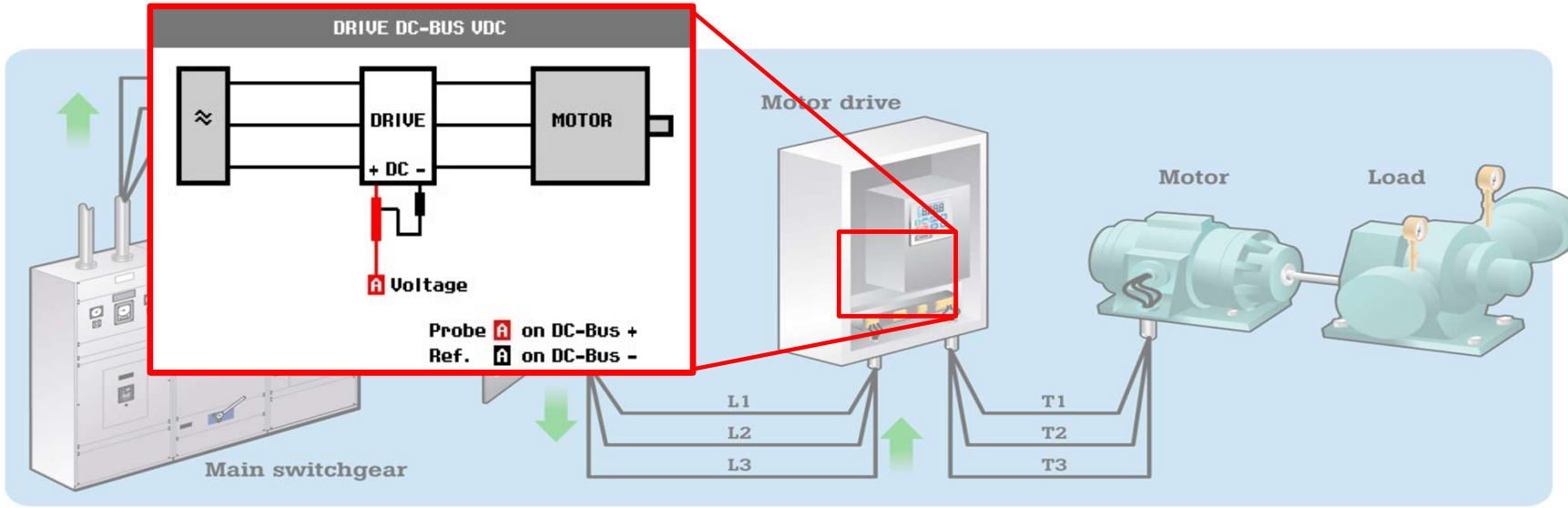
- DC Bus
- Nominal Output Voltage and Current
- Voltage & Current unbalance
- Output Pulse Width Modulation, reflections, dV/dt and potential winding insulation breakdown

What is the DC bus?



- DC Bus functions as a voltage buffer
- Direct current (dc) voltage derived from AC rectifiers
- Constant energy supply to switching circuit

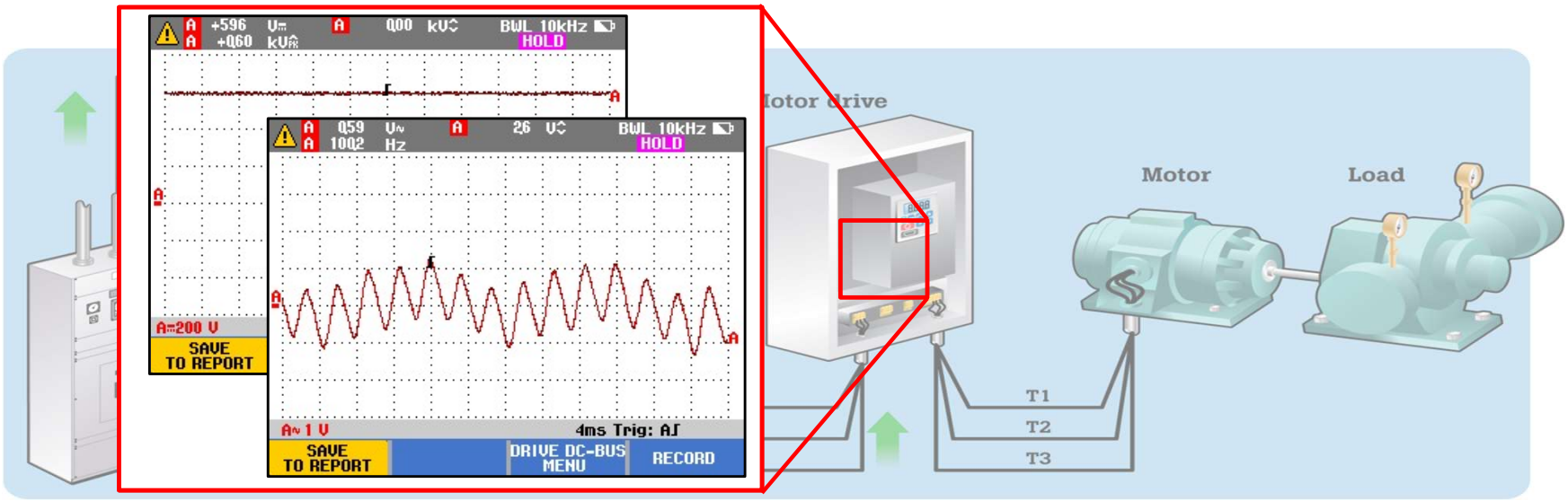
Measuring DC bus voltage



Measure the DC bus voltage across the + and - terminal.

- Use a portable oscilloscope, AC or DC input coupling, to measure the absolute or ripple voltages
- Make sure the scope and probe are rated appropriately to measure the voltage level

Interpreting DC bus measurements

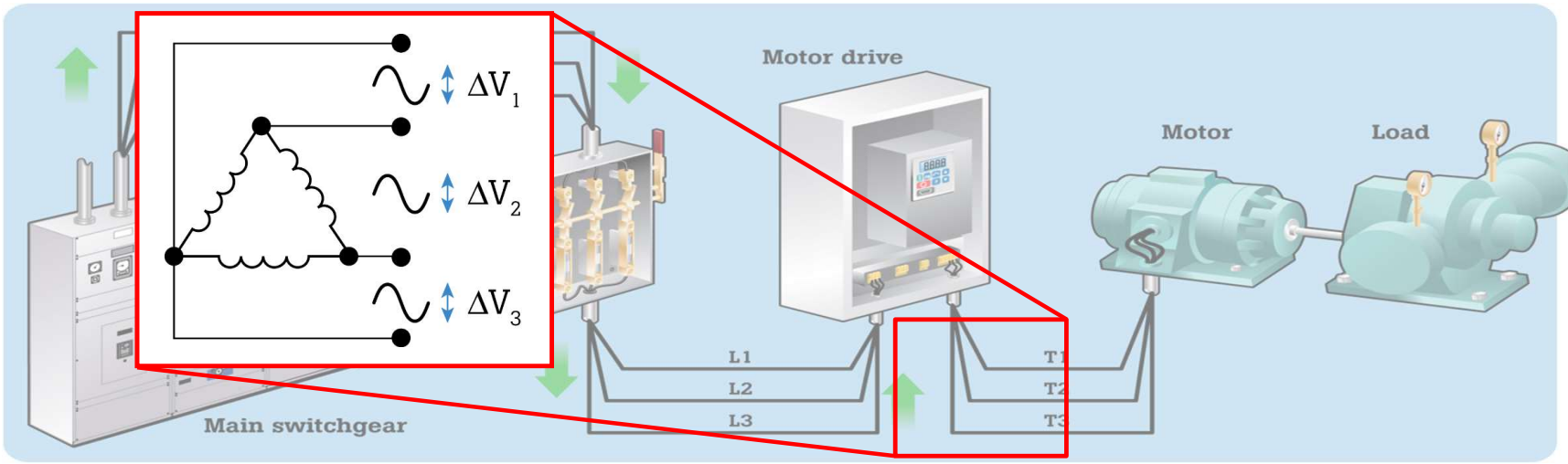


- DC bus voltage is ~1.414 x the RMS line voltage
- If the peaks of the ripple have a different repetitive level it is an indicator that one of the rectifier diodes is possibly malfunctioning.

Corrective actions

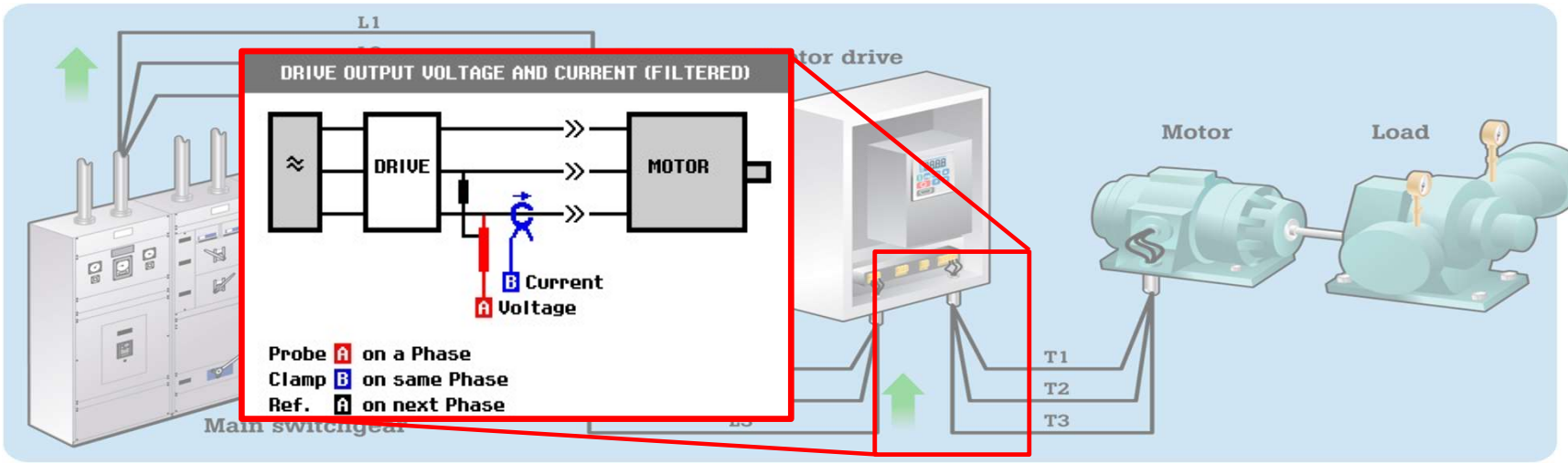
Symptom:	Measurements:	Solution:
• Voltage level high/low bus fault, improper operation or drive failure	• Perform min/max recording of the bus DC voltage and AC ripple/noise	• Correct drive's AC input voltage • Replace drive input card and/or failing capacitor bank • Confirm drive rating is compatible with the motor and load

What is nominal output voltage, current and frequency?



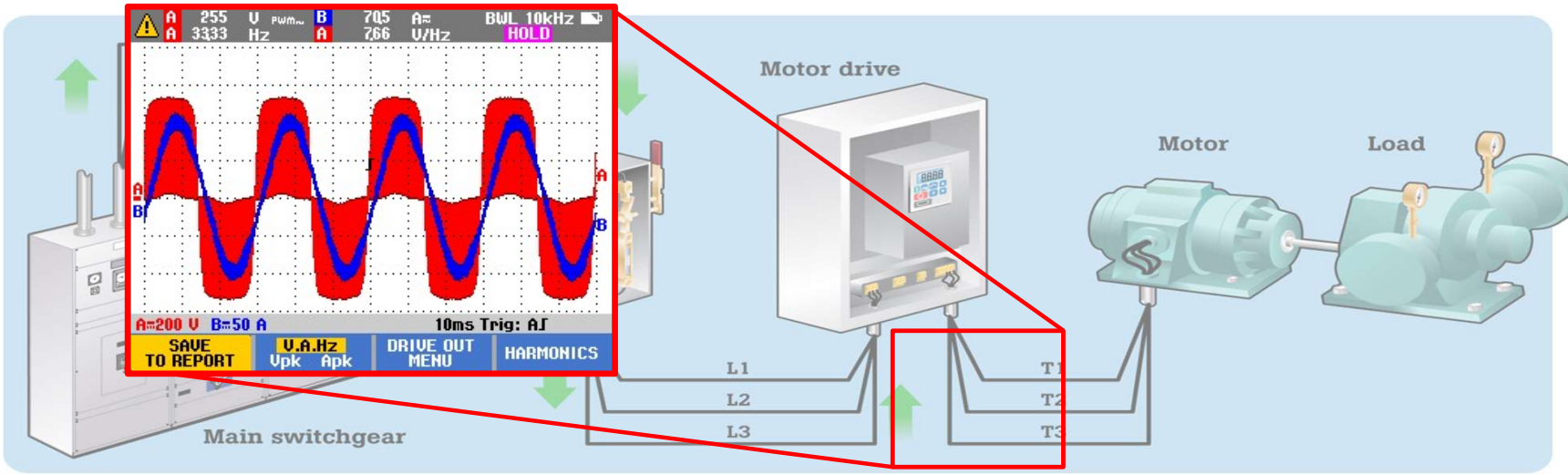
- Determines the electrical energy used to create mechanical work.

Measuring nominal voltage, current and frequency



- Measure the drive output voltage, current and frequency.
- Next check the output voltage and current unbalance.
- Any unbalance could be problematic for the motor.

Interpreting drive output nominal measurements

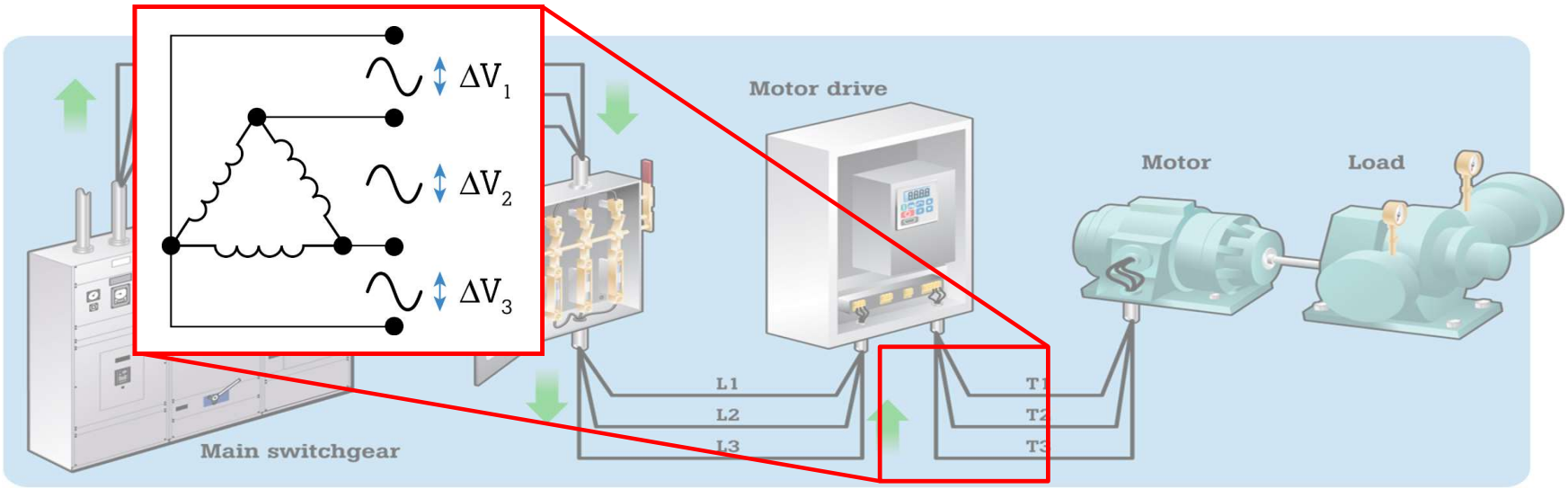


- Compare measured values to motor nameplate, check if any parameters are out of limits.
- Check if the voltage/frequency ratio (V/Hz) is within specified limits for the motor or intended application.

Corrective actions

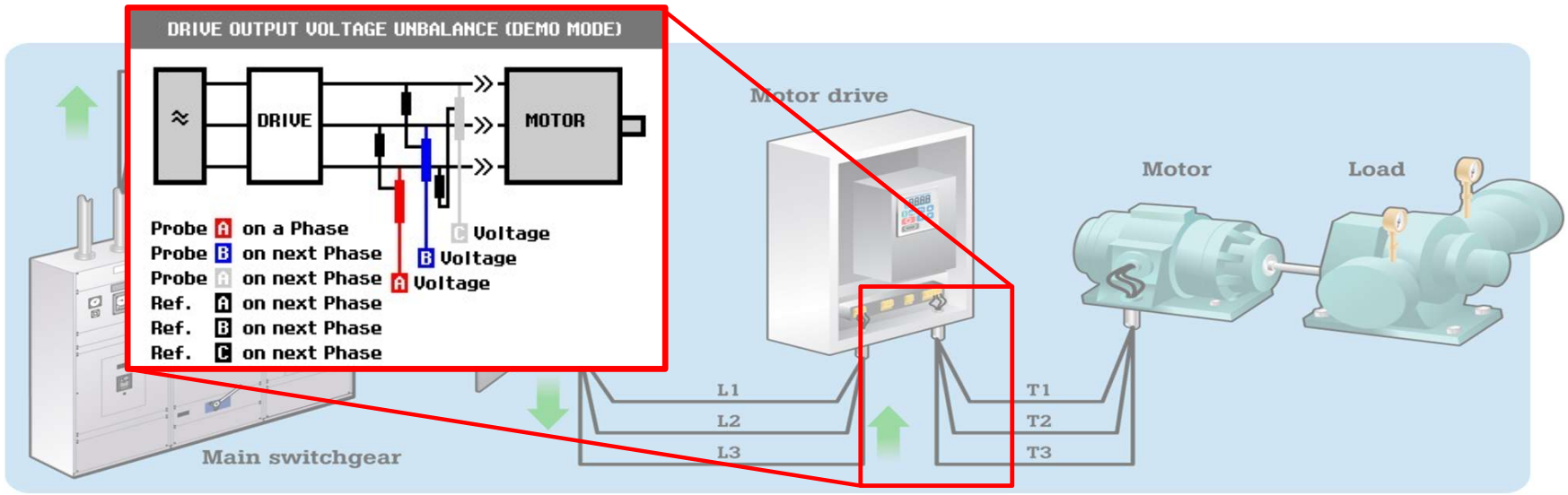
Symptom:	Measurements:	Solution:
• Motors are running at elevated temperatures	• Measure drive output voltage and current. Taking into account the motors service factor, check if measured current exceeds the nameplate rating	• Inspect for mechanical constraints (blockages, buildup or wear) in driven component, eliminate or replace as necessary • Resize the driven component and motor if needed

What is voltage unbalance?



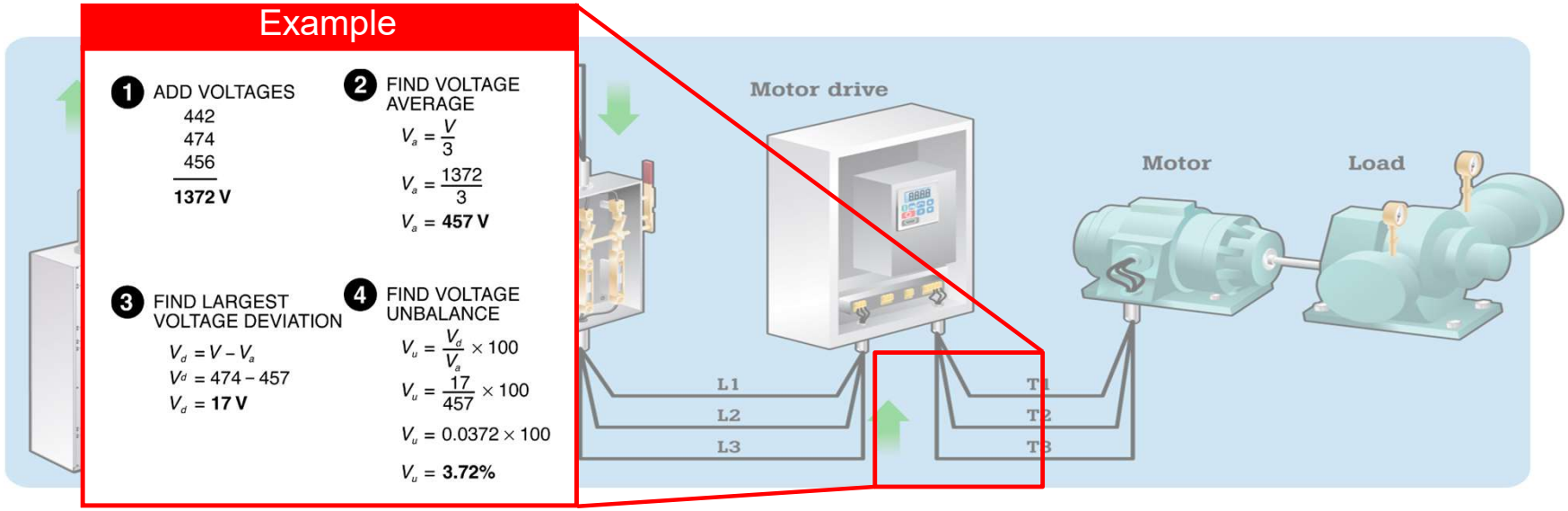
- Occurs when three phase voltages differ in magnitude.

Measuring voltage unbalance



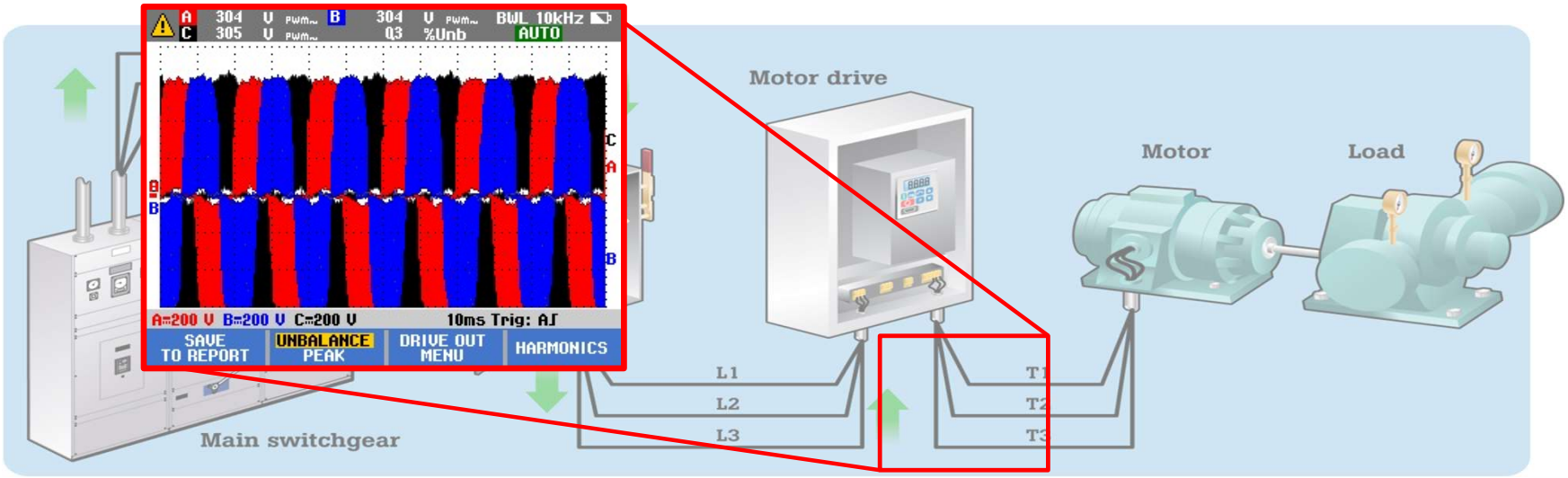
- Measure the voltage on each terminal at the drive output.
- Next check the voltage at the motor terminals.
- Any unbalance could be problematic for the motor.

Calculating voltage unbalance



% Voltage (V) unbalance = (Max deviation from average V/average V) x 100

Interpreting voltage unbalance measurements

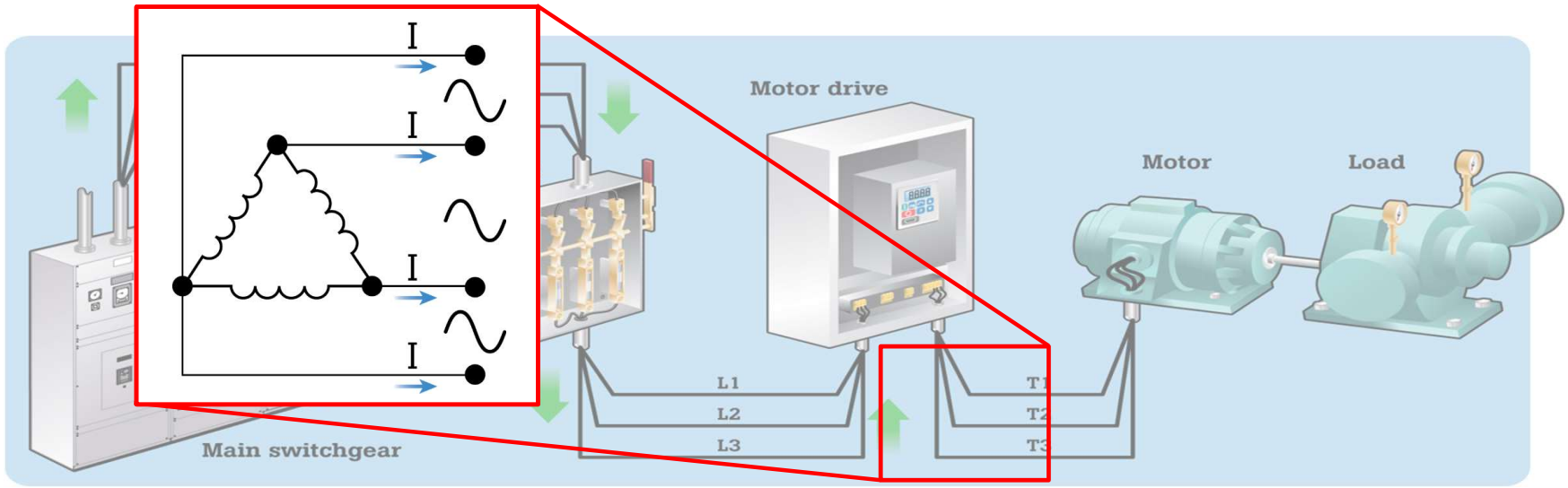


- Unbalance greater than 2% is problematic.
- This measurement rules out motor overheating due to voltage unbalance.
- Can’t rule out other overheating causes.
- Next, check for current unbalance.

Corrective actions

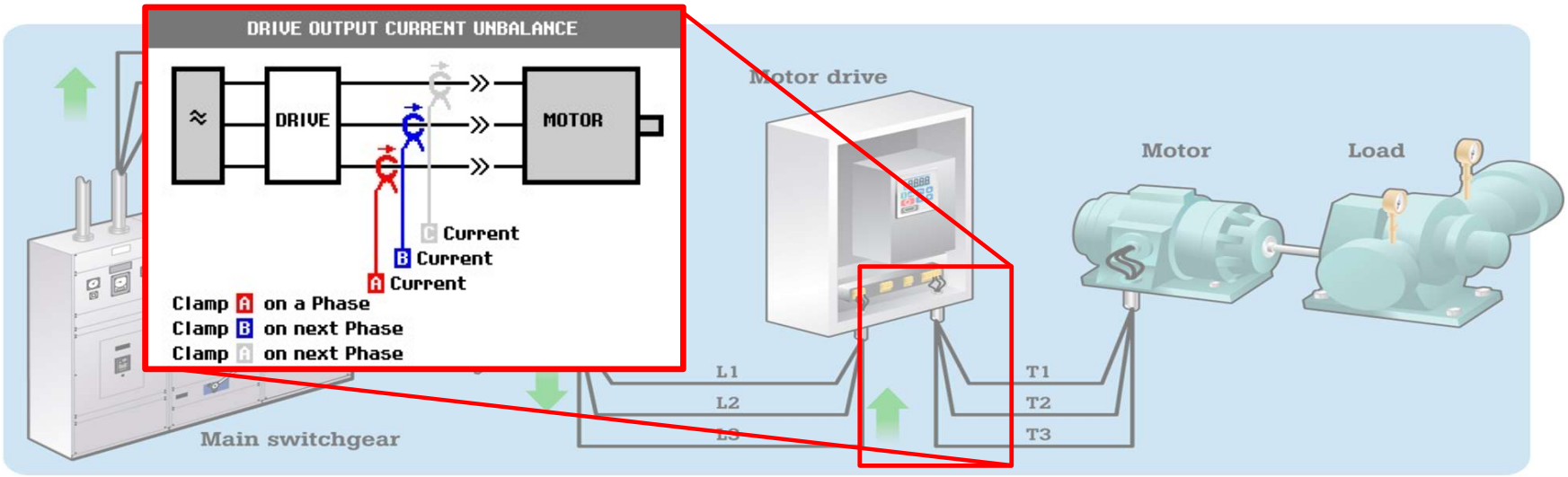
Symptom:	Measurements:	Solution:
• Voltage/current level high - low output fault • Elevated motor temperatures • Improper operation or drive failure	• Perform phase voltage measurements (will influence current balance) • Perform phase current measurements • Measure motor temperature • Measure winding resistance and insulation	• Disconnect the load on the motor and confirm balance changes – improvement over load probable cause • Disconnect the motor and confirm voltage balance changes – improves motor, then perform winding and insulation measurements • Confirm drive rating is compatible with the motor and load

What is current unbalance?



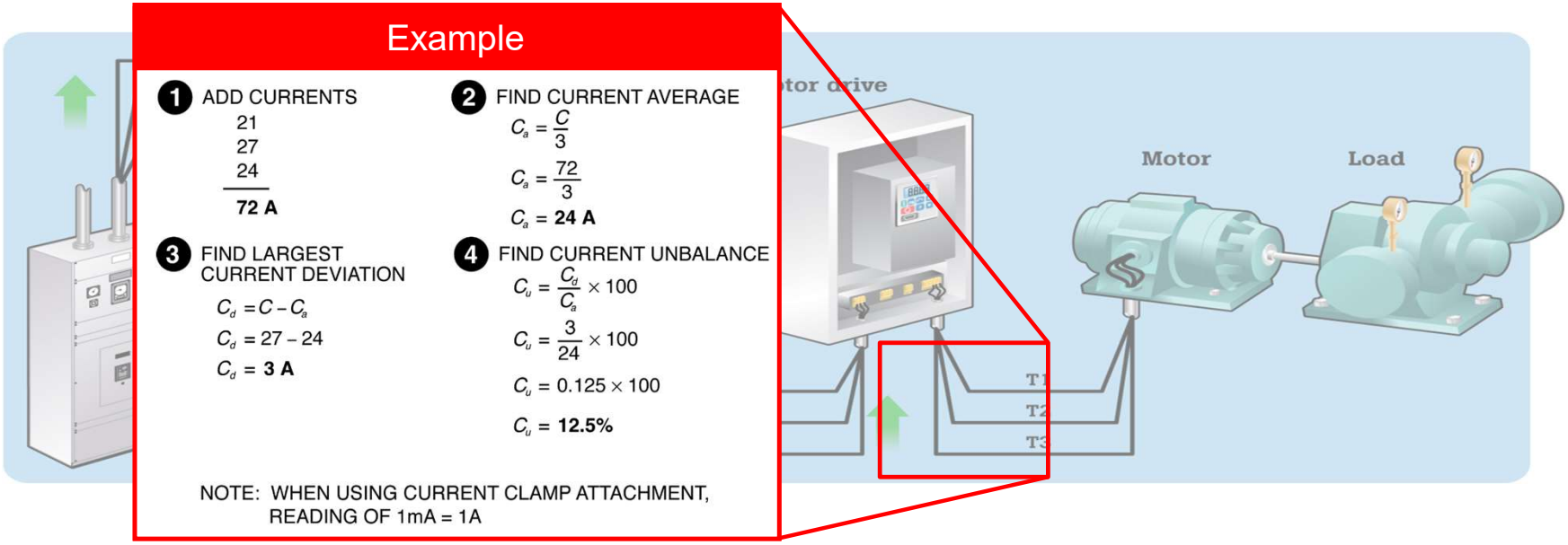
Occurs when three phase currents differ in magnitude.

Measuring current unbalance



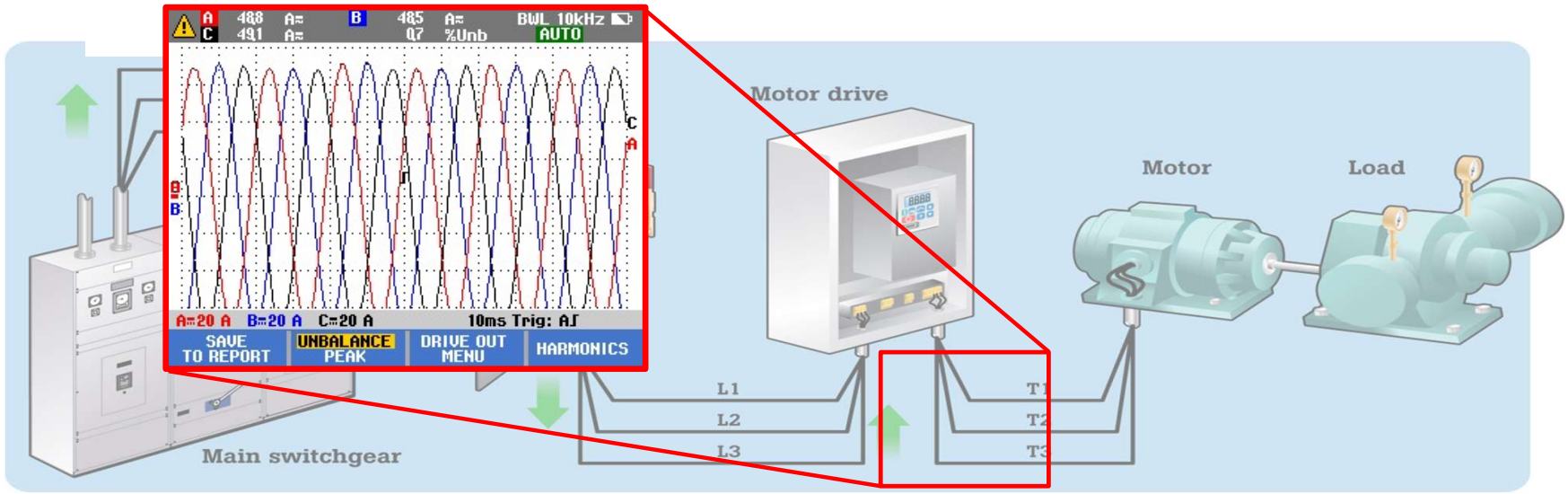
Use a dedicated motor drive analyzer with a current clamp on all three drive output terminals separately to measure the current draw on each terminal.

Calculating current unbalance



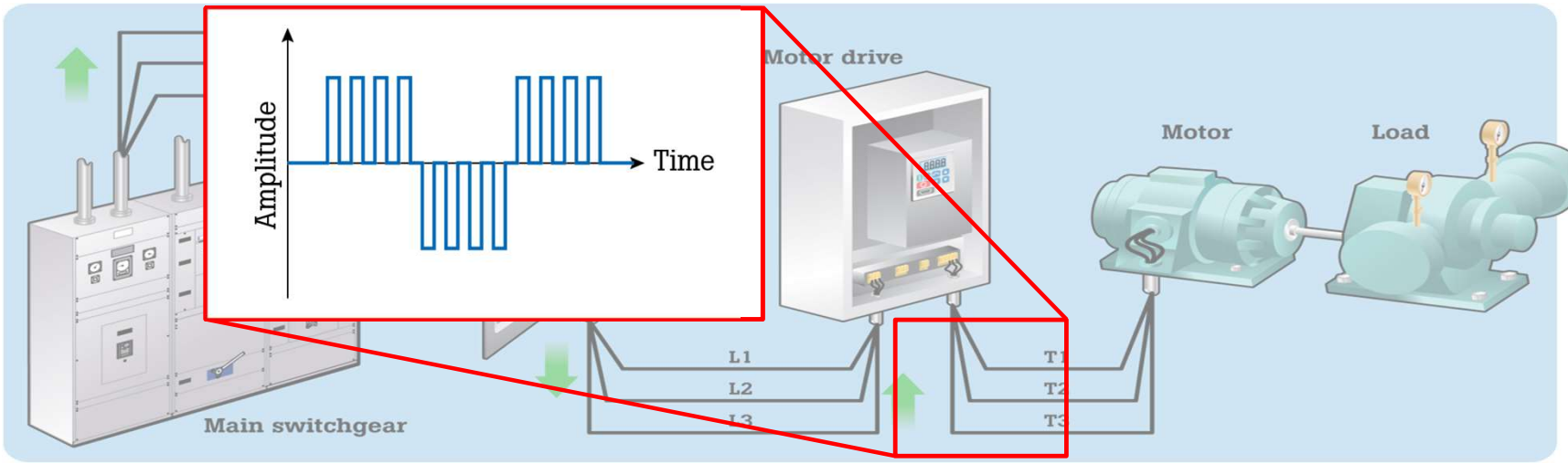
% Current (I) unbalance = (Max deviation from average I/average I) x 100

Interpreting current unbalance measurements



- A current unbalance of more than a few %, should be investigated further.

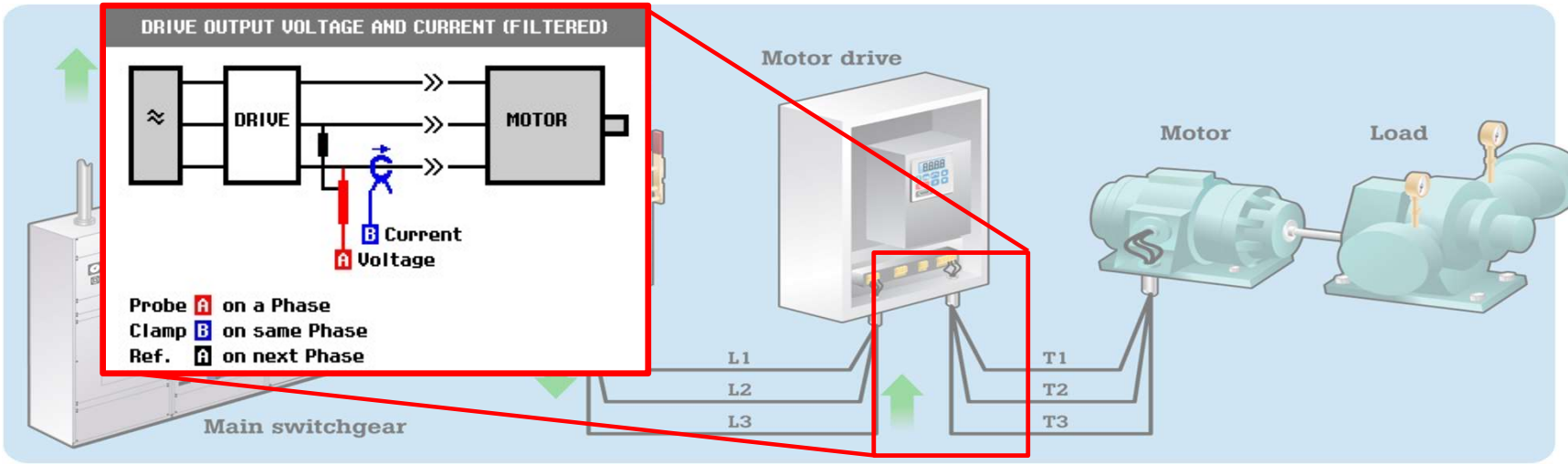
What is output voltage pulse width modulation?



Reflections:

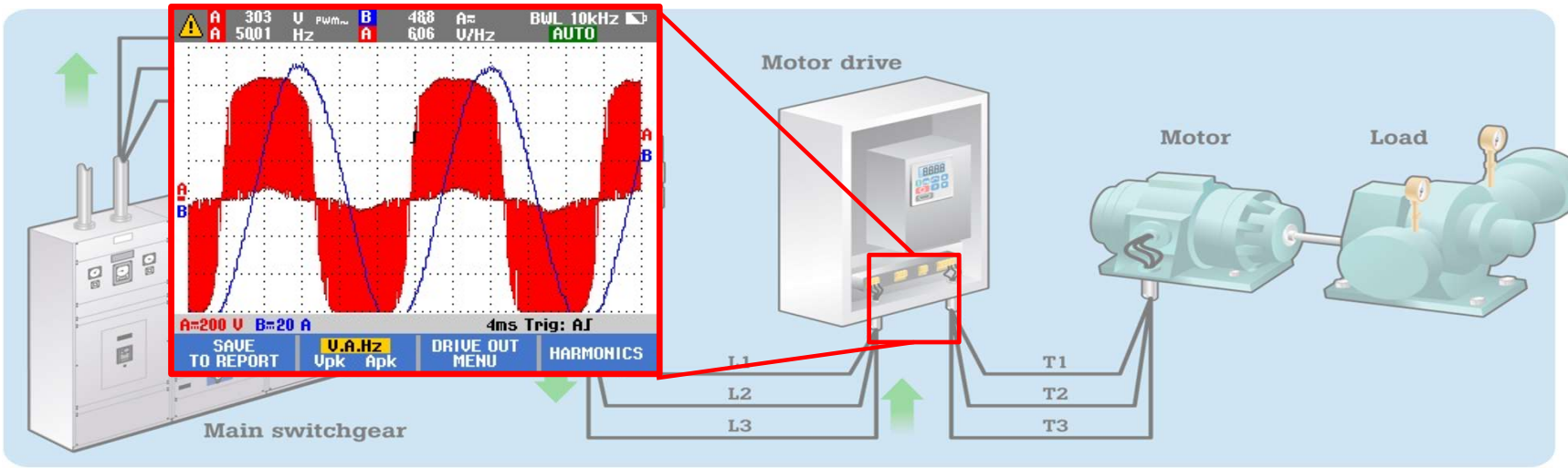
- IGBT's (Insulated gate bipolar transistor) connected to DC+ and DC- voltage supply are switched to generate bursts of positive and negative going pulses of energy.
- The burst of energy generate the rotating stator magnetic fields that rotates the shaft producing torque.

Measuring output nominal voltage current and frequency



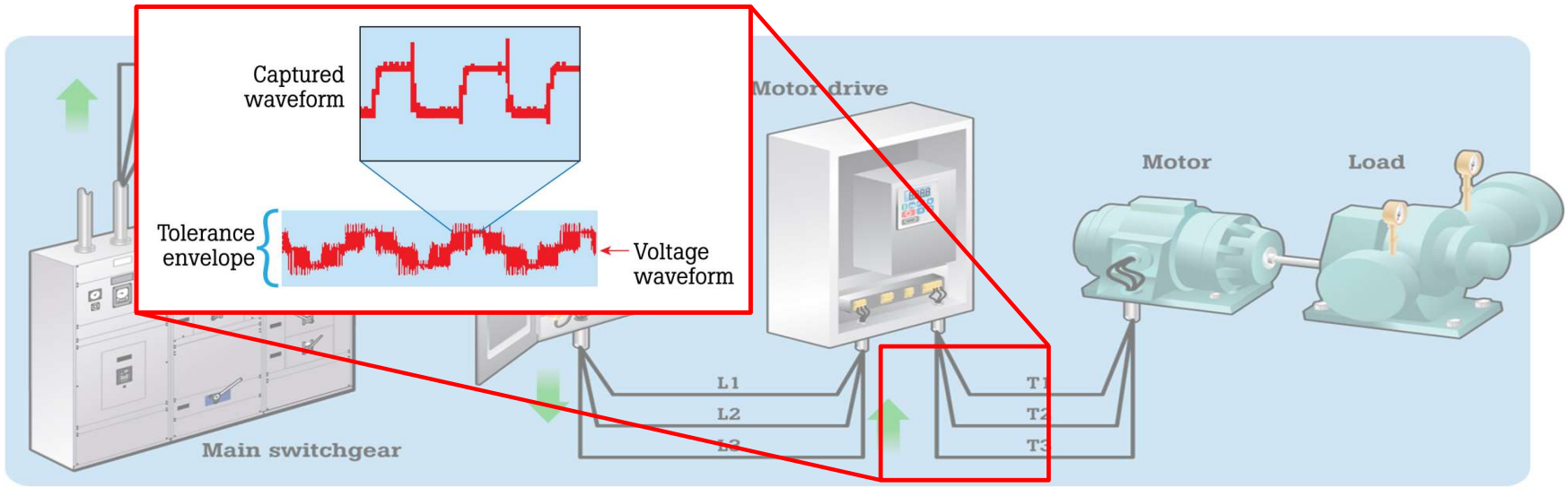
- The drive output is made up of fast switching pulses and is best measured with fast sampling motor drive analyzer.
- Attach to drive output terminals.

Interpreting output nominal voltage, current and frequency



- Check that the output voltage (Vpwm) and frequency matches the drive setting.
- Compare the current under operating load to the maximum current rating of the motor to ensure the motor is not being overloaded.

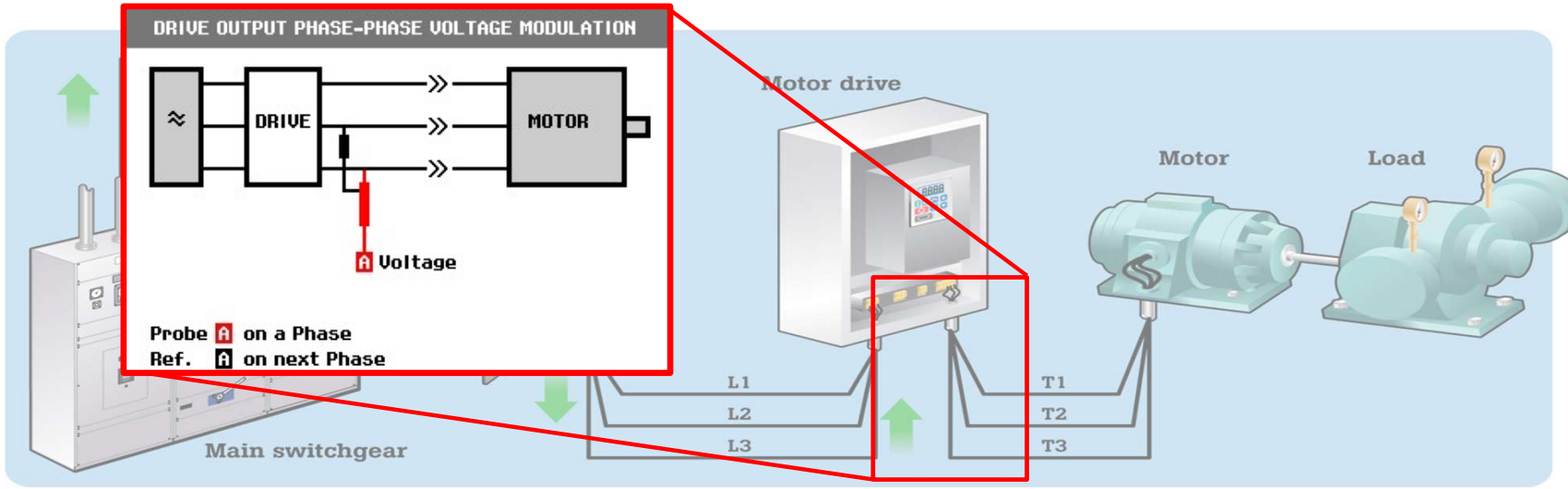
What are output reflections?



Reflections:

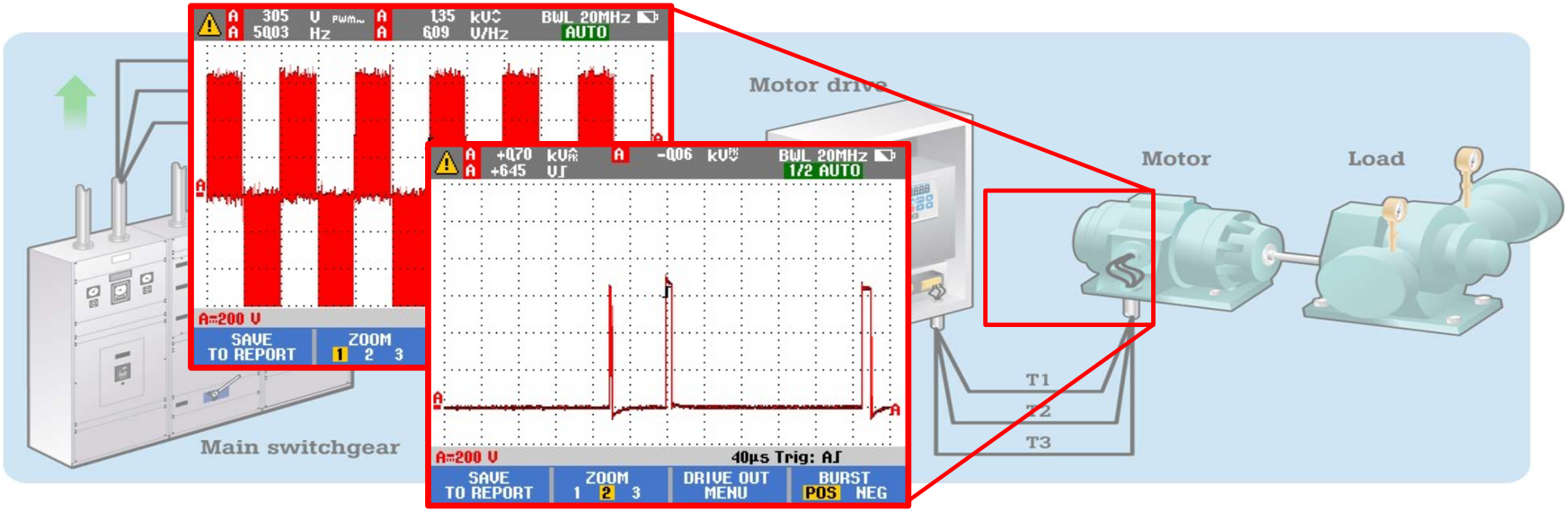
- Occur as a result of impedance mismatch and motor winding inductive reactance.
- Have a wide range of waveforms, amplitudes, and durations.
- Show up as spikes on an oscilloscope display.

Measuring output reflections



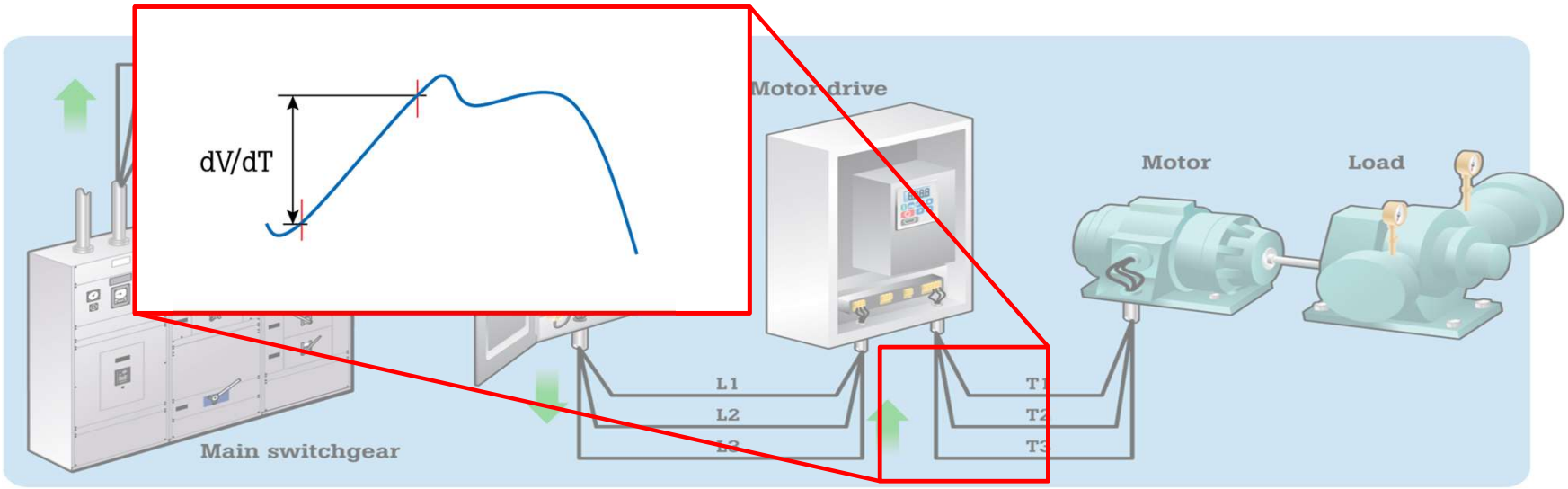
- Fast output transients and reflections on pulse width modulated waveform can only be measured with an oscilloscope.
- Attach to motor terminals.

Interpreting output reflection measurements



- Reflections or transients > 50% of nominal voltage are problematic.
- Reflections of the PWM signal as a result of a too long cable.
- Make sure the level does not exceed the motor insulation rating.

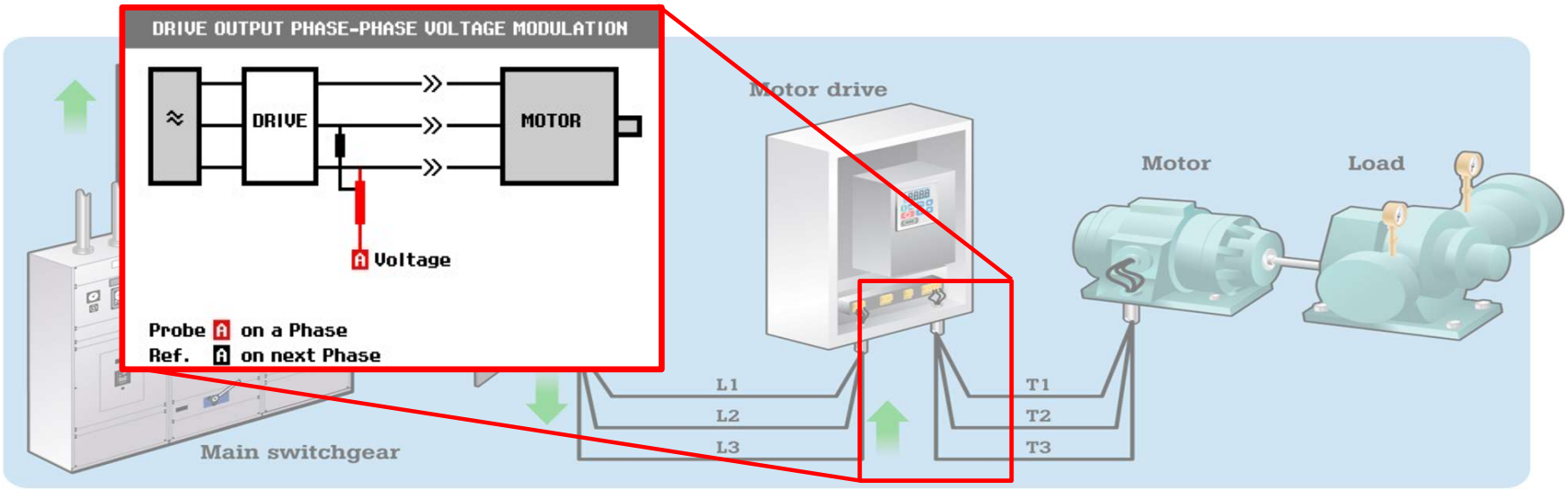
What is drive output pulse dV/dt?



dV/dt Ratio:

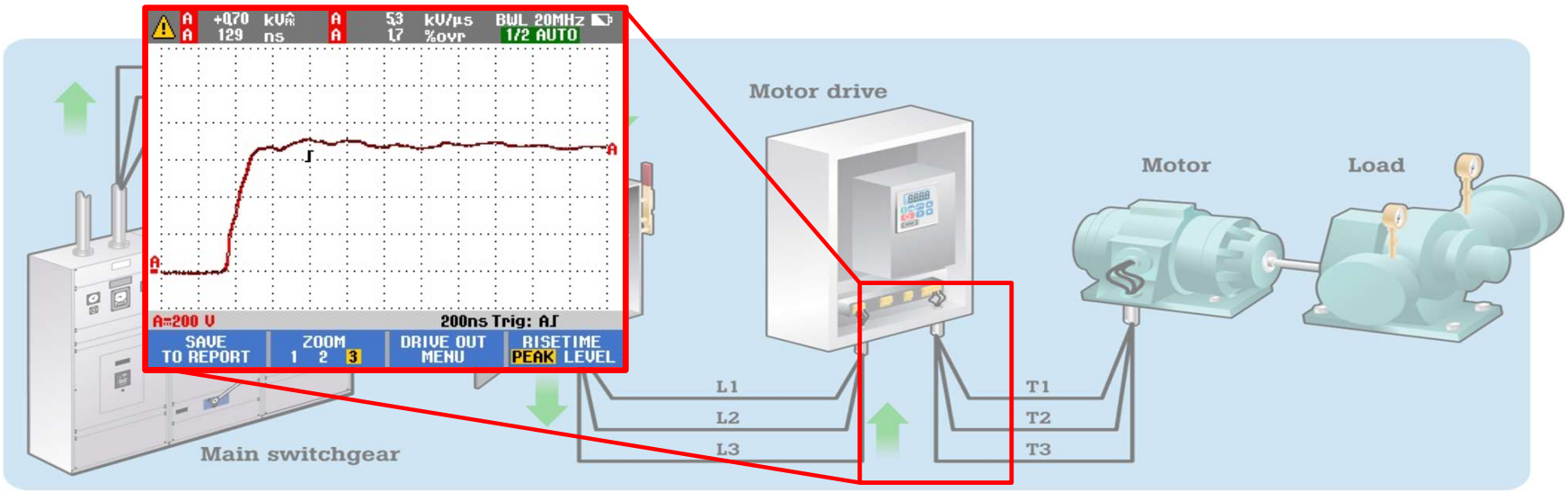
- Occur as a result of impedance mismatch and stator winding inductive reactance.
- Have a wide range of waveforms, amplitudes, and durations.
- Excessive peak voltage can break through winding insulation and cause a motor winding short.

Measuring output reflections



- Pulse width modulated waveform dV/dt can only be measured with high resolution oscilloscope.
- Attach to motor terminals.

Interpreting output pulse dV/dt



- The peak voltage can reach 2x DC bus voltage.
- 2006 NEMA MG 1, Part 31 guideline states for definite purpose inverter fed Polyphase Motors with a 480V AC fed VFD, the motor insulation can withstand 1490 V.

Corrective actions

Symptom:	Measurements:	Solution:
• Noisy motor • Drive output voltage and current faults • Shorten life of Drive, cabling, bearings and motor	• Perform phase voltage measurements peak to peak • Measure motor temperature • Measure winding resistance and insulation • Vibration test for bearing health	• Shorten cabling between the drive and the motor or • Install low pass filter, series line reactors or RC-impedance matching filter between the drive and motor • Rewind motor windings and cabling with higher insulation rating if reflections not reduced • Replace bearings

Drive and drive output – Summary

1. Measure the DC bus voltage to determine if one of the rectifier diodes or capacitor is malfunctioning, or the drive rating is too small for the connected motor and load.
2. Identify motor problems by analyzing the electrical energy used to create mechanical work by measuring the nominal output voltage, current and frequency using an oscilloscope.
3. Measure voltage on each terminal at the drive output to identify voltage unbalance, any level above 2% is problematic.
4. Output reflections or transients greater than 50% of nominal voltage are problematic and could be a result of a too long cable.

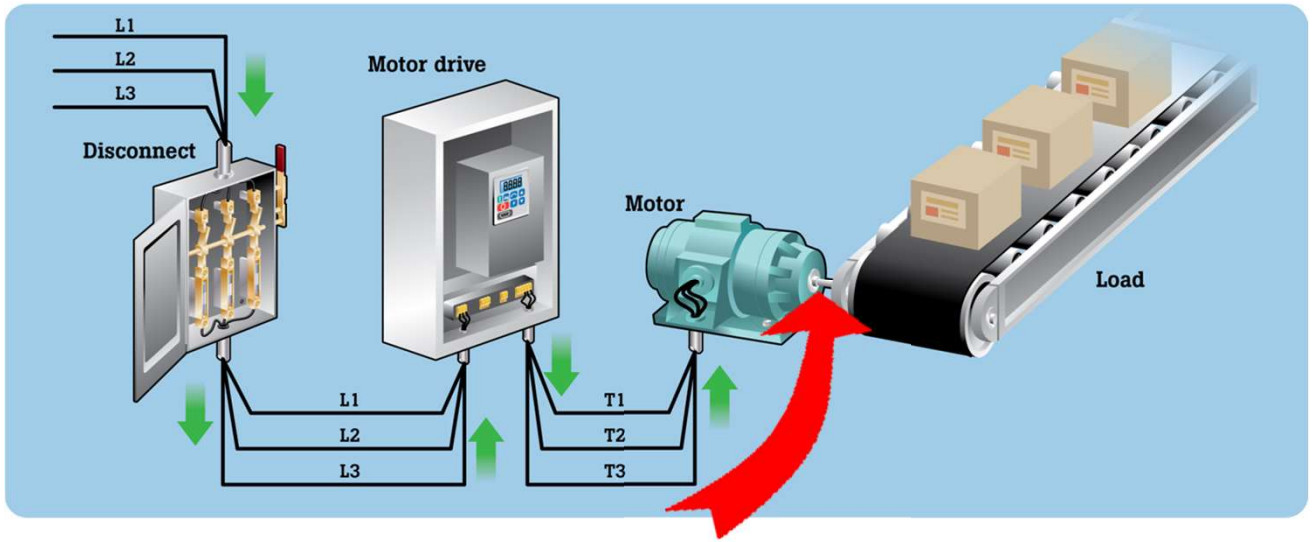
- Arrive at problem resolution faster.
- Prolong motor drive and motor life.
- Reduce potential of winding insulation breakdown.
- Avoid tripping overvoltage circuits.

SEMINAR SERIES

Measurement best practices for troubleshooting motors and drives

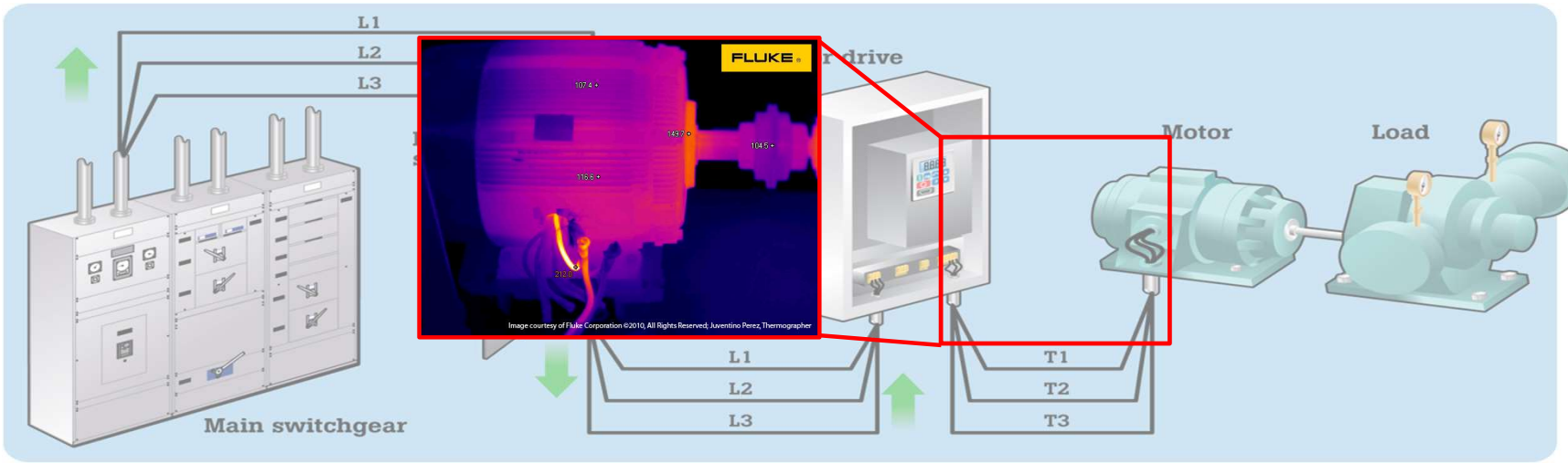
Motor and Drive Train Measurements

Introduction to motor and drive train measurements



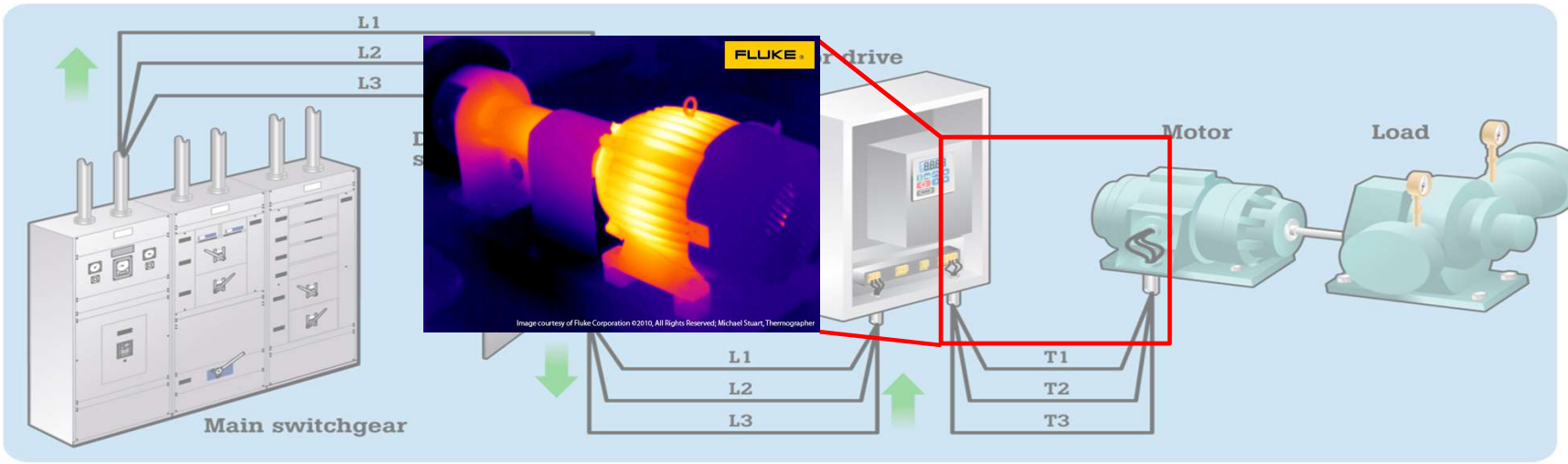
- Thermal signature, symptoms of overload conditions

Thermal signatures of key components in the motor drive output



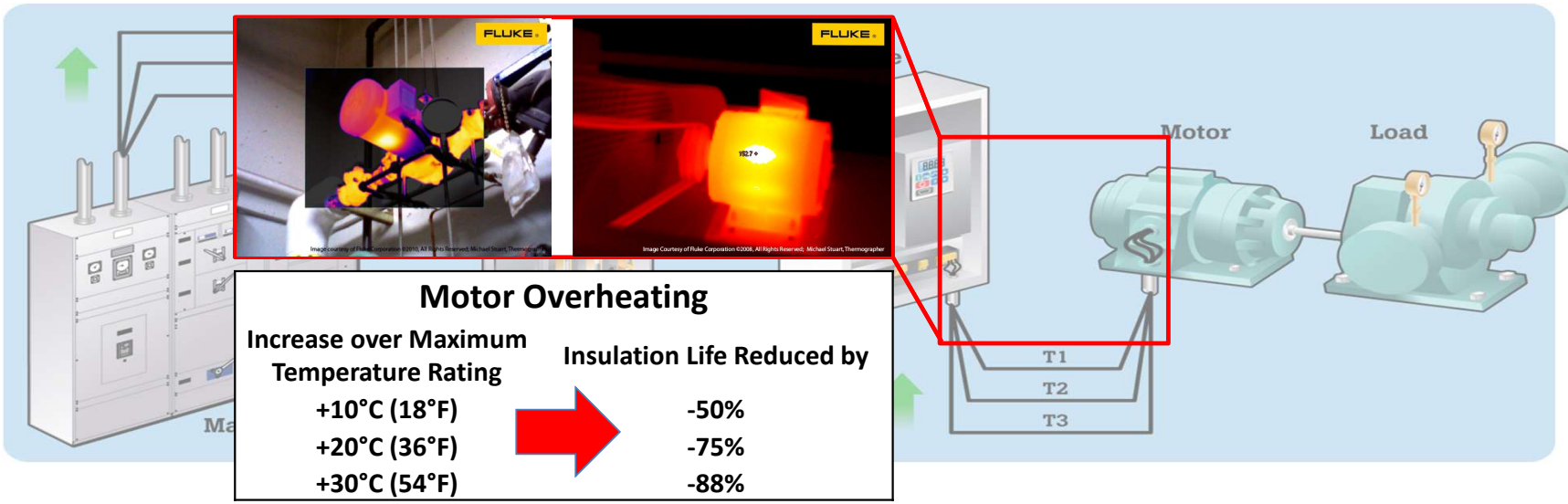
- Thermal imagers can be used to scan the motor drive output to identify hot spots or abnormal heating conditions.

Measuring the thermal signatures of key components in the motor drive output



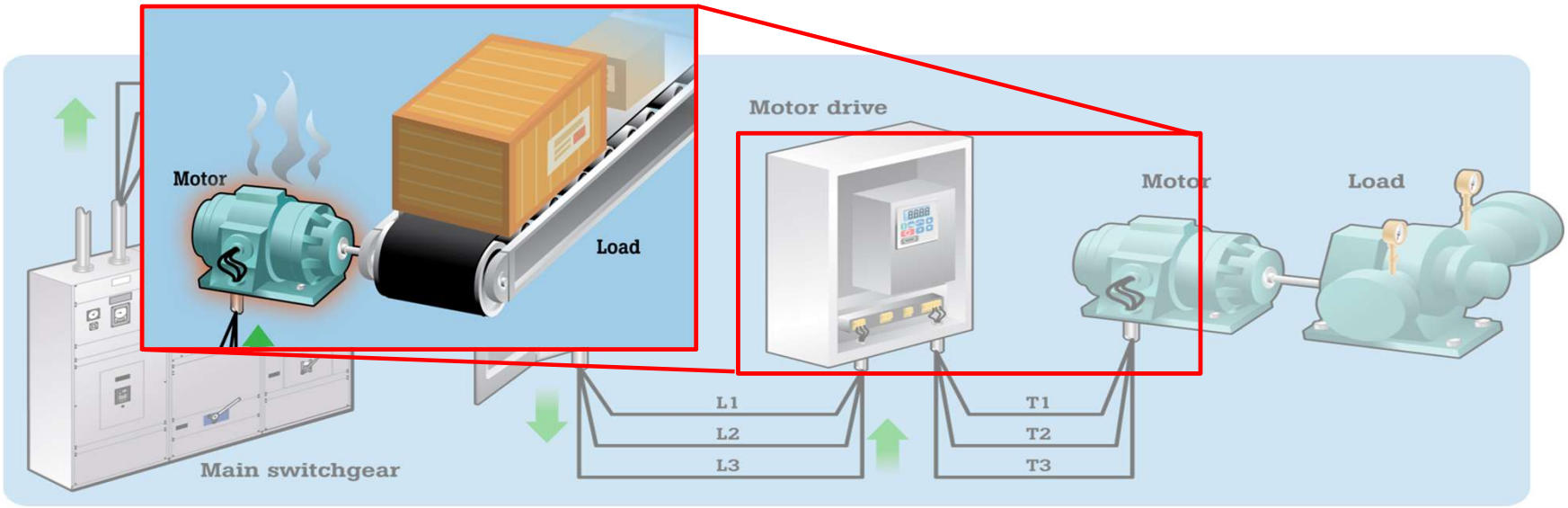
- Use a thermal imager to scan the component and look for irregular and non-uniform thermal patterns or anomalies.

Interpreting the thermal signatures of key components in the motor drive output



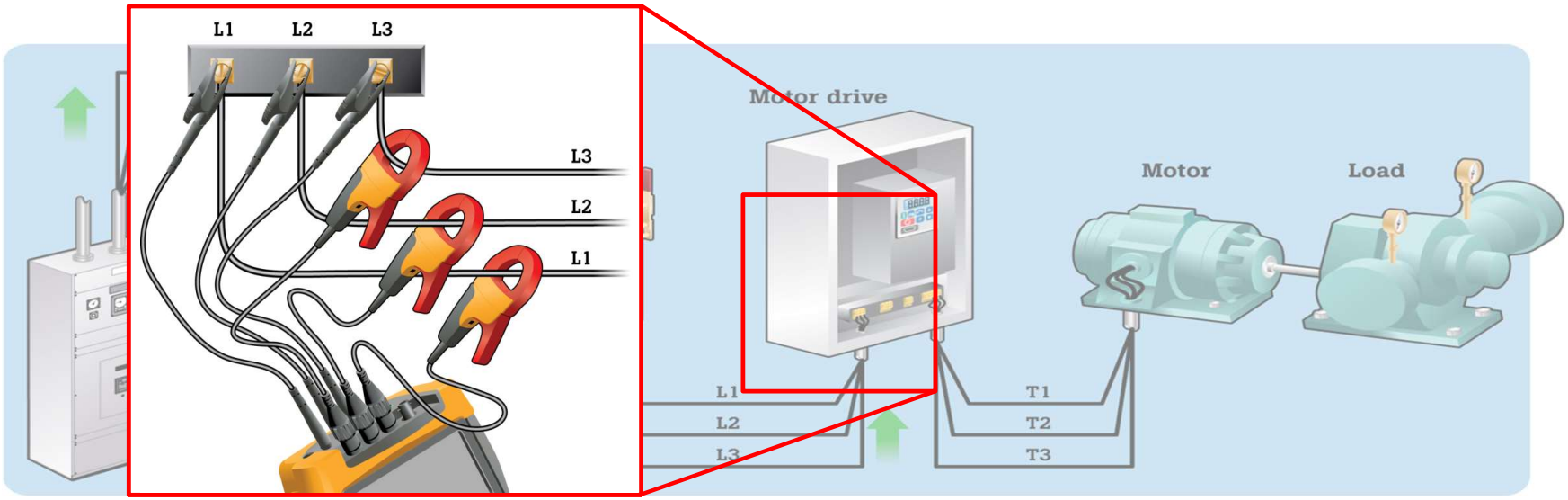
- High resistance connections, phase imbalance and current overload contribute to variations in thermal signatures.
- Motor overheating can be caused by winding insulation and cooling problems.

What is an overloaded motor?



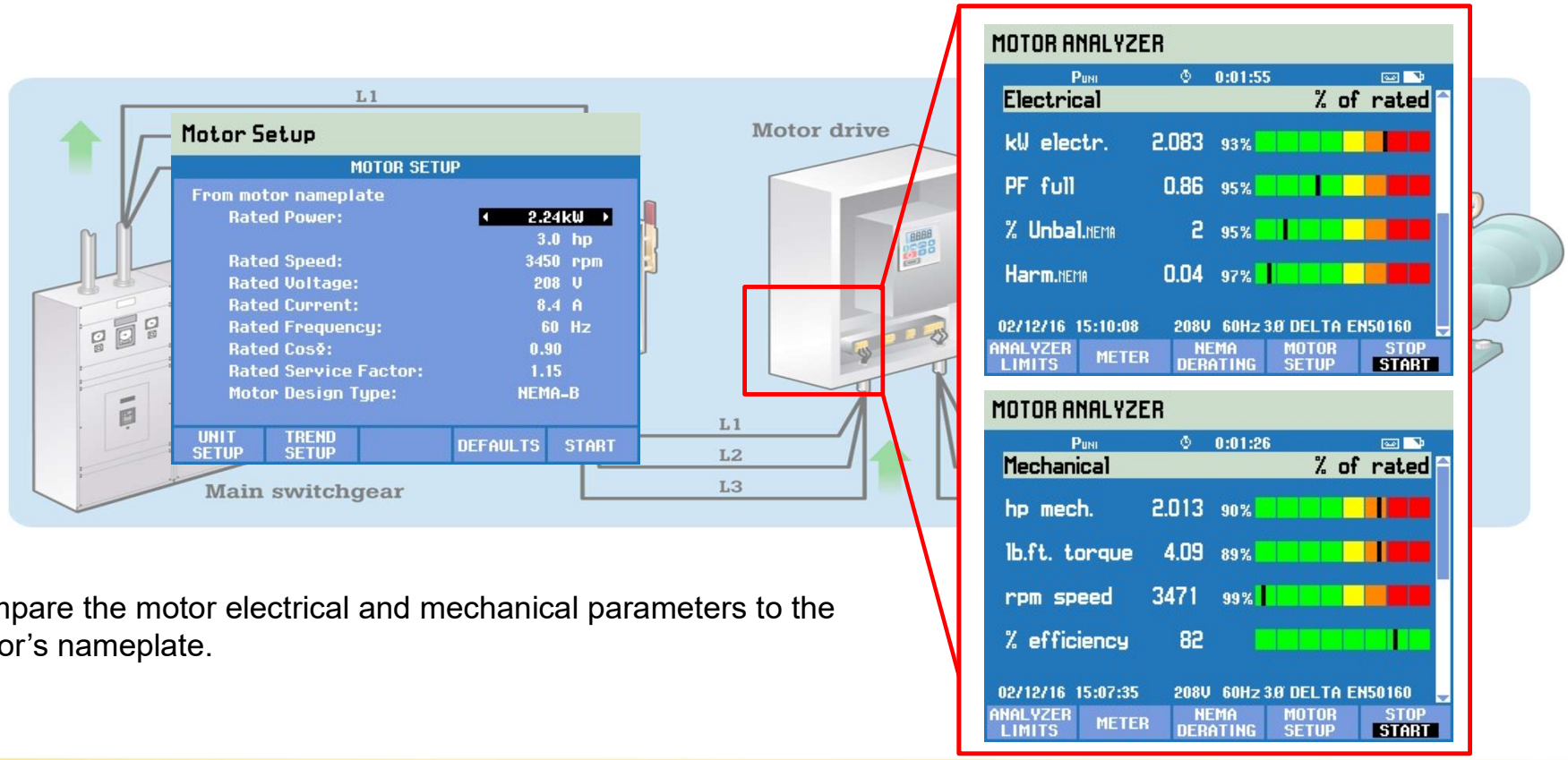
- Excessive load on a motor causes overload.
- The condition of the electrical feed can impact the performance of a motor and therefore negatively impact motor electrical and mechanical load factor.

Measuring an overloading motor



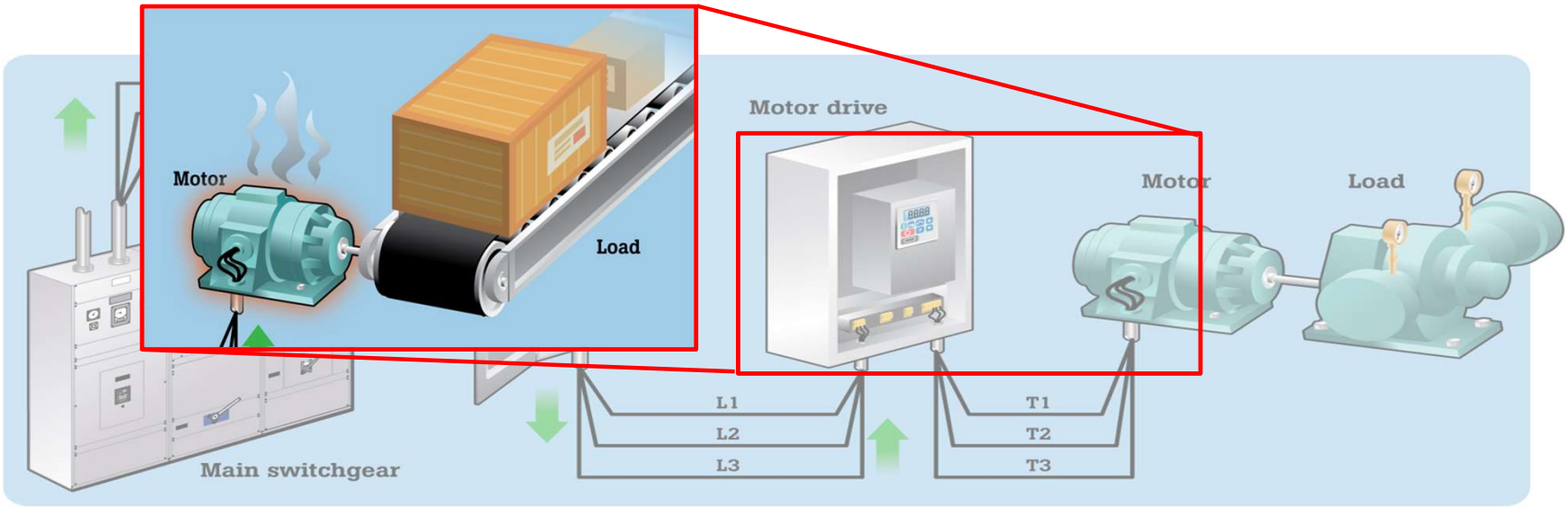
- Use a 3-phase power quality and motor analyzer to test power quality, electrical load and mechanical load.

Interpreting overloaded motor measurements



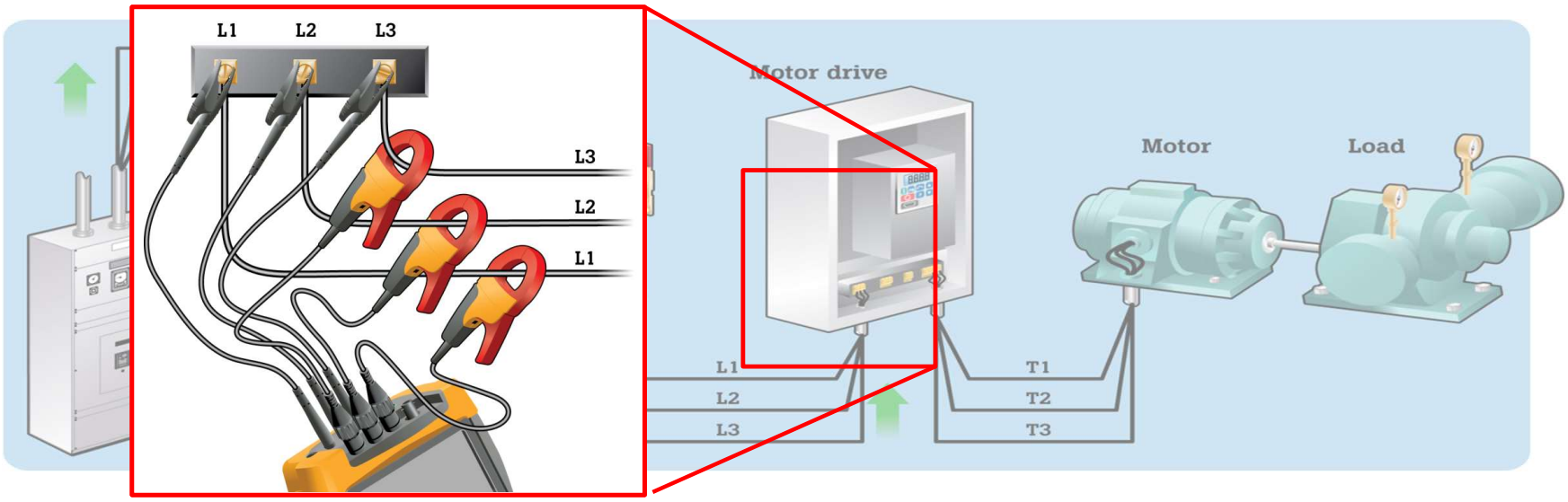
- Compare the motor electrical and mechanical parameters to the motor's nameplate.

What is motor derating according NEMA ?



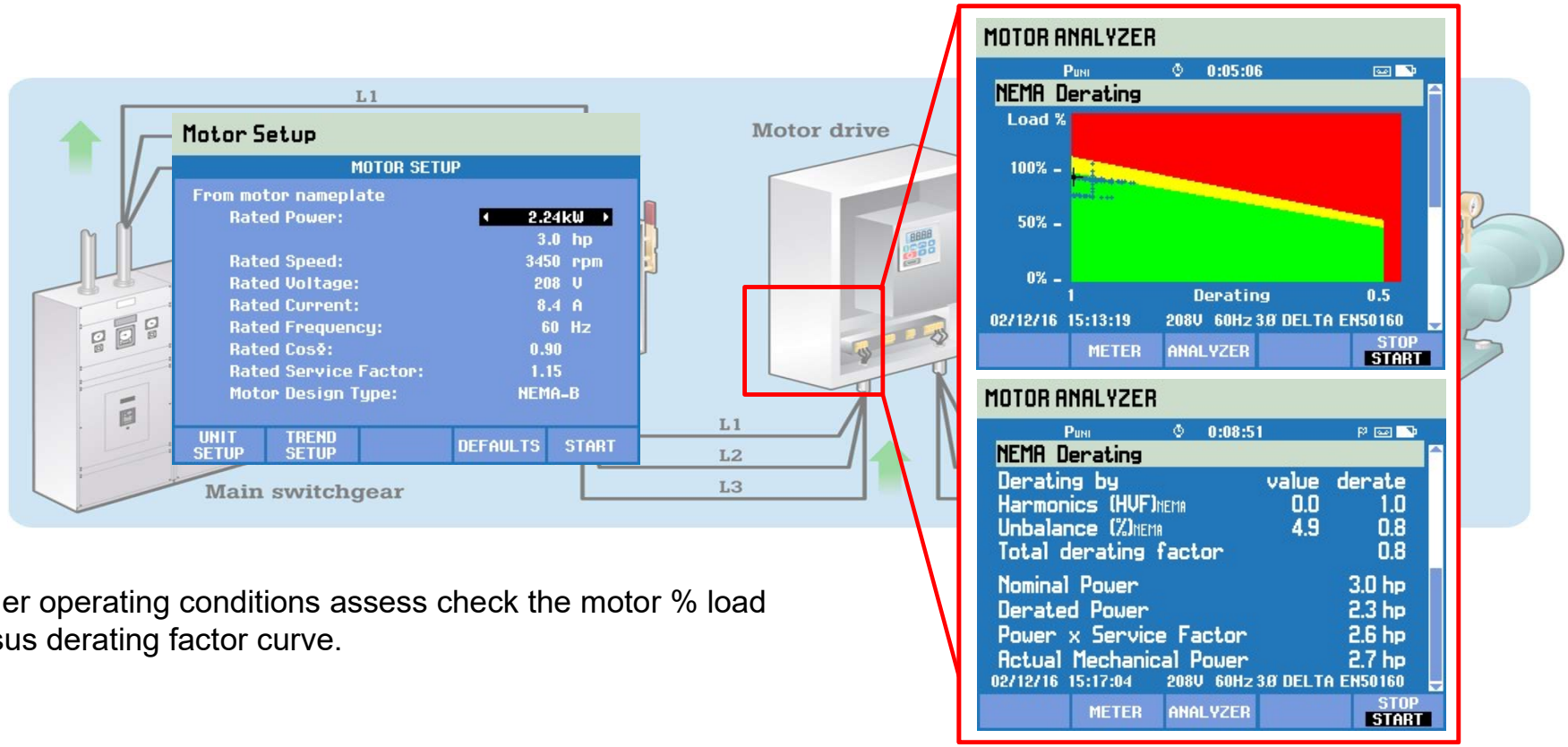
- The condition of the electrical feed can impact the performance of a motor and therefore negatively impact motor electrical and mechanical load factor.

Measuring motor derating factor according to NEMA



- Use a 3-phase power quality and motor analyzer to test power quality and measure electrical and mechanical load.

Interpreting overloading motor measurements

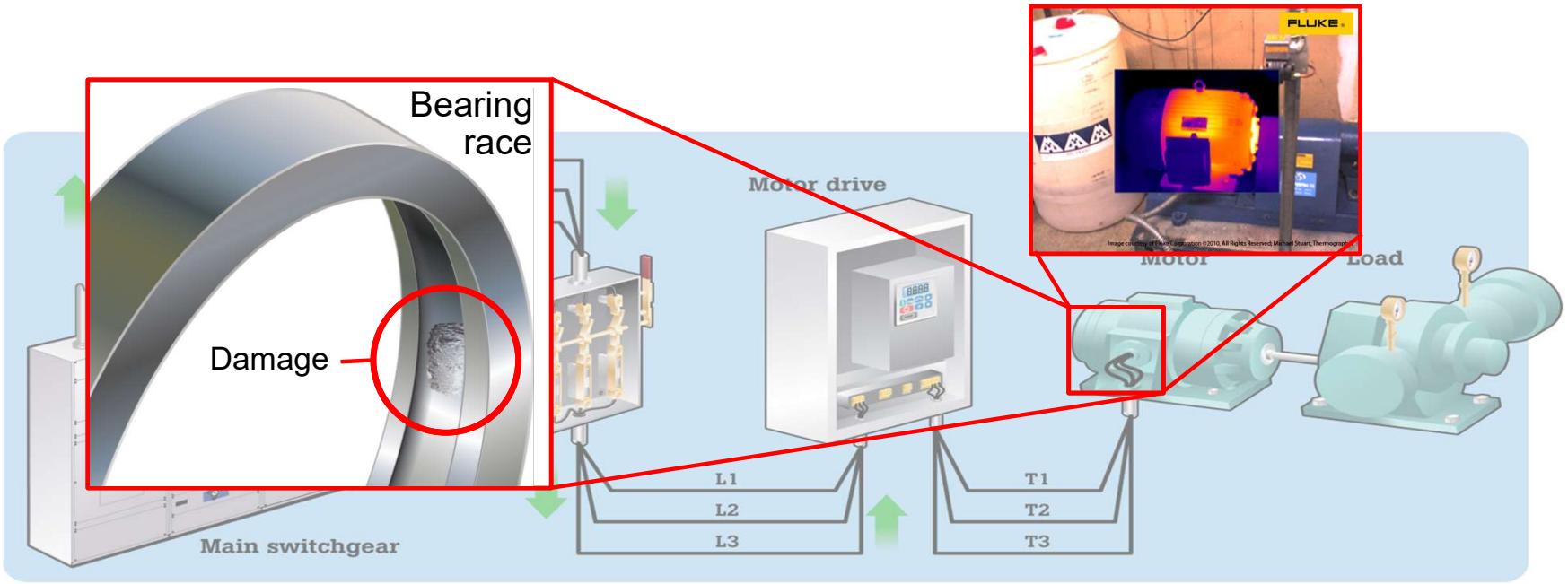


- Under operating conditions assess check the motor % load versus derating factor curve.

Diagnostic benefits

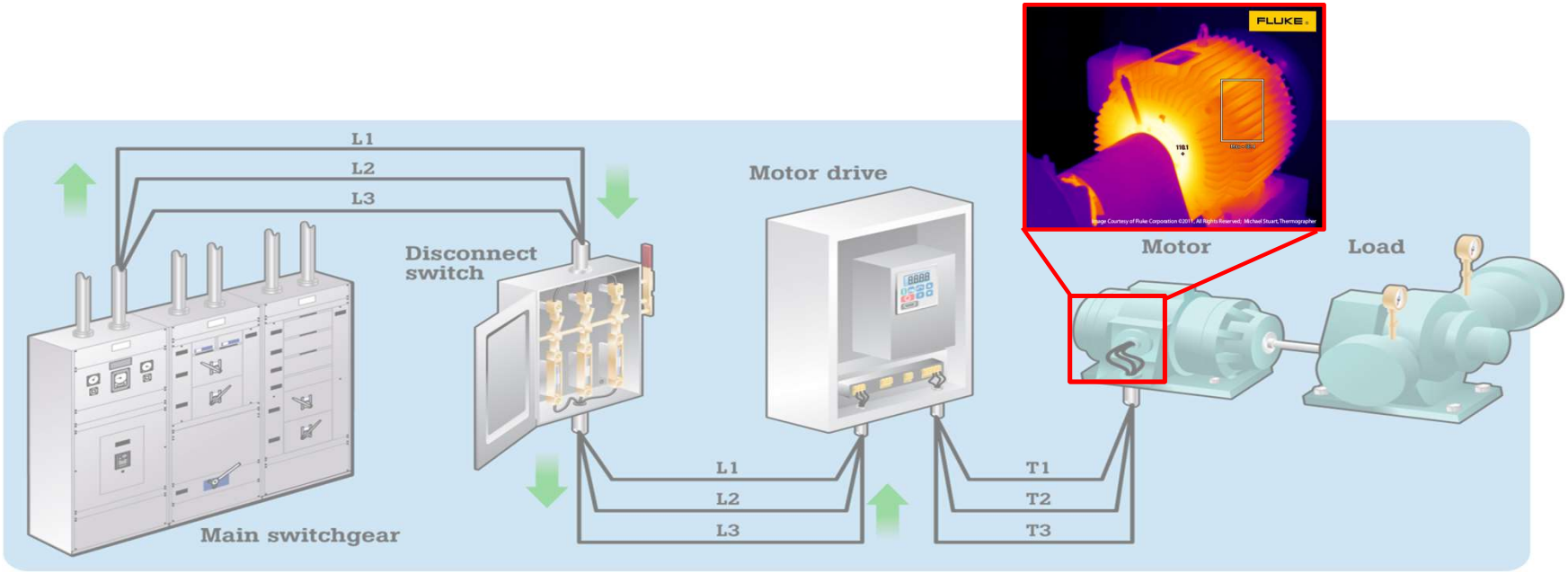
- Extend motor life.
- Avoid catastrophic failure.
- Reduce downtime and economic losses.

What are bearing failures?



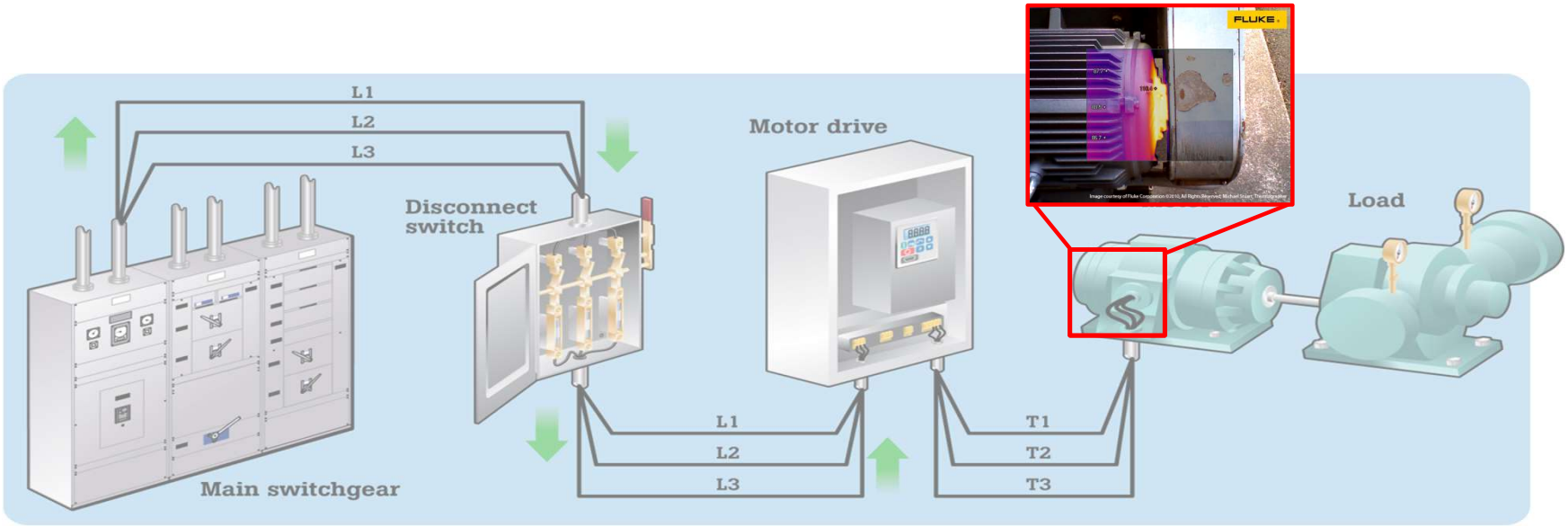
- A failed bearing is operating at reduced efficiency due to some type of failure.

Measuring motor bearing failures



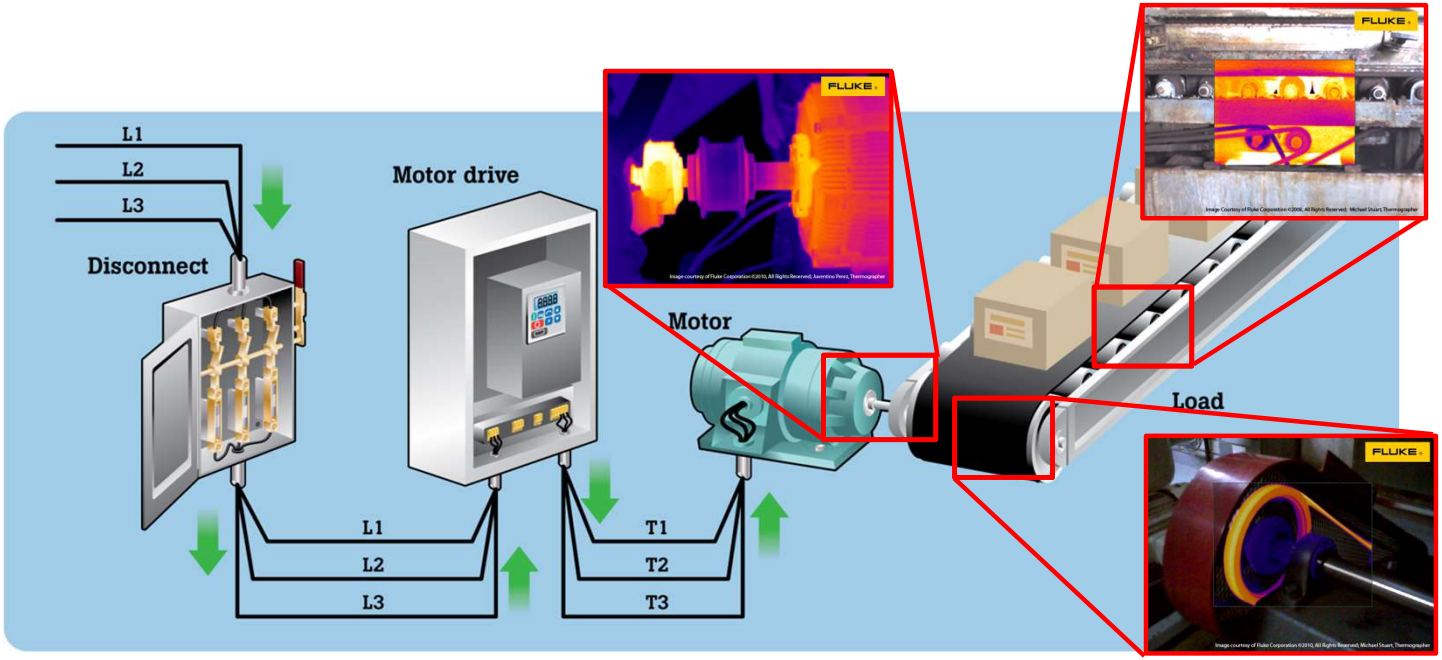
- Use either a thermal imager to look for abnormal heating or IR thermometer to compare suspect bearing to a known good bearing.

Interpreting bearing failure measurements



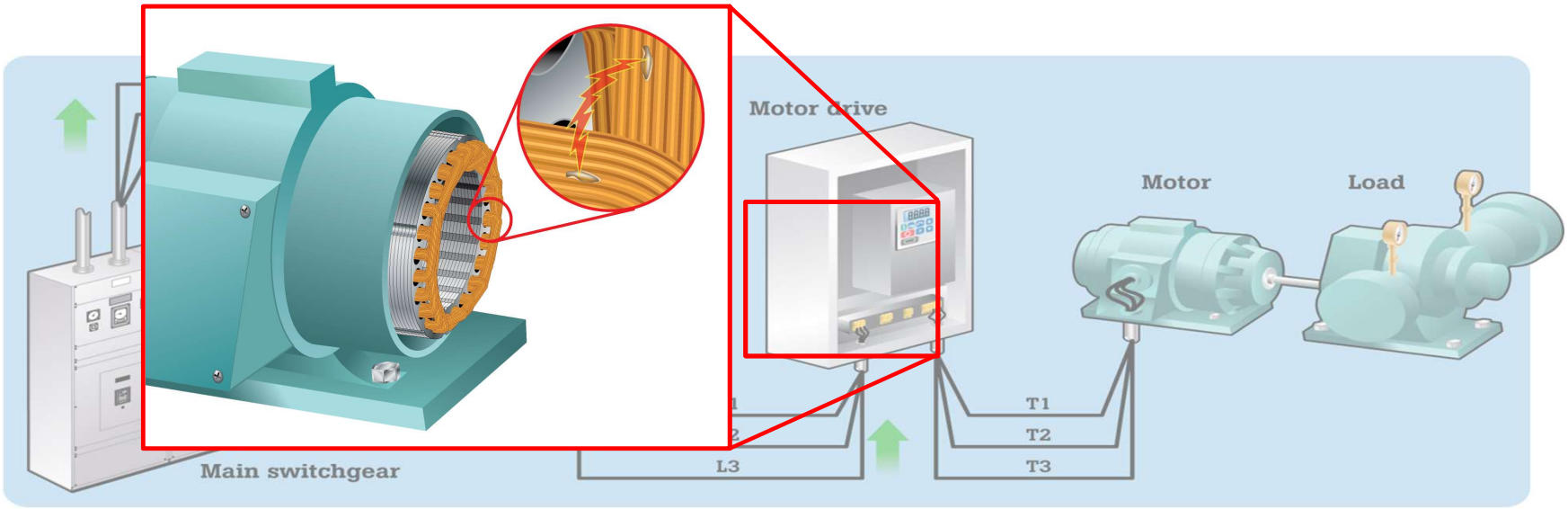
- A properly maintained and lubricated motor bearing should not typically be more than 5° C warmer than the motor casing.
- A temperature differential of more than 10 degree C may indicate the need bearing repair or replacement.
- Next, check for misalignment.

Other areas of drive train inspection



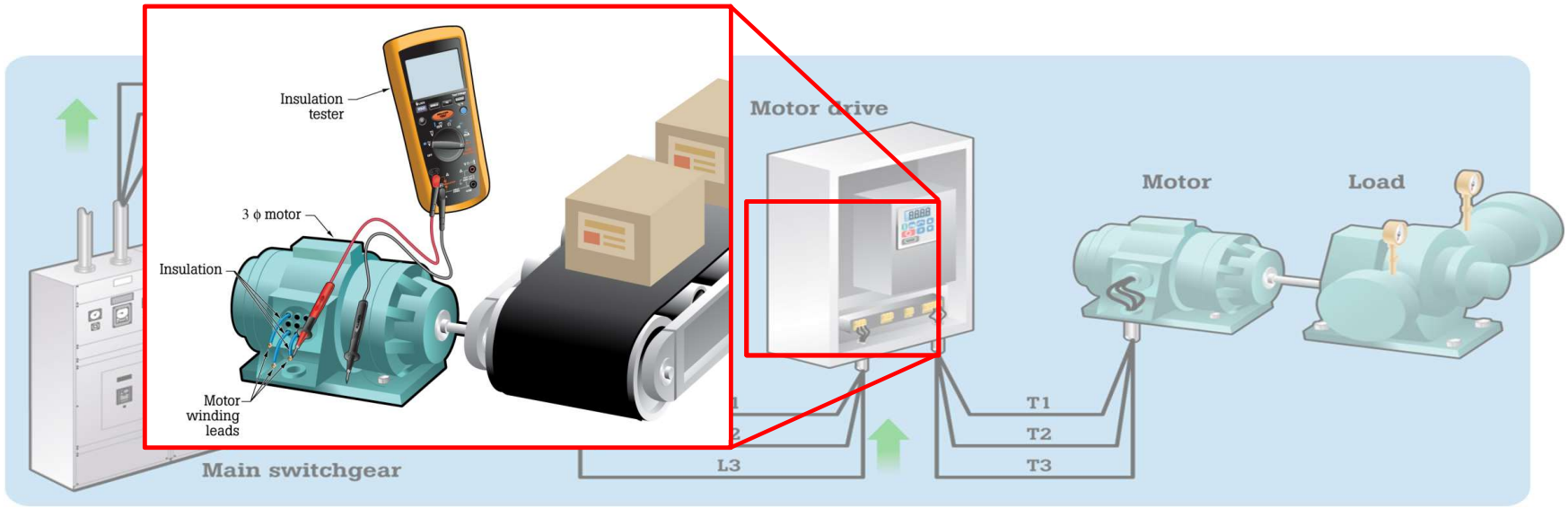
- Thermal imagers are also quite useful as a non-contact way to inspect couplings, roller bearings, belts, drive trains, and gear boxes.
- Sometimes, problems or failures in these components can be the root cause of a bearing issue on a motor.
- Problems or failures in these areas can often reduce or negate the system efficiency gained by the use of the motor drive in the first place.

What is insulation breakdown?



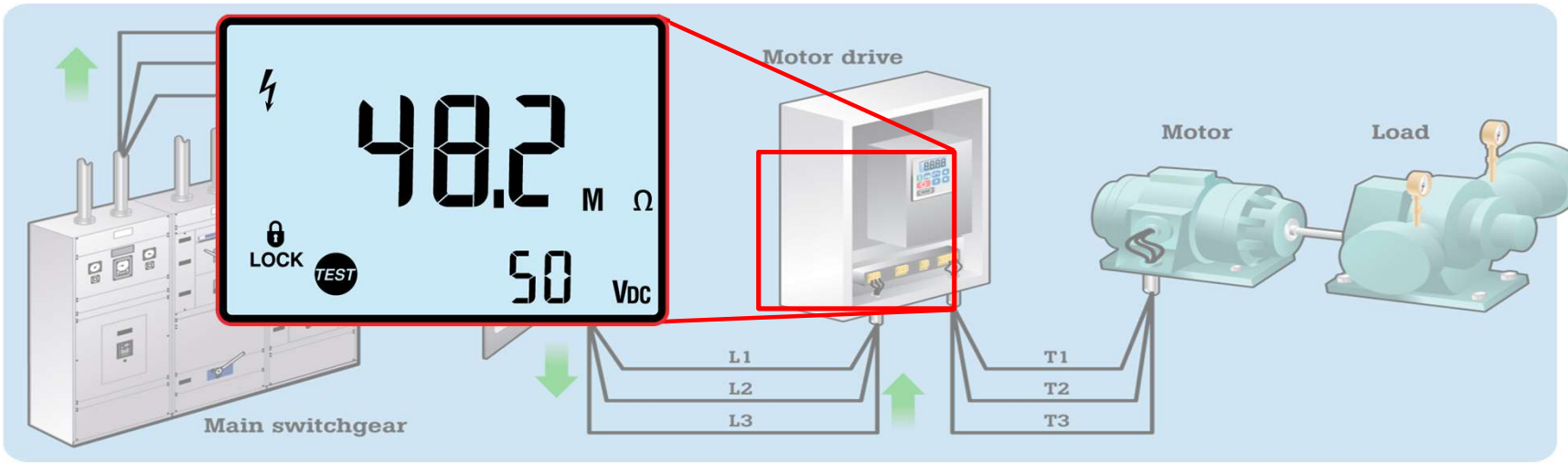
- Occurs when the insulation between motor windings deteriorates, causing a short circuit in the windings.

Measuring insulation breakdown



- Use an insulation resistance tester to measure each phase of the motor stator windings to ground.

Interpreting insulation breakdown measurements



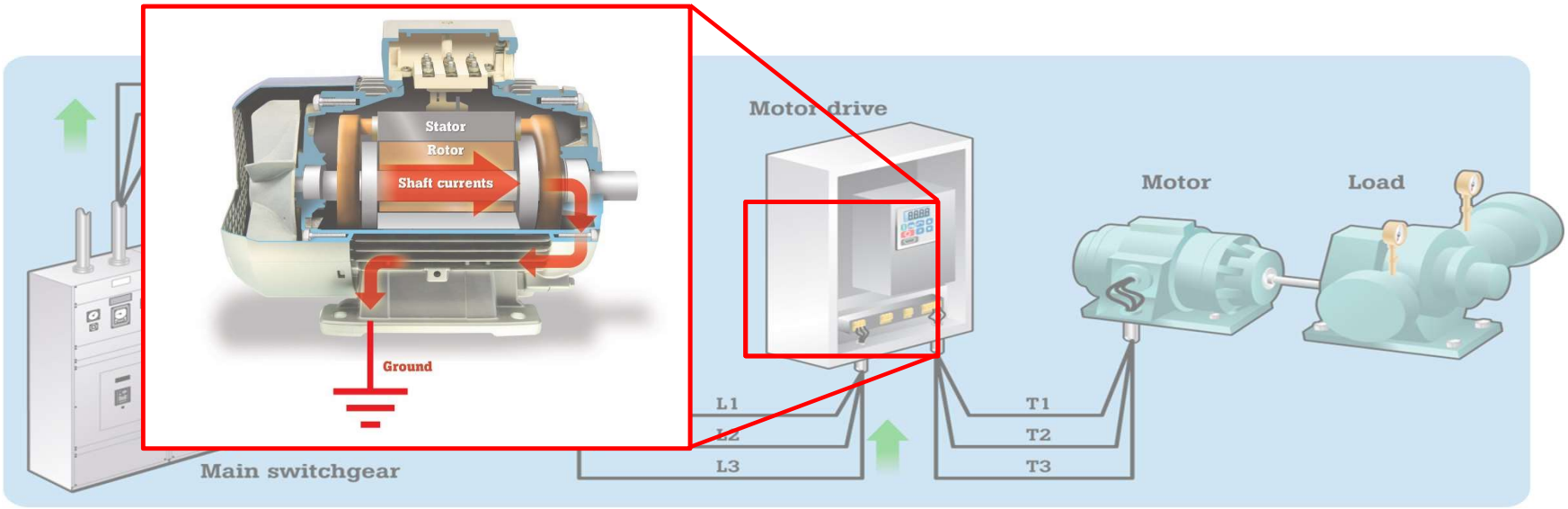
- Look for a resistance value of >1 megaohm per kilovolt.
- Best if part of periodic maintenance schedule.
- Next, check for shaft voltage and bearing current.

Diagnostic benefits

- Avoid catastrophic motor failure
- Avoid downtime and economic losses

What is shaft voltage?

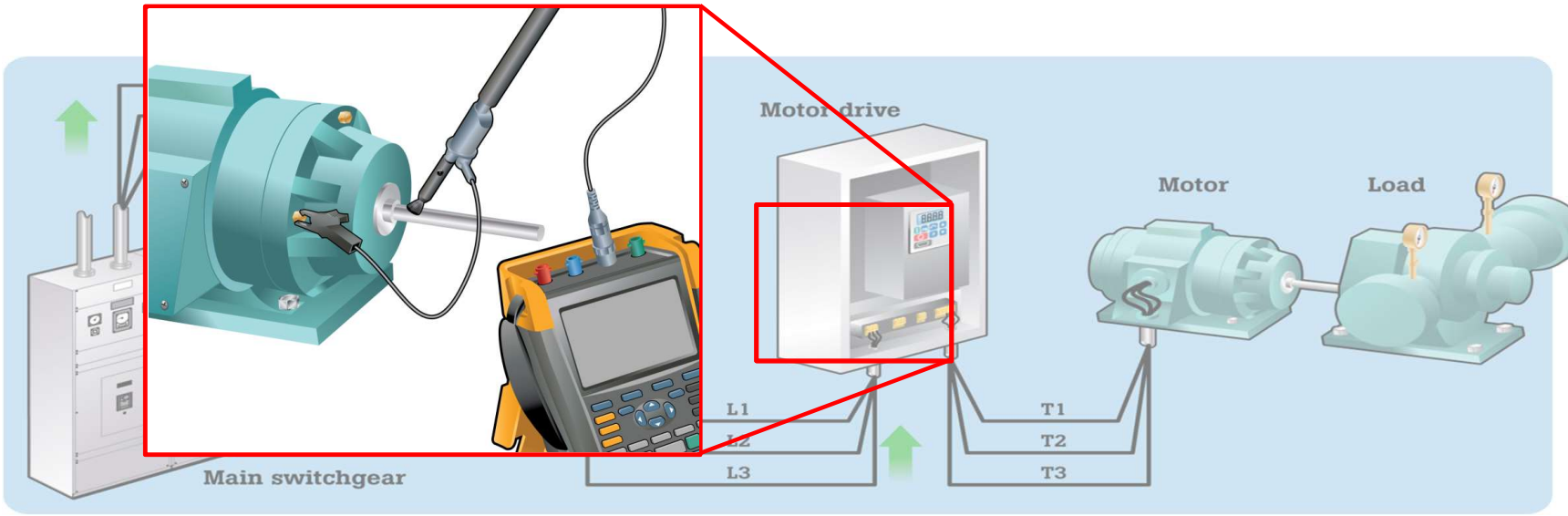
Advanced topic



- High frequency PWM voltages are capacitively coupled to the rotor and shaft.
- When the voltage on the motor shaft exceeds the insulating capability of the bearing lubricant, current flows through the bearing.

Measuring shaft voltage

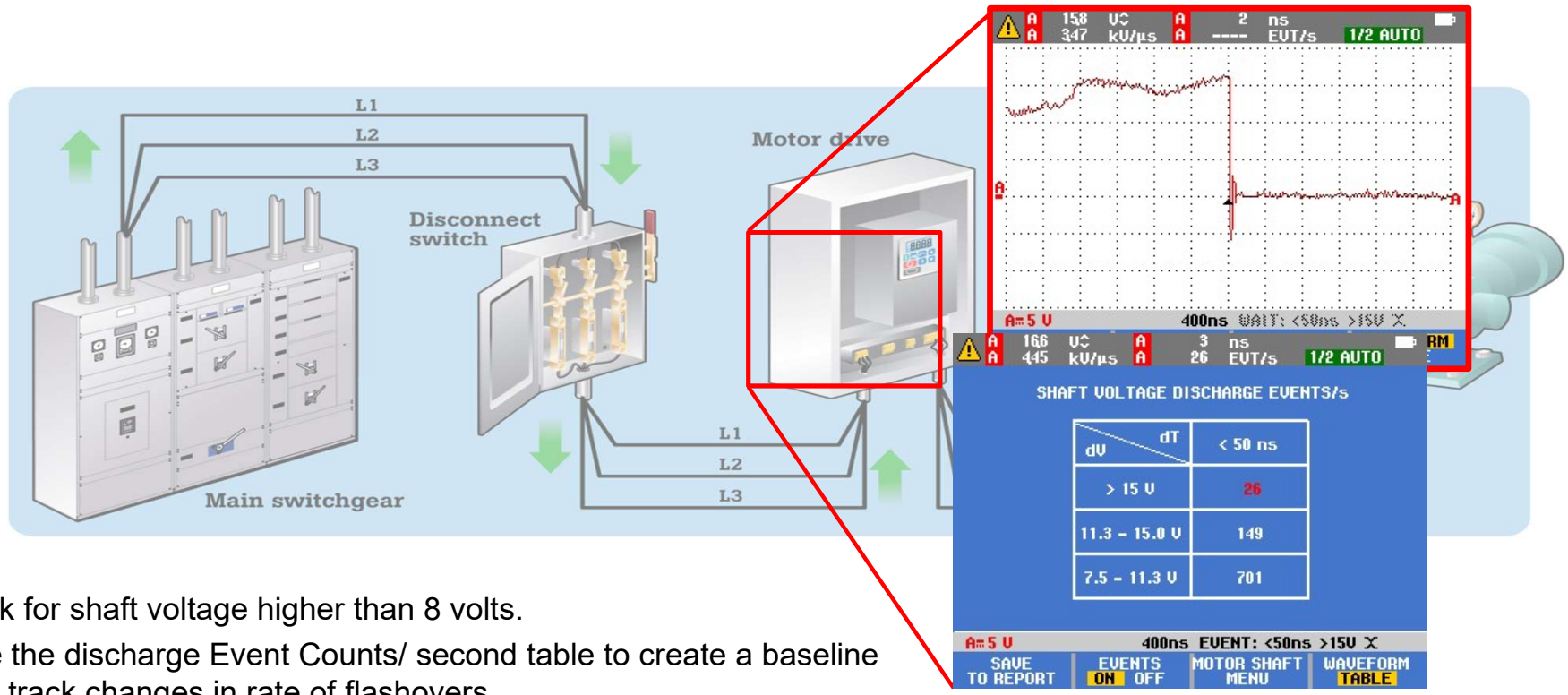
Advanced topic



- Use an oscilloscope and carbon brush or stranded wire probe to measure the voltage between the motor chassis ground and the drive shaft.

Interpreting shaft voltage measurements

Advanced topic

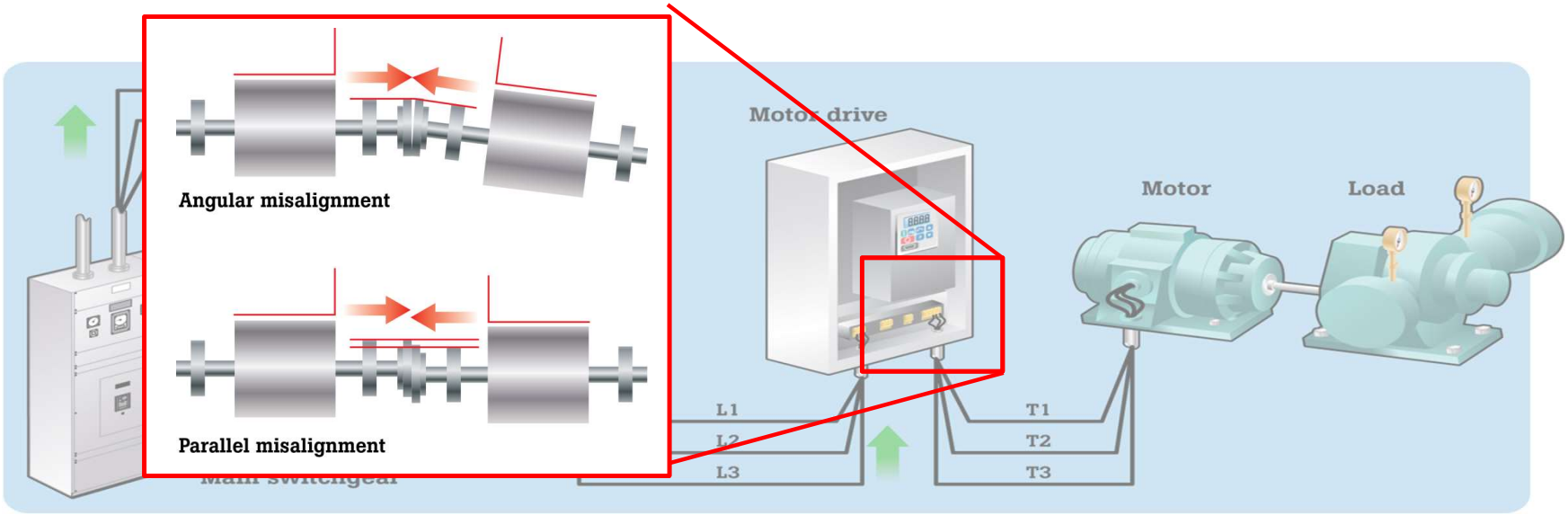


- Look for shaft voltage higher than 8 volts.
- Use the discharge Event Counts/ second table to create a baseline and track changes in rate of flashovers.

Motor measurements – Summary

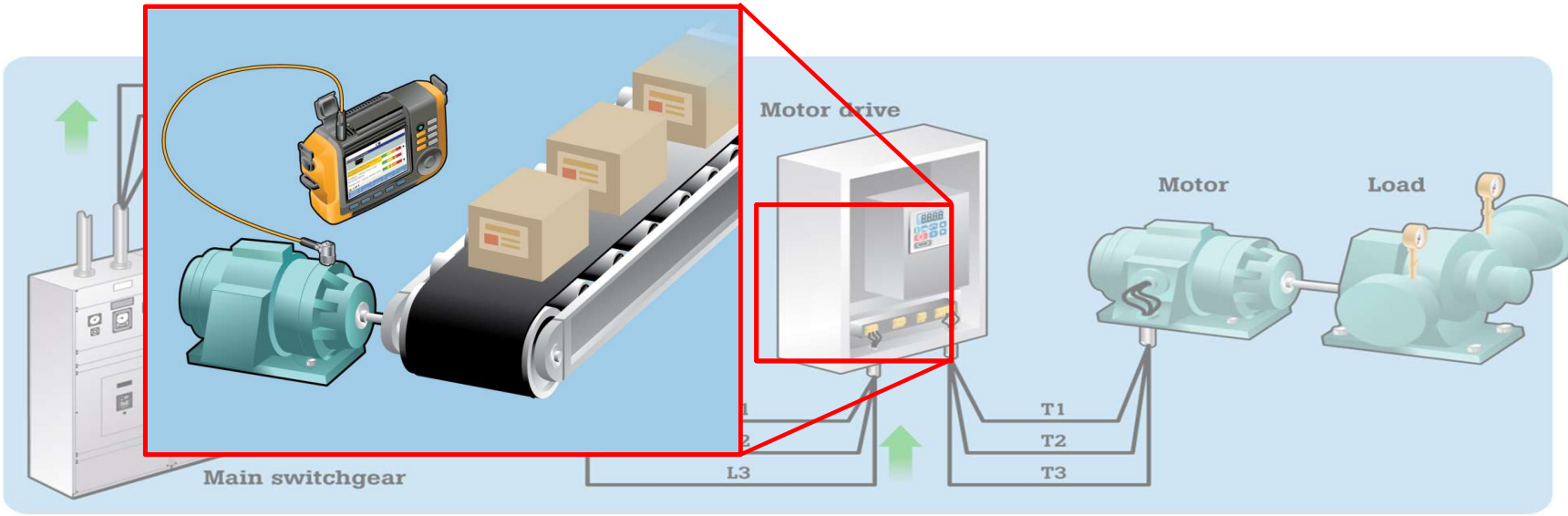
1. Thermal imagers can be used to scan the motor drive output to identify hot spots or abnormal heating conditions which identify electrical or mechanical issues.
2. An increase of 54˚ F over the motor's maximum temperature rating reduces the motor insulation life by 88%.
3. Use a 3-phase power quality and motor analyzer to test power quality, electrical load and mechanical load.
4. A properly maintained and lubricated motor bearing should not typically be more than 5˚ C warmer than the motor casing. A temperature differential of more than 10 degree C may indicate the need bearing repair or replacement.
5. Use an insulation tester to find a potential problem with a motor winding due to contamination, excessive, heat, over voltage transients or other factors, look for a resistance value of >1 megaohm per kilovolt.

What is misalignment?



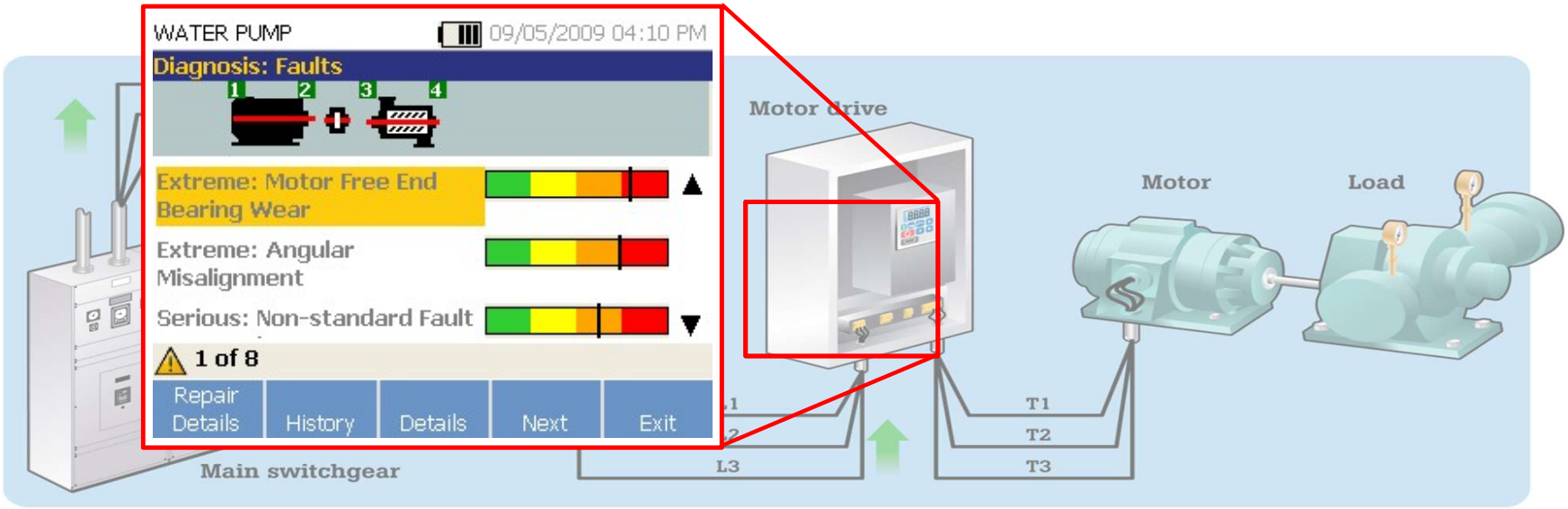
- In motor drivetrains, perfect alignment occurs when the centerline of two coupled shafts coincide.
- When they do not coincide, misalignment exists.

Measuring misalignment



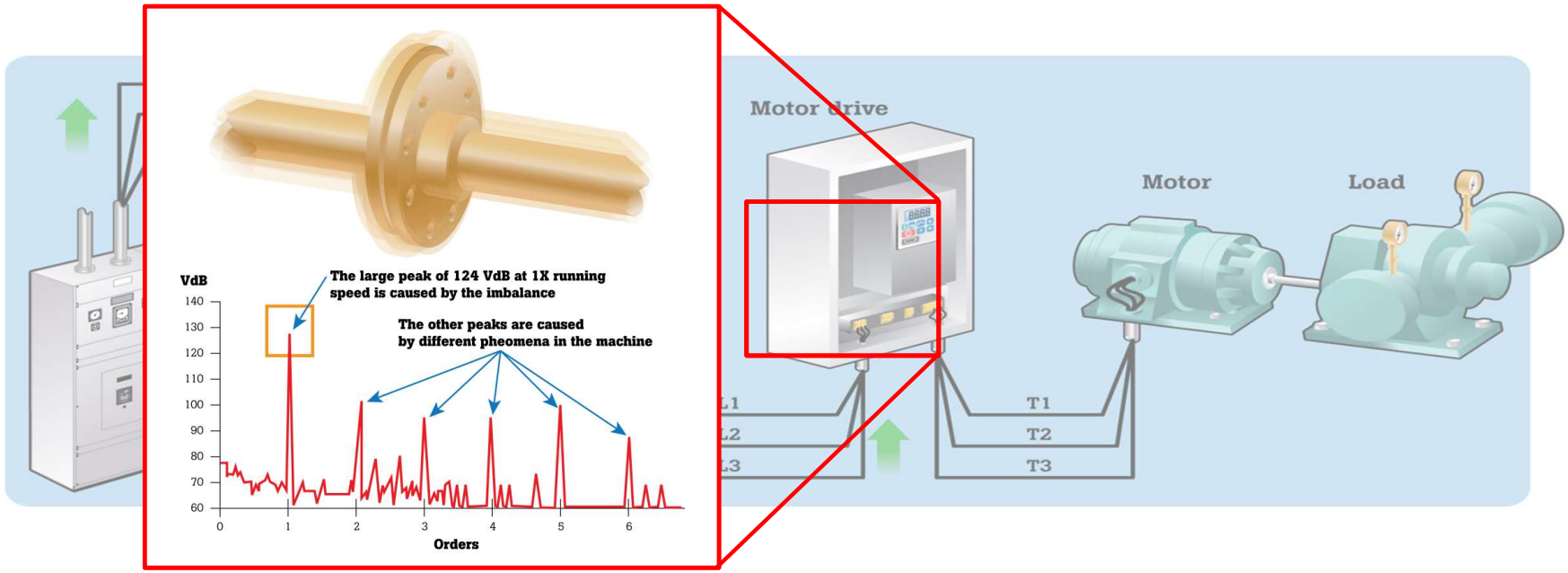
- Use a vibration tester to identify the vibration problem.
- In the case of misalignment, use a dial indicator or laser alignment device to correctly re-align device.

Interpreting misalignment measurements



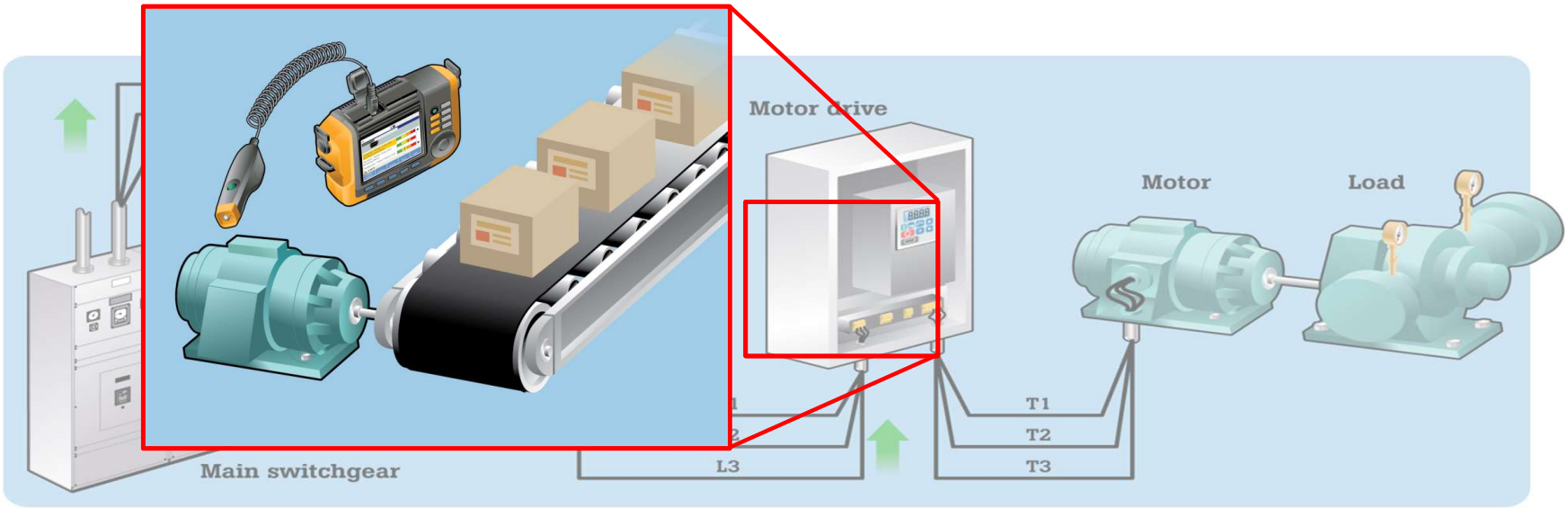
- The Fluke 810 makes this part easy.
- The 810 compares vibration data against an extensive database to generate an analysis.

What is Imbalance?



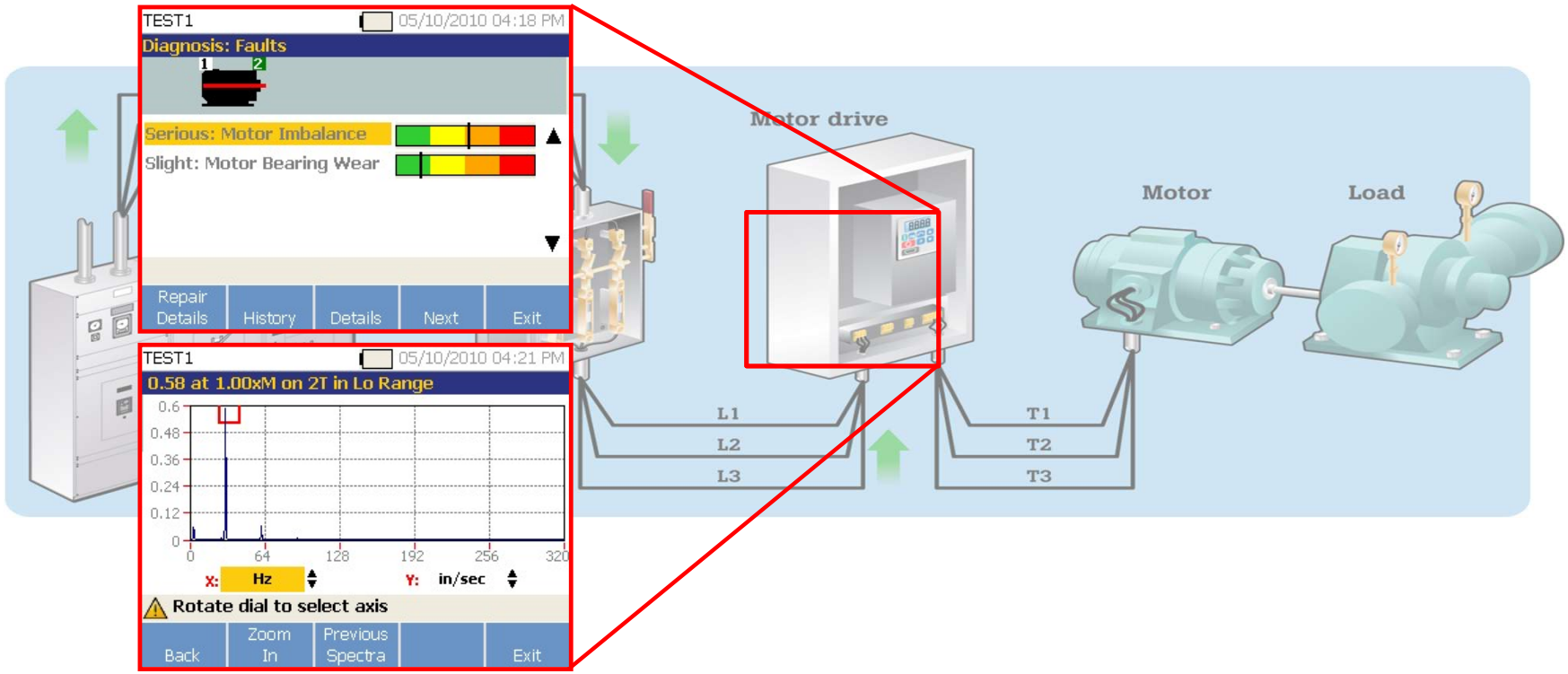
- Occurs when center of mass is not on center.
- Causes vibration.

Measuring imbalance



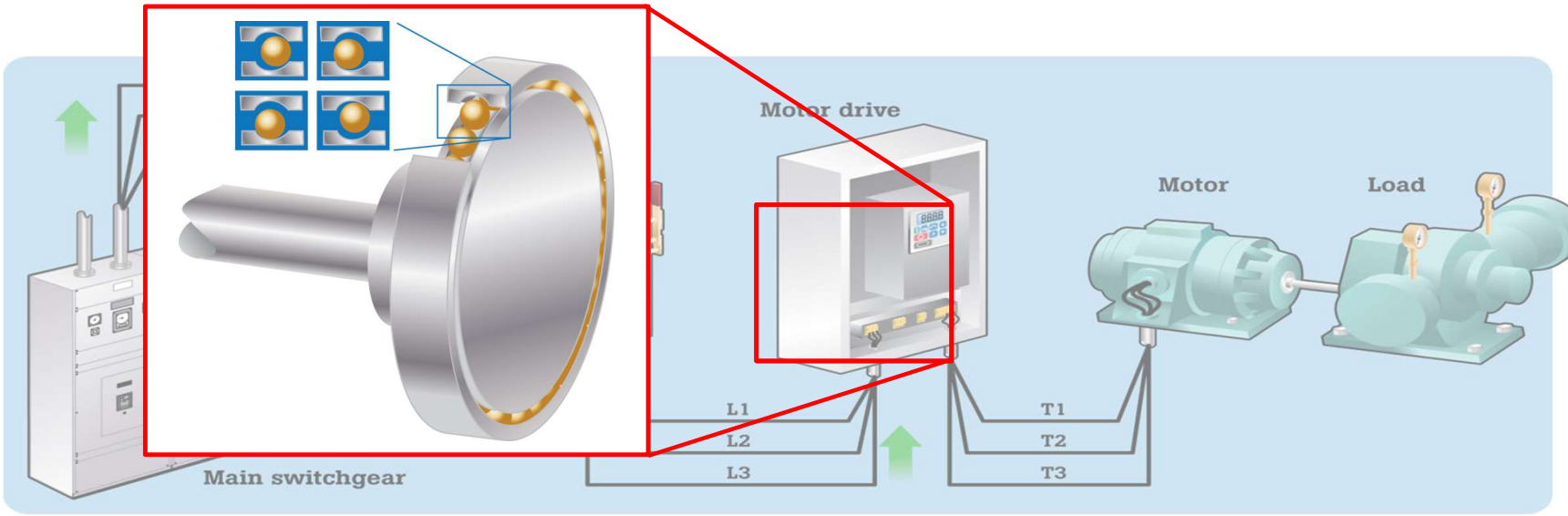
- Use the Fluke 810 vibration tester to measure imbalance.

Interpreting imbalance measurements



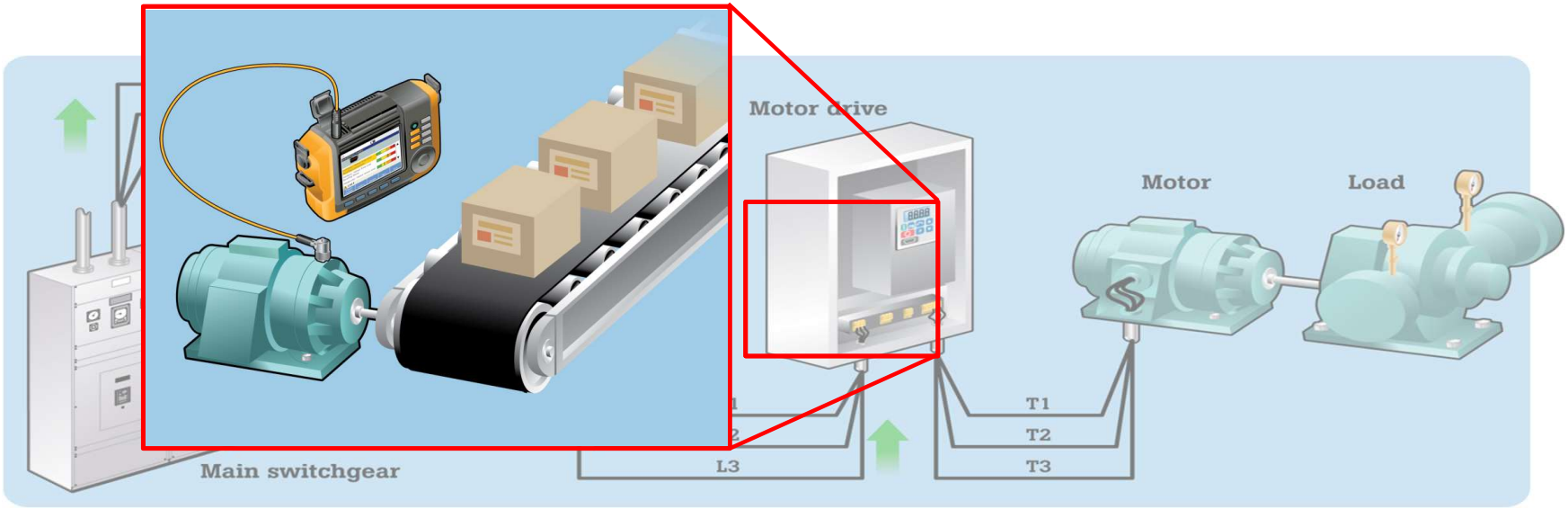
- The Fluke 810 does the interpretation for you using its extensive database of vibration profiles.

What is looseness?



- Excessive clearance between parts is known as looseness.
- Looseness can exist in rotating and non-rotating or normally stationary parts.

Measuring looseness



- Use the Fluke 810 vibration tester to measure looseness.

The right tools for troubleshooting drives and motors

VFD fault codes – Tripping, DC bus, and input power

- Is the error due to issues with motor or load?
- Is the error due to line power quality issues?
- Is the drive faulty?

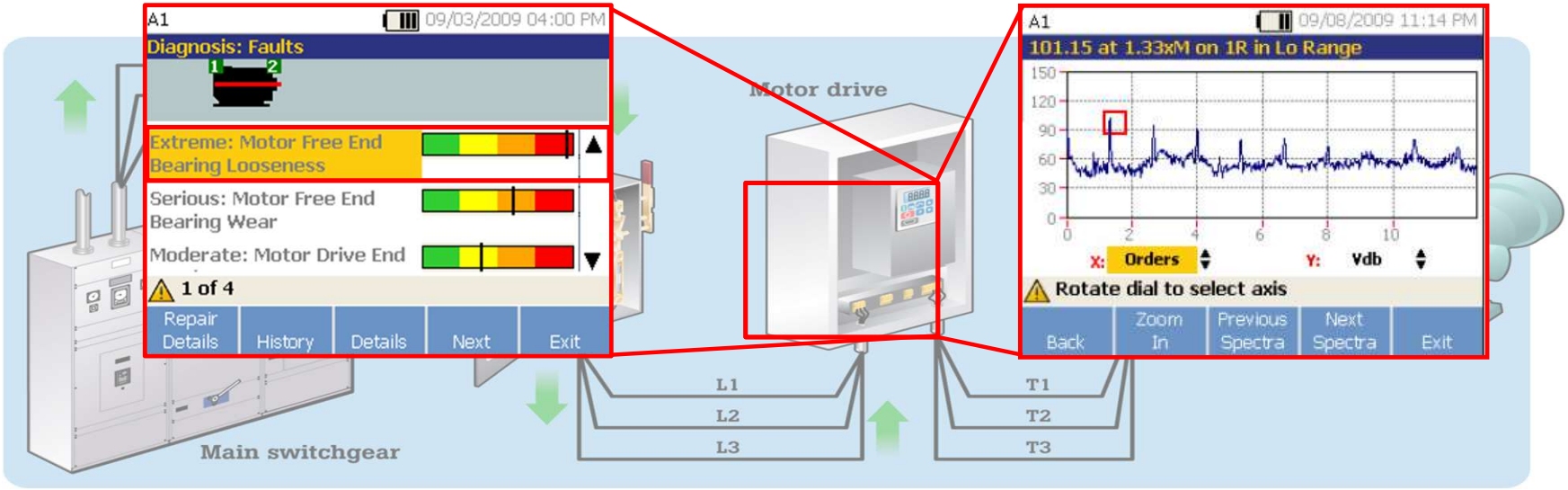
The MDA-550 will verify incoming power and power quality vs DC bus.

Motor insulation breakdown or bearing failures ?

- Is the insulation deteriorating due to mechanical load or electrical issues?
- Is the motor running at elevated temperatures due to overload or electrical issues?
- Is the bearing failing due to peak reflective voltages exceeding winding insulation?
- Will electrical issues cause repeat failures?

The MDA-550 will verify electrical signal quality and the Fluke-438 will measure the mechanical load.

Interpreting looseness measurements



- The Fluke 810 does the interpretation for you using its extensive database of vibration profiles.

Motor drive train – Summary

- Misalignment causes un-needed wear on the motor, and increases the apparent mechanical load feeding vibration into both the load and the motor drive shaft.
- Rotating looseness is caused by excessive clearance between rotating and stationary elements of the machine, such as in a bearing while non-rotating looseness is a looseness between two normally stationary parts, such as a foot and a foundation, or a bearing housing and a machine.
- If not diagnosed and corrected, alignment, bearings, imbalance and looseness can accelerate wear of motors and other mechanical equipment, and can create catastrophic failure, safety problems, and damage to close proximity equipment.

- Reduce mechanical wear
- Avoid overheating and failure.
- Improve efficiency, reduce power consumption
- Reduce downtime and economic losses.

The right tools for troubleshooting drives and motors

VFD fault codes – Tripping, DC bus, and input power

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CHESS CONTROLS

Motor insulation breakdown or bearing failures ?

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The right tools for troubleshooting drives and motors

MDA-550 Motor Drive Analyzer
- Displays *Input Power* conditions that cause drive failures, harmonics that disrupt sensitive control equipment.
- Displays *Drive Output* PWM Waveforms and cabling issues that cause motor failures.
- Finds arc flash-overs across bearing races causing *Motor Bearing Failures.*

438-II PQ & Motor Analyzer
- Analyzes *VFD Input Power Quality* which leads to extended equipment failures.
- Calculates and analyzes *Motor Overload* which reduces lifespan while *underload* wastes operating expense $'s.

Ti 480 Pro Thermal Imager
- Identifies heat manifested from *Overloads and Bad Connections* causing intermittent & permanent failures.

1587 FC Insulation Resistance Tester
- Stress tests and analyzes *Degrading Insulation Resistance* identifying pending motor failure.

810 Vibration Tester
- Identities *Excessive Vibration* leading to premature wear and failure.

830 Laser Alignment
- Accurately calculates *Misalignment* causing excessive vibration, bearing and seal failures.