Operator Training Committee of Ohio, Inc

# Variable Frequency Drives, Benefits and Energy Savings

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# What is a VFD?

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# How does a VFD control the speed of a motor?

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# What are the benefits of using a VFD?

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# How does a VFD improve our process control?

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# How does a VFD save energy and money?

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# The Basics of Variable Frequency Drives

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# VFD BASICS



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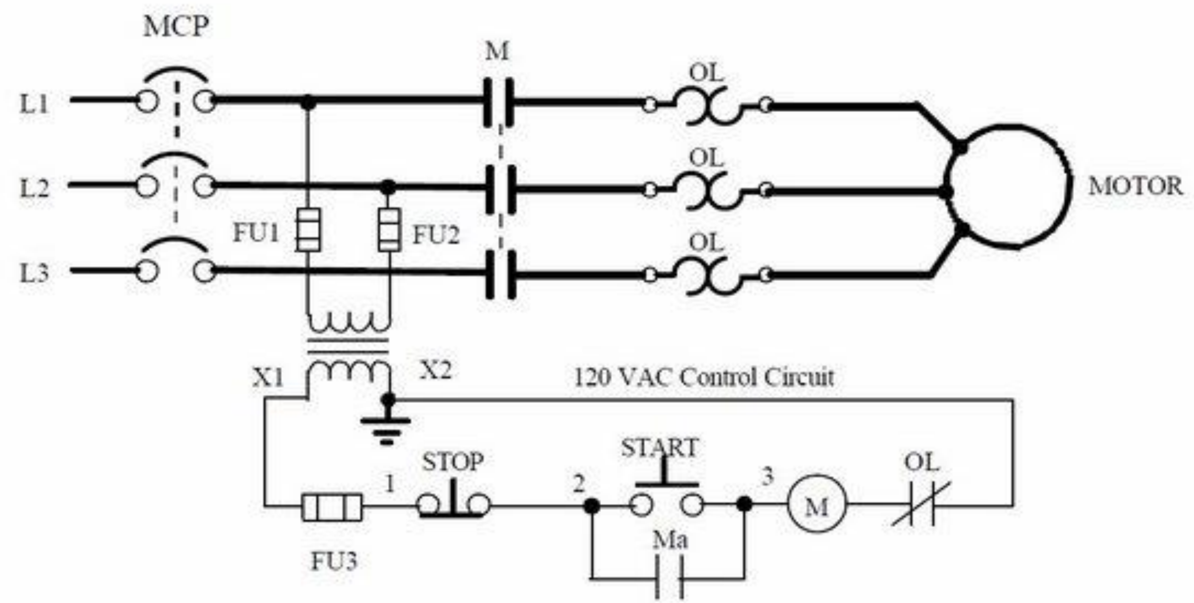
# A VFD Replaces a Motor Starter

- What is a motor starter?

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# VFD Protection

- Branch Circuit Protection
- A VFD Protects the motor
- Circuit breakers
- Incoming Power Fuses
- Line Reactors
- Harmonic Filters

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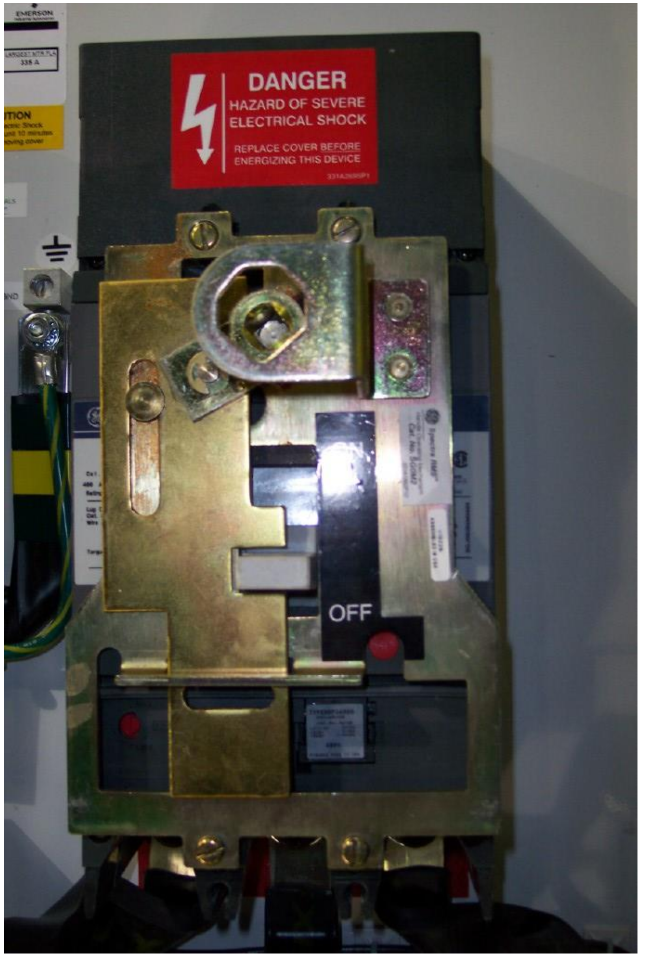
# 3 Phase Circuit Breaker

- Circuit Breakers serve as the disconnect switch inside of your enclosure.
- Safety Lockout
- Thru door or flange type
- Instantaneous overcurrent protective devices.
- Once a circuit breaker is tripped it can be reset unlike fuses.

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# Connections

- There are three terminals on each side of the Circuit Breaker. Line and load.
- Connections must be tight.
- Loose terminals can cause serious thermal damage, and/or injury.

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# Trip Ratings and Sizes

- A Circuit Breakers instantaneous trip rating is approximately 10 times the full load amps of the devices it is protecting.
- Circuit Breakers can be single pole or two pole or 3 pole.

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# Incoming Power Fuses

- Semi-conductor fuses
- Protect Drive


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# Fuse Types

- FNM- Slow Blow 250V or less
- FNQ- Slow Blow 500V or less
- KTK- Fast Blow lower amp rating
- FWH- Fast Blow lower amp rating
- R-type Fuse Rejection style model

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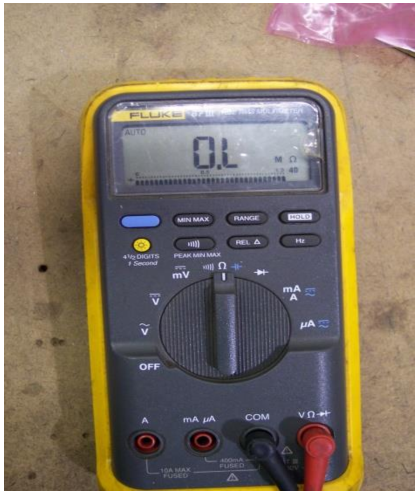
# Checking Fuses

- Fuses can be checked to verify that they are good by using the “Ohm” setting on a meter
- Fuses will read approx. 000.1or a very low resistance
- When fuses are bad they will read open, or “O.L.” as pictured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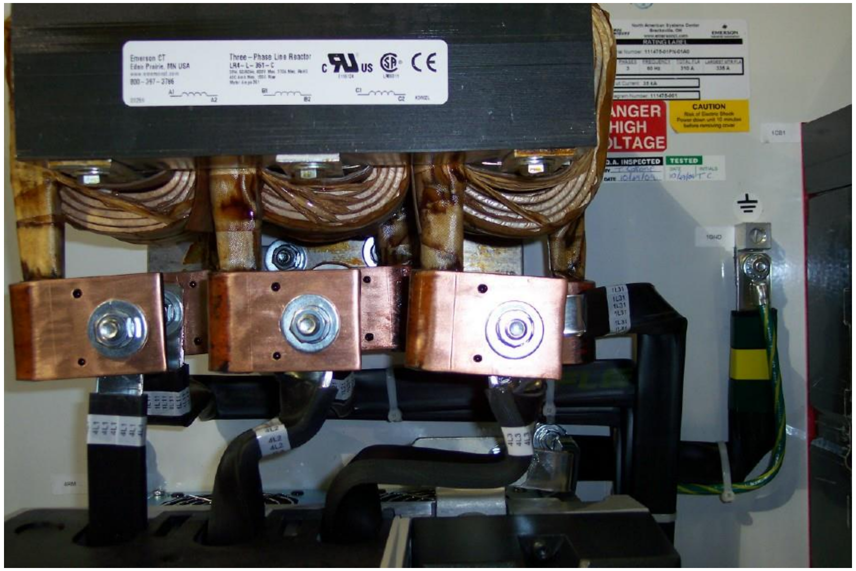
# Line Reactors

- A Line Reactor is the third part of "Pre-VFD protection"
- It uses a principal called inductance to oppose any rapid changes in voltage or current that could be harmful to the drive

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# Three Main Properties of Inductance

- 1. Opposes rapid change in current and voltage
- 2. Prevents line noise from entering the drive
- 3. Prevents drive noise from getting back onto the incoming line.
- 4. Reduces harmonic distortion

# Three Main Sections Make Up a VFD

- Input Rectifier/ Converter Section with Pre-charge circuit
- DC Bus Capacitor Bank
- Output Inverter Transistor Section

# Power Stage

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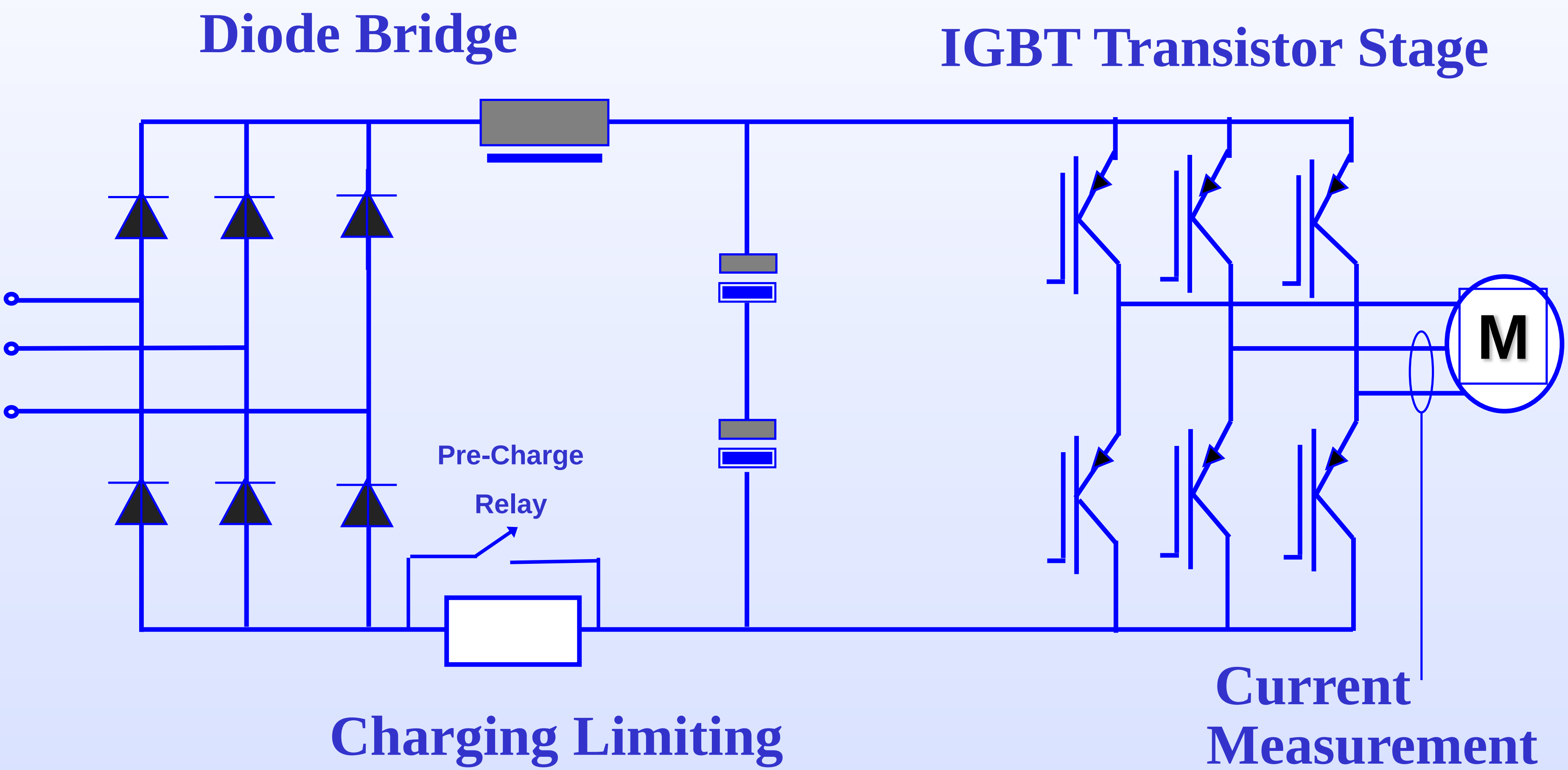
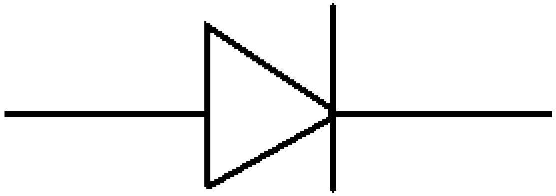


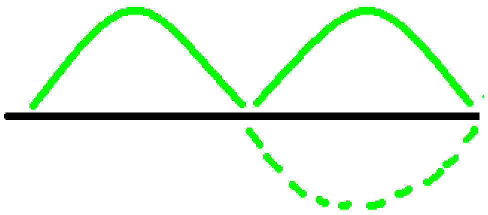
# Diodes

- Only allows the diode to pass one half of the AC waveform
- This creates a “Rectified” DC voltage



# Rectifier Section

- SCRS and Diodes rectify the negative part of the wave form to the positive side.



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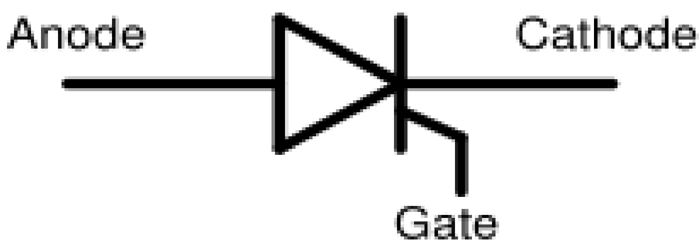
# SCR Technology (Silicone Controlled Rectifier)

- An SCR is a controlled diode
- It is a diode that can be controlled of how “hard” it turns on.
- Current will flow from the cathode to the anode.
- It will limit current flow depending on how much signal voltage the gate is receiving.

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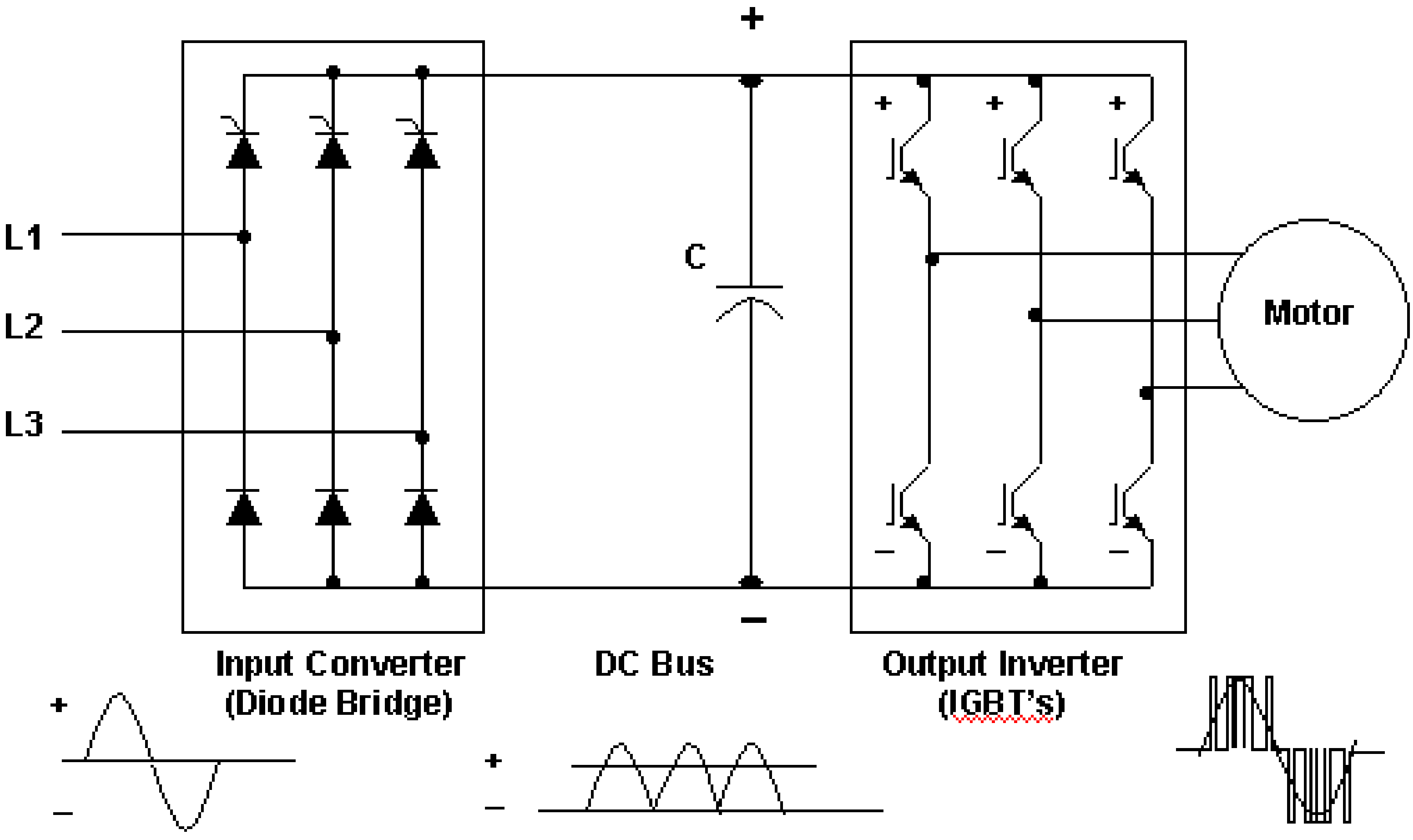
# The Pre-Charge Circuit

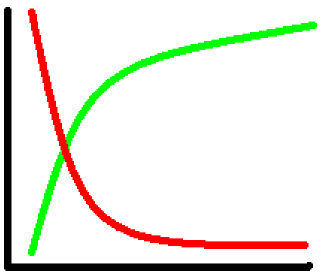
- At first when power is applied to the VFD, the capacitors look like a short circuit to AC
- SCRS limit current flow for a certain amount of time to charge the Bus Capacitors
- Once the capacitors are charged, SCRS are turned fully on to allow current flow and normal operation of the VFD

# Capacitor Section



# Charging of Capacitors

- Capacitors charge over a breif period of time
- Current is very high upon power up



- *Y axis= time*
- *X axis= voltage*
- *Green= charging of cap (voltage)*
- *Red= current*

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# Capacitors

- Capacitors are made up of a conductor-dielectric material- conductor “sandwich”
- When voltage is applied to the conductors a charge becomes present in the core of the capacitor
- Dielectric material is simply a non-conductive material

# DC Bus Capacitor Section

- Holds a charge of 650-700VDC (approx.)
- Regulates the DC voltage to eliminate "ripple"
- If AC voltage above 1volt can be measured on the bus, the capacitors are not doing their job

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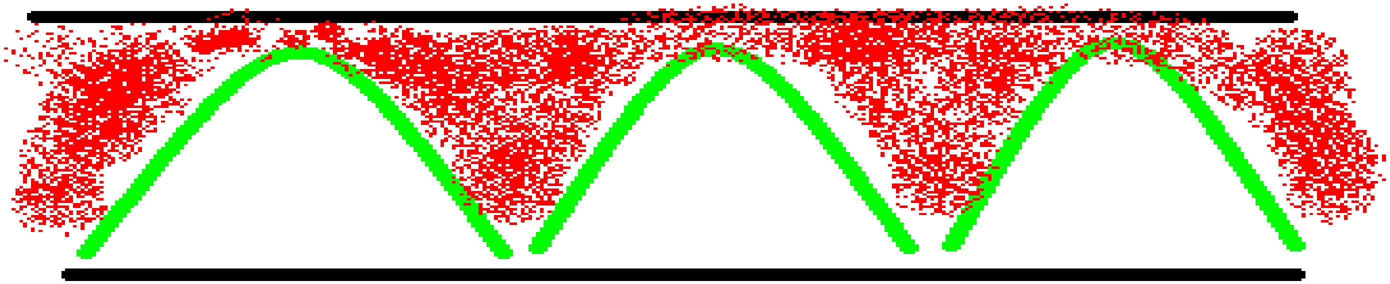
# Ripple Voltage

- Ripple is “raw” unregulated voltage
- The capacitors fill in the “peaks and valleys” of the wave form and regulate it to an average voltage of approx. 700 VDC



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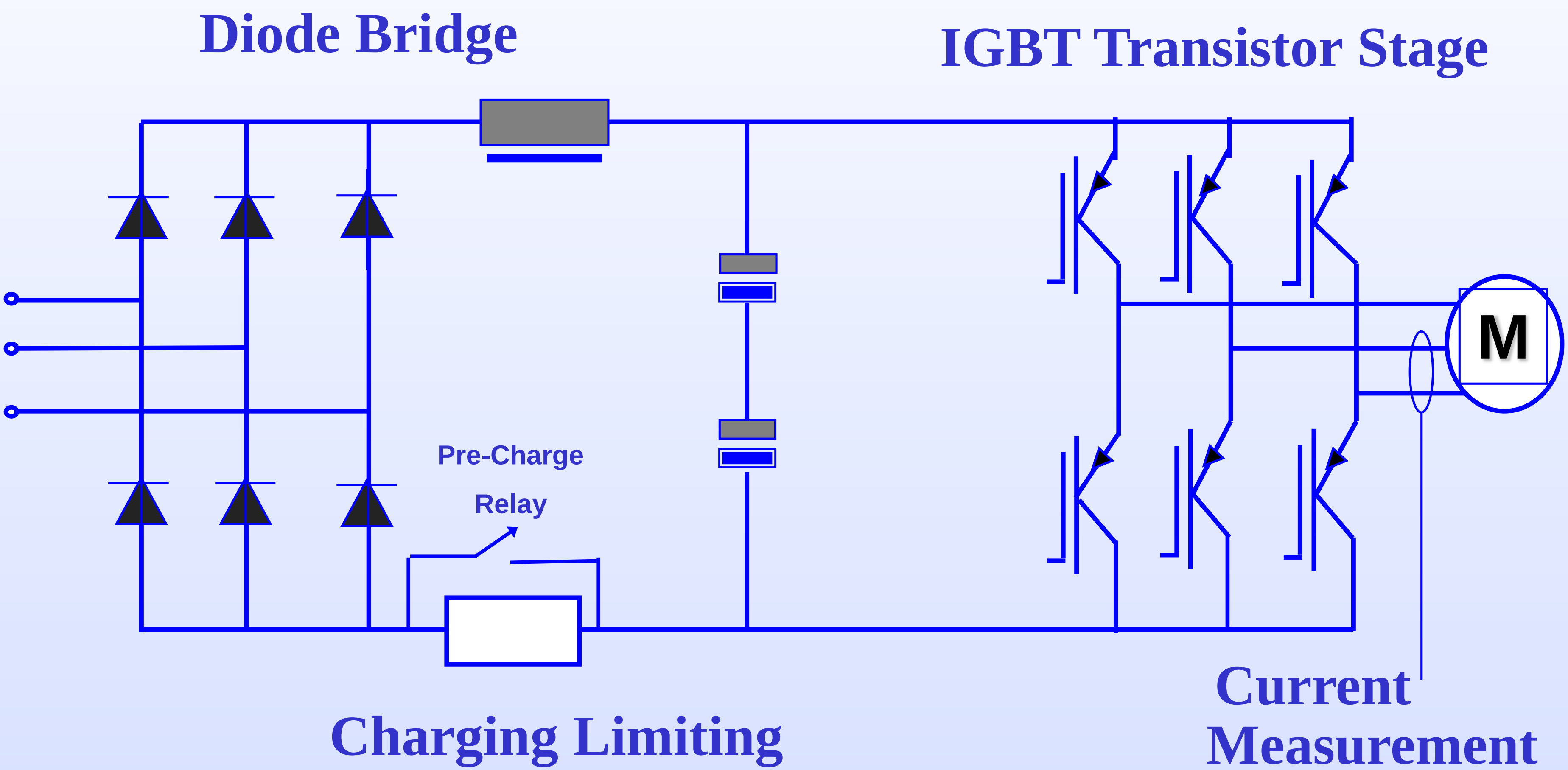
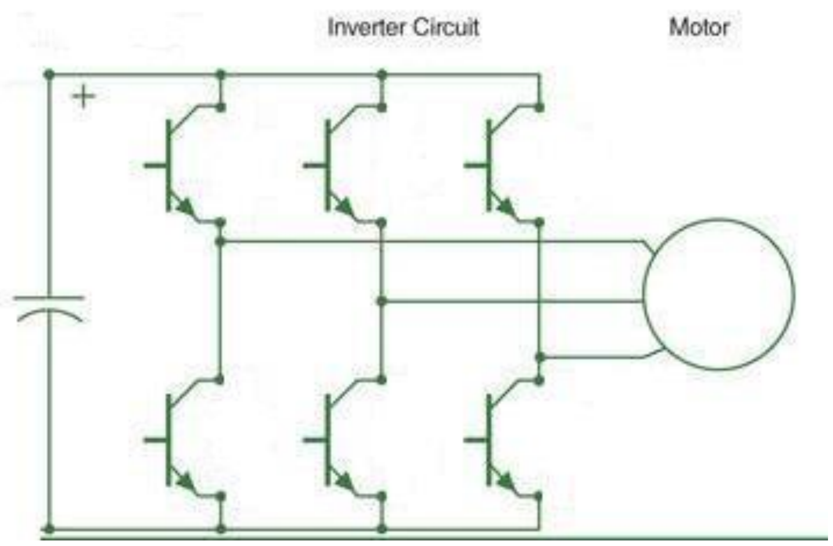
# Power Stage


Diode Bridge
IGBT Transistor Stage
M
Pre-Charge
Relay
Charging Limiting
Current
Measurement

# Inverter Section

- The Transistor Section uses Insulated Gate Bipolar Transistors (IGBTS) to switch on and off to create a simulated output wave form
- This output wave form is called Pulse Width Modulation (PWM)

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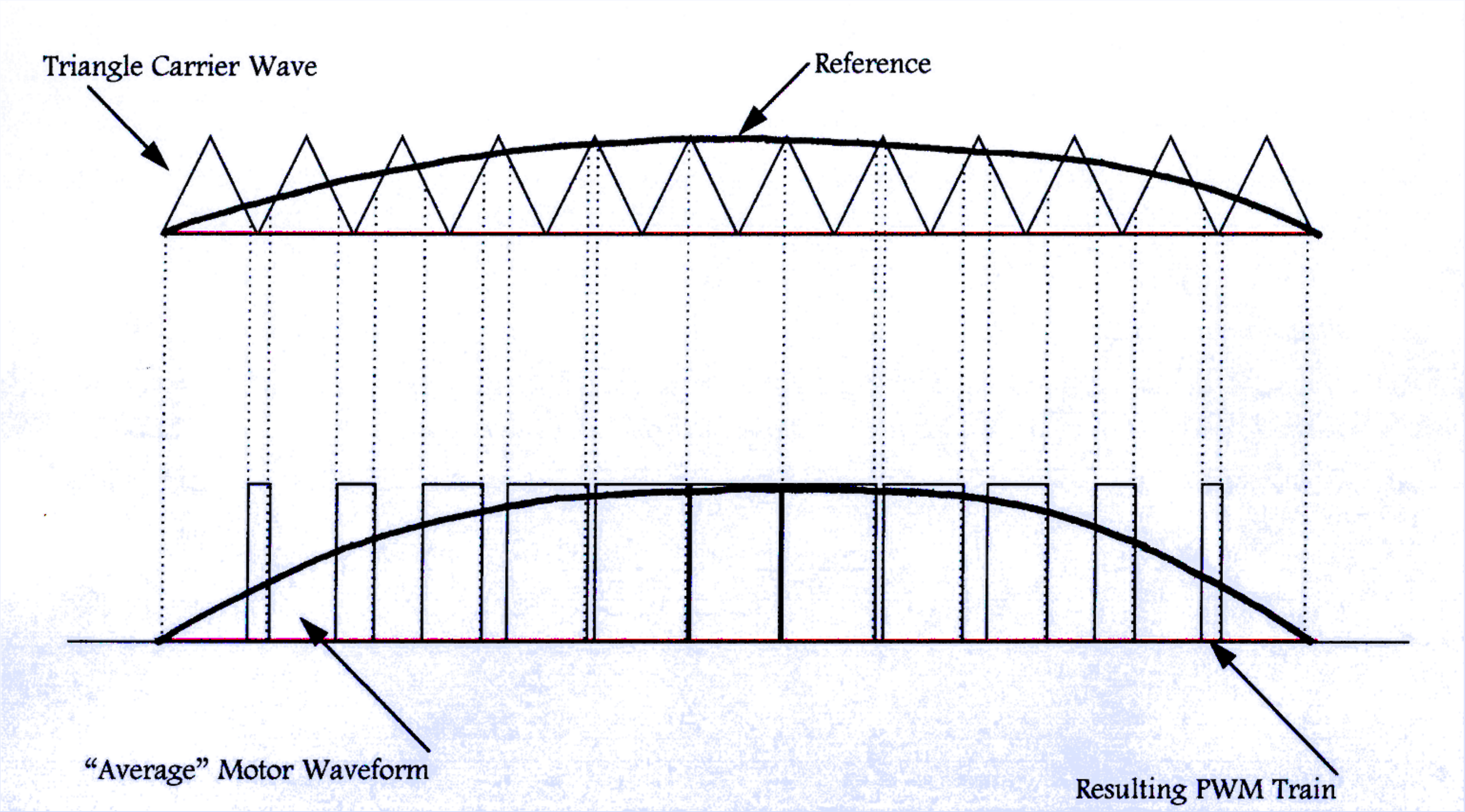
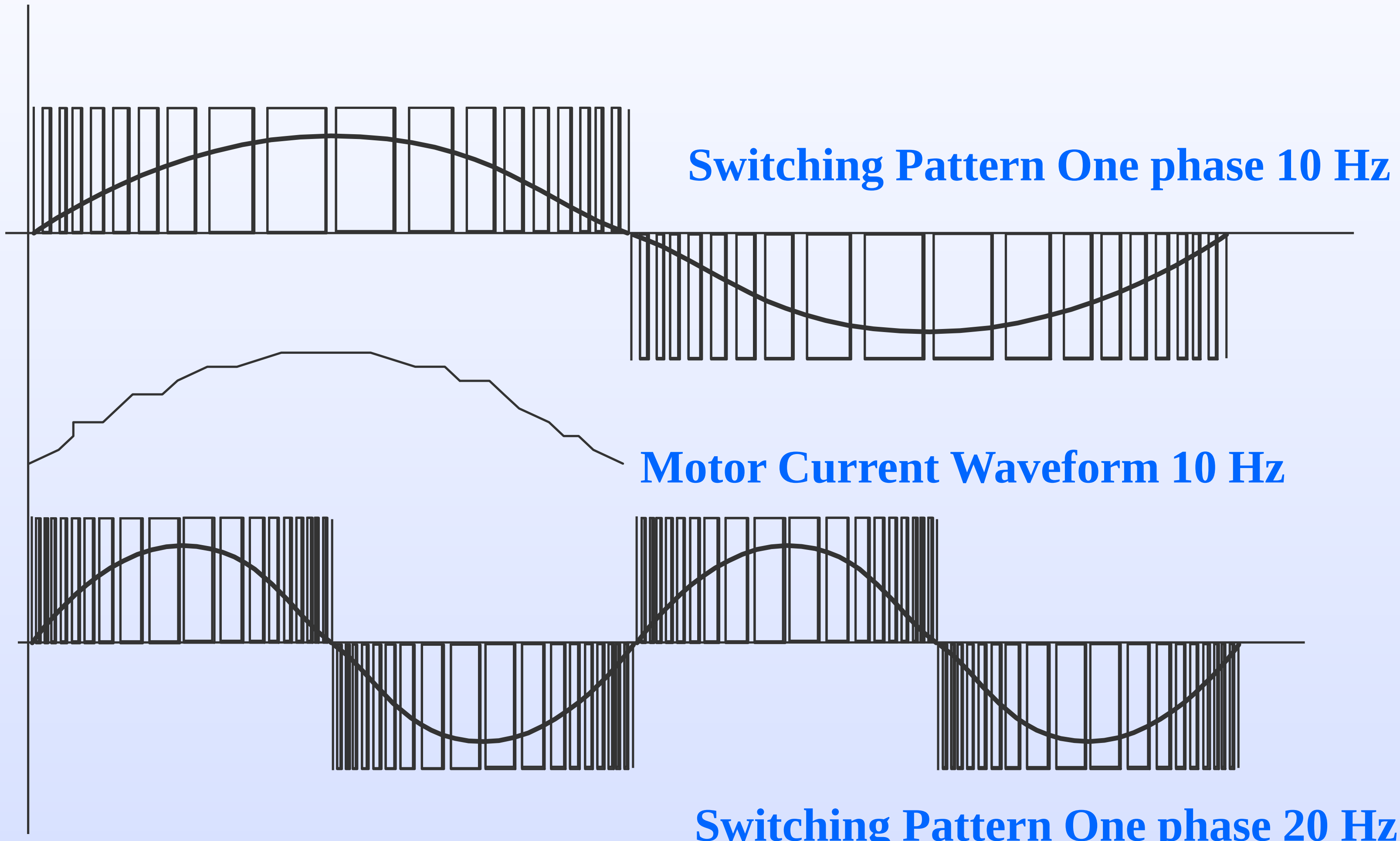
# Pulse Width Modulation

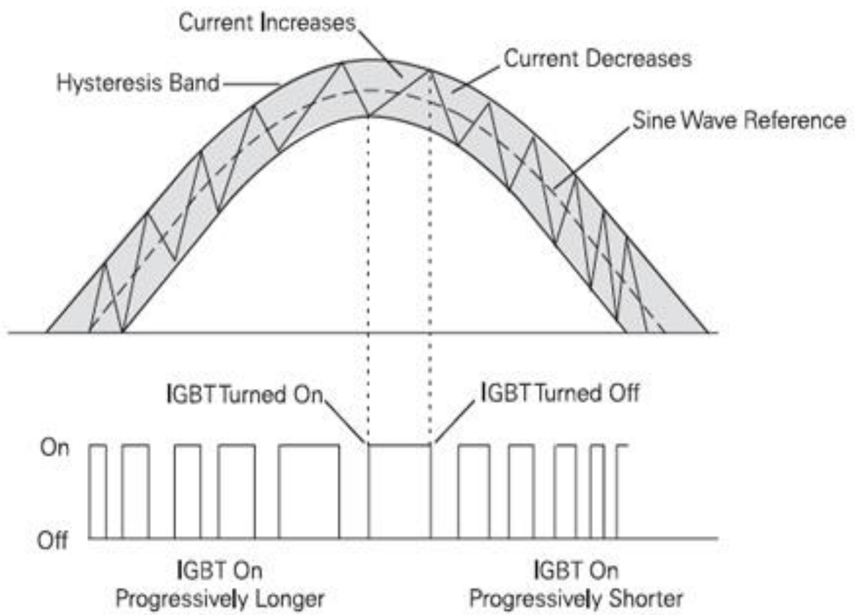


# PWM Switching Patterns



# Pulse Width Modulation

- IGBTS are fully *on* or *off*
- The time (pulse) a transistor is on or off can be varied and is expressed as the *width*
- Current flow uses the motor as the return path to complete is flow; this is similar to how the front end of the drive uses the power source

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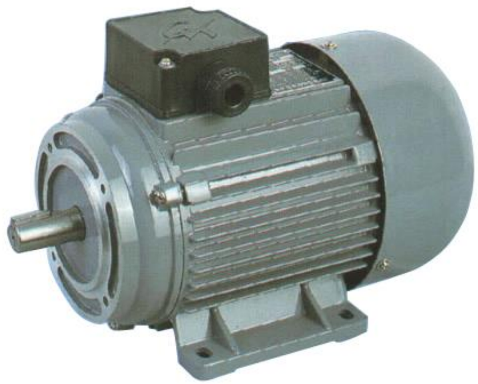
# *Post VFD Power Section*



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# Three Parts Make Up the Post VFD Power Section

- Output Line Reactor
- Output LineReactor
- Output dV/dT filter
- Motor or multiple motors

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# Output Line Reactors

- Output line reactors use the same principle as input reactors.
- Induction

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# Situations that require output line reactors

- When the run of the motor lead length is 250 feet or longer from the VFD to the motor
- Multiple motors used on one VFD
- Overvoltage, common nuisance trip if a line reactor is not in place.

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# Long Motor Leads

- Extensive runs of motor leads 250 feet + can carry the same trait of a capacitor
- The output line reactor prevents this and reduces the possibility of voltage doubling

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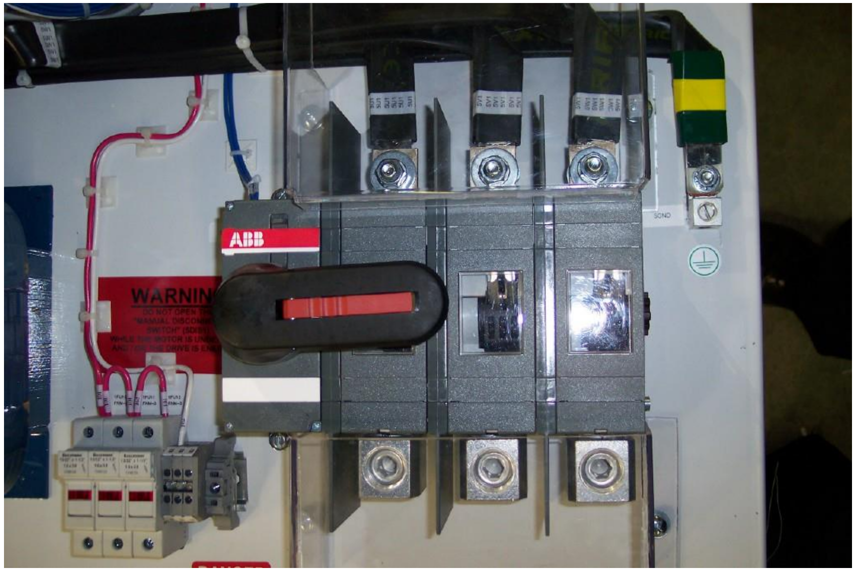
# Output Disconnect Switch

- Convenient disconnect switch separates the VFD from the motor
- Although when the switch is open, the VFD is "inhibited"

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# Disconnect Switch Continued

- In some scenarios this disconnect switch can be used to easily remove the motor from he VFD to run it unloaded
- OI.AC is a common trip where the service person will need to troubleshoot the machine open circuit

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# Motors and Loads

- All VFD’s spin motors of different voltages, and sizes
- Loads can be constant torque application or variable torque applications

# Basic Application Information

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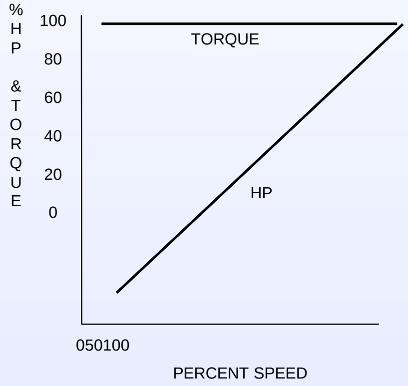
## CONSTANT TORQUE LOAD

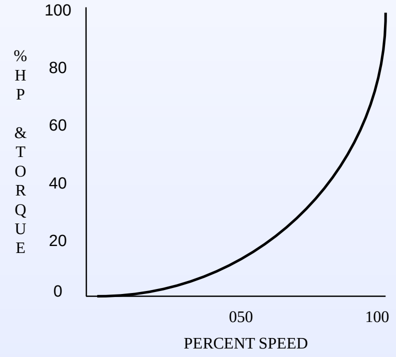



Load requires the same amount of torque at low speeds as at high speed.

Torque remains constant throughout the speed range, and the horsepower increases and decreases in direct proportion to the speed.

Used in applications such as conveyors, and when shock loads, overloads, or high inertia loads are encountered.

## VARIABLE TORQUE LOAD




Load requires much lower torque at low speeds than at high speeds.

Horsepower varies approximately as the cube of the speed, and the torque varies approximately as the square of the speed.

Used in applications such as centrifugal fans, pumps, and blowers.

# Constant Torque Applications

- A constant torque application would be an example of a conveyor or extruder
- The load may change but the amount of torque remains the same throughout the speed range
- Typically these VFDS can apply about 150% or the FLA for a short period of time

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# Variable Torque Applications

- Typically there is a linear curve meaning at low speeds there is low torque and at high speeds there is high torque
- A pump, or fan can be considered a variable torque load.
- A variable torque VFD can only supply 110% of the FLA for a short period of time

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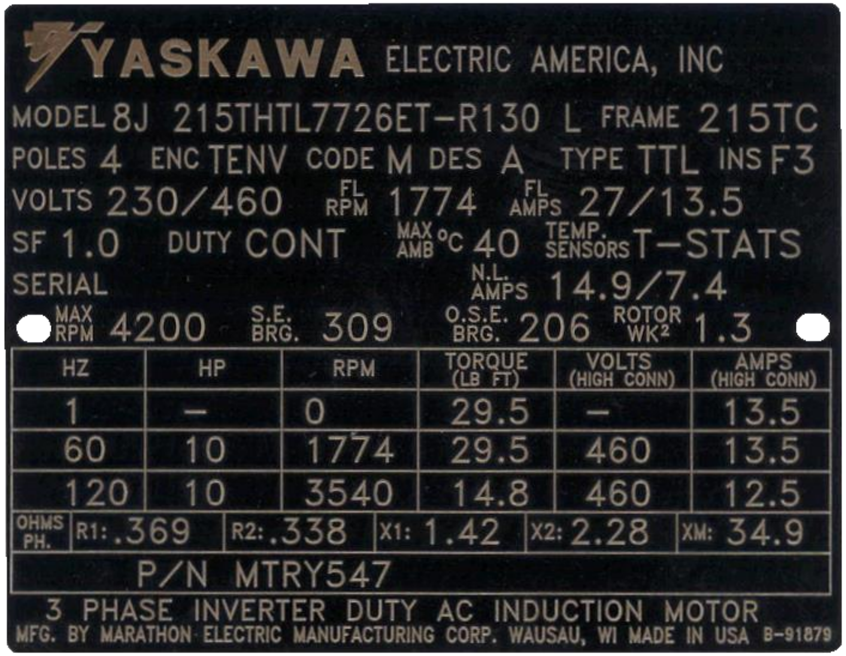
# Motor Nameplates

- Important information needed to size a VFD appropriately to a motor.
- Type of load (VT or CT)
- Full Load Amps
- Voltage
- Additional info- HP, RPM

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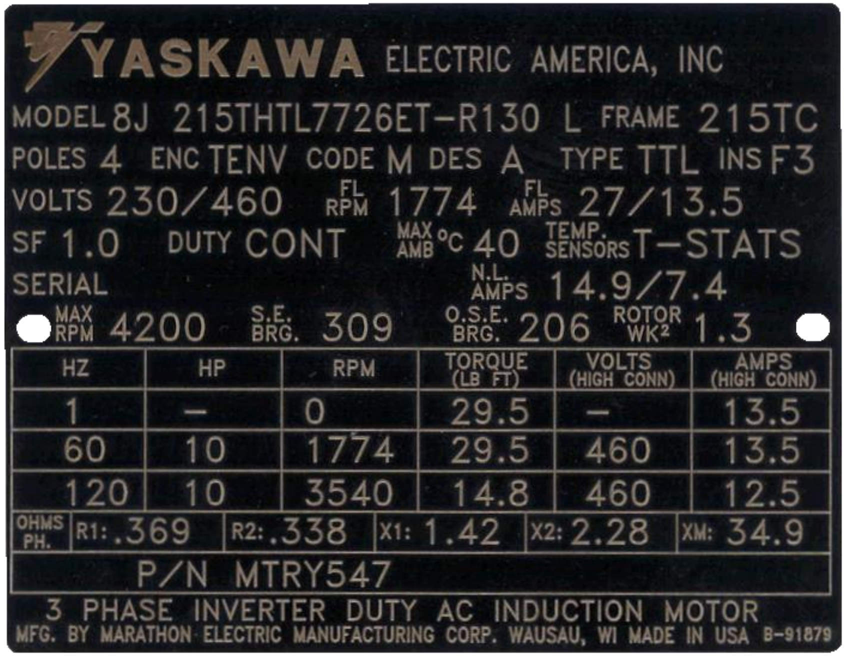


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**VFD Benefits**

•Process control of level, pressure, flow.

•Lower maintenance costs, as lower operating speeds result in longer life for bearings and motors.

•The motor does not require a starter.

•Limits torque to a user-selected level protects driven equipment that cannot tolerate excessive torque.

•Users can utilize multi-motor applications, such as pumps or fans, with one control unit.

•High-speed applications, pump motors can be run faster than 60 Hz.

•Energy Savings

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# Energy Savings

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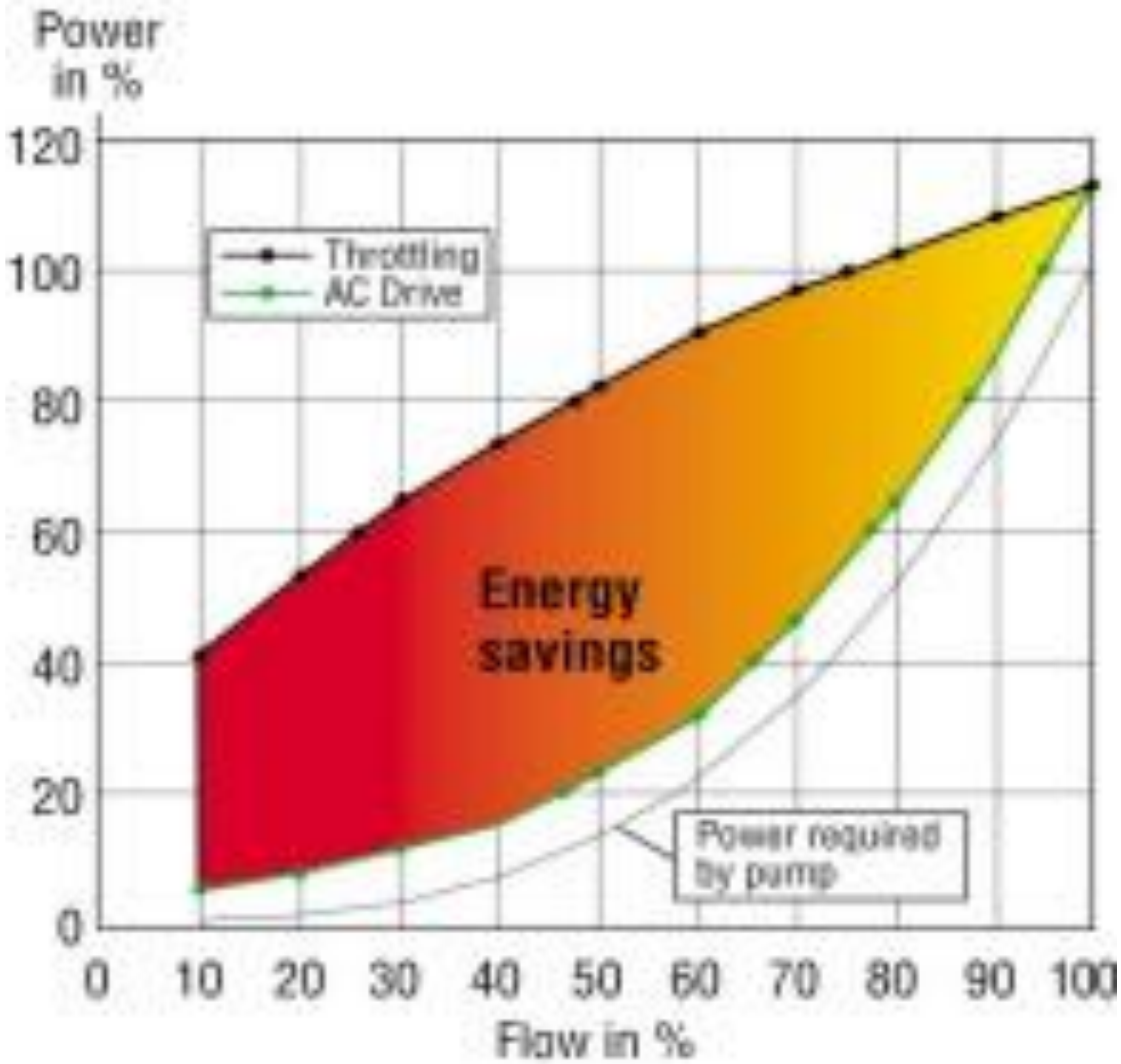


This is how much energy a variable speed drive saves at different speeds compared to traditional control methods

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The affinity laws (Also known as the "Fan Laws" or "Pump Laws") for pumps/fans are used in hydraulics, hydronics and/or HVAC to express the relationship between variables involved in pump or fan performance (such as head, volumetric flow rate, shaft speed) and power. They apply to pumps, fans, and hydraulic turbines. In these rotary implements, the affinity laws apply both to centrifugal and axial flows.

Power (kW) is proportional to the cube of shaft speed.

# Thank you!

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# Rapid Troubleshooting Variable Frequency Drives and Motor Controls

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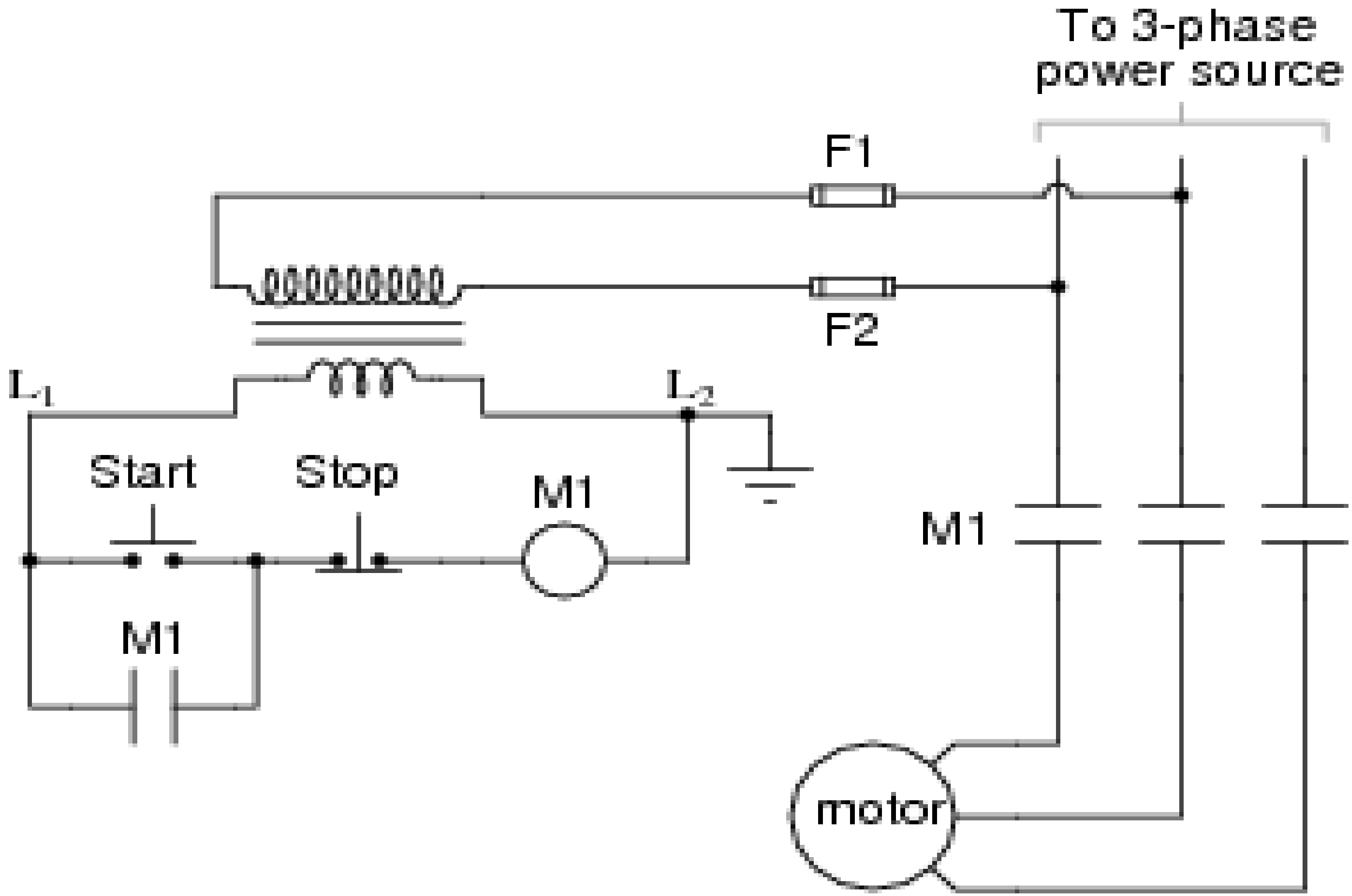
When a motor or drive goes down, how do you resolve the problem quickly?

When a variable frequency drive (VFD) goes down, you're under pressure to get it back online fast. Don't let this pressure make you take even longer to resolve the problem.

Rapid troubleshooting.

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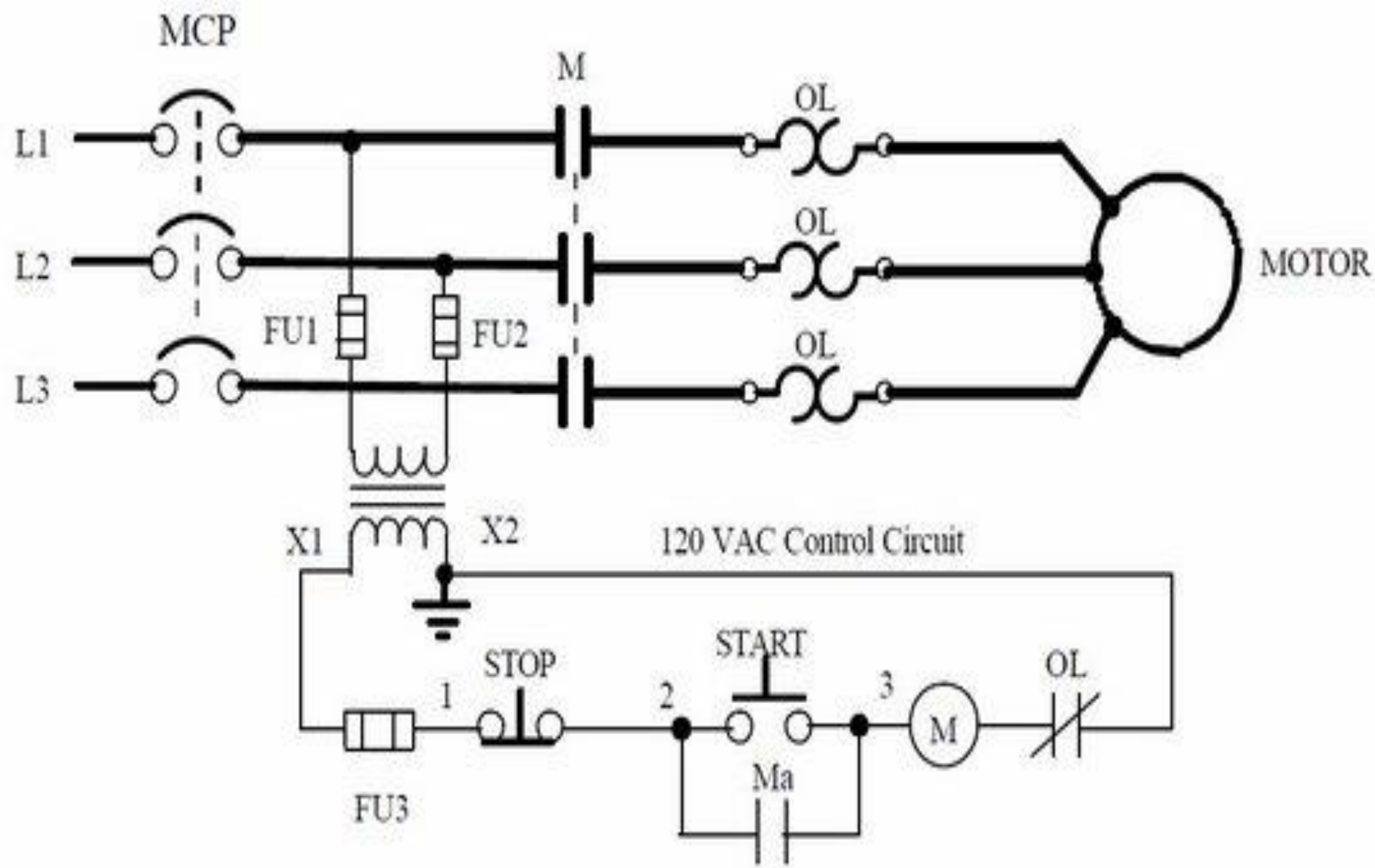


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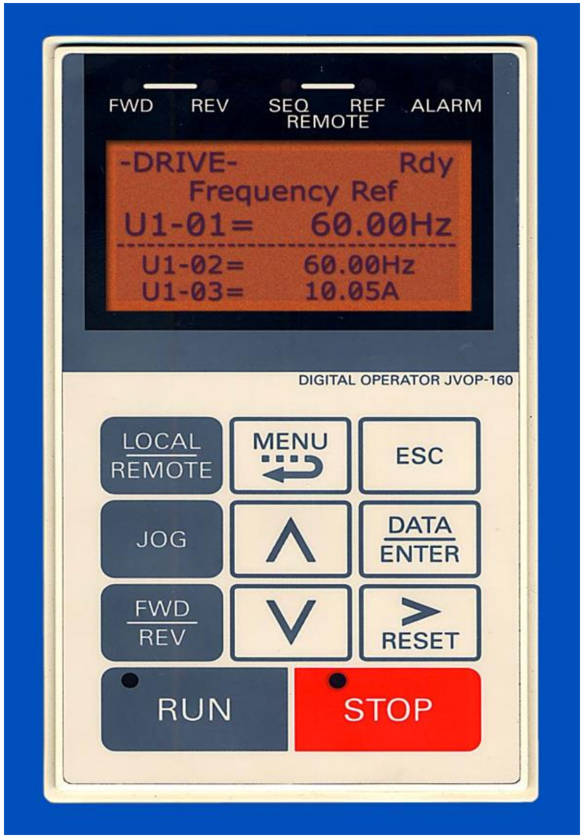


*Check the controller display.* Most VFD controllers include an interface to set up the drive for operation, and display information about its operation. Although the information varies, most controllers tell you about high current, high and low voltages on the input and output sides, high temperatures, internal faults, and even some advanced power diagnostics.

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Check the connections. If the fault codes can't help you track down the problem, check the connections.

Surprisingly, loose connections are among the most common causes of faulty operation in VFD applications. Just eyeballing a connection is sometimes enough to know it's loose. But, you can also check for a voltage drop across a connection if you're still powered up; or resistance through a connection if you're powered down.

Don't forget to isolate the connection to ensure a reliable reading.

Check temperatures. Checking the temperature of connections with a temperature probe or IR-thermometer is one way to tell if they're loose. They should never be hotter than the connecting wires.

You can check temperatures in the drive and at the motor. For example, if a controller's heat sink overheats because of infrequent cleaning, it can shut down the drive. Or, if the motor insulation is unsuitable for VFDs, it'll gradually degrade until it develops a short. Such shorts are often too small to blow a fuse, and too intermittent to trip an overload. However, they're enough to shut down a controller.

An IR thermometer can show what is going on. Also, use your nose: If a motor smells hot, it is.

- Visual inspection
- Electro mechanical connections
- Check fuses
- Inspect cooling fans for proper operation
- Use keypad to verify voltages, inputs, analog inputs etc.

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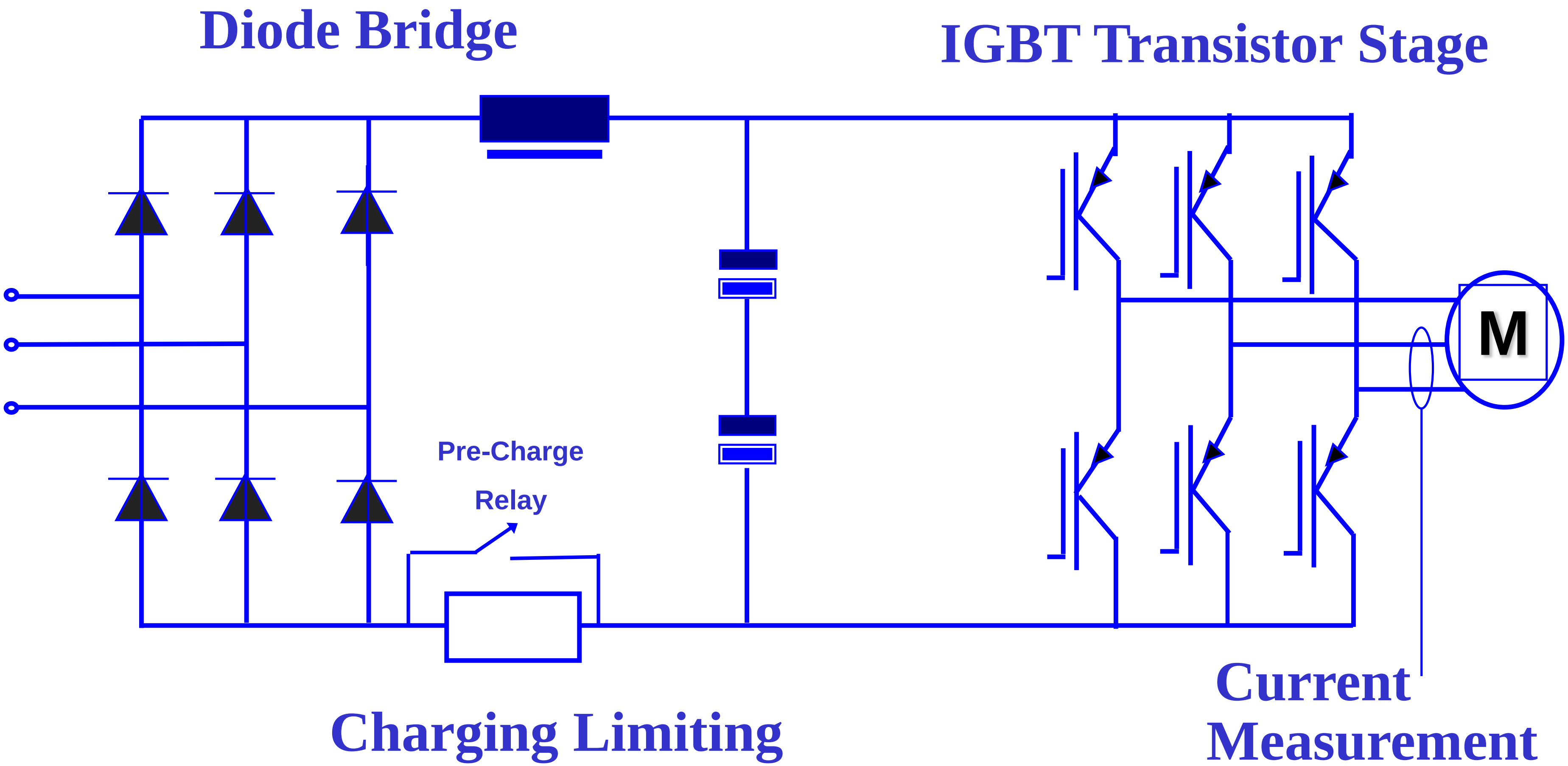
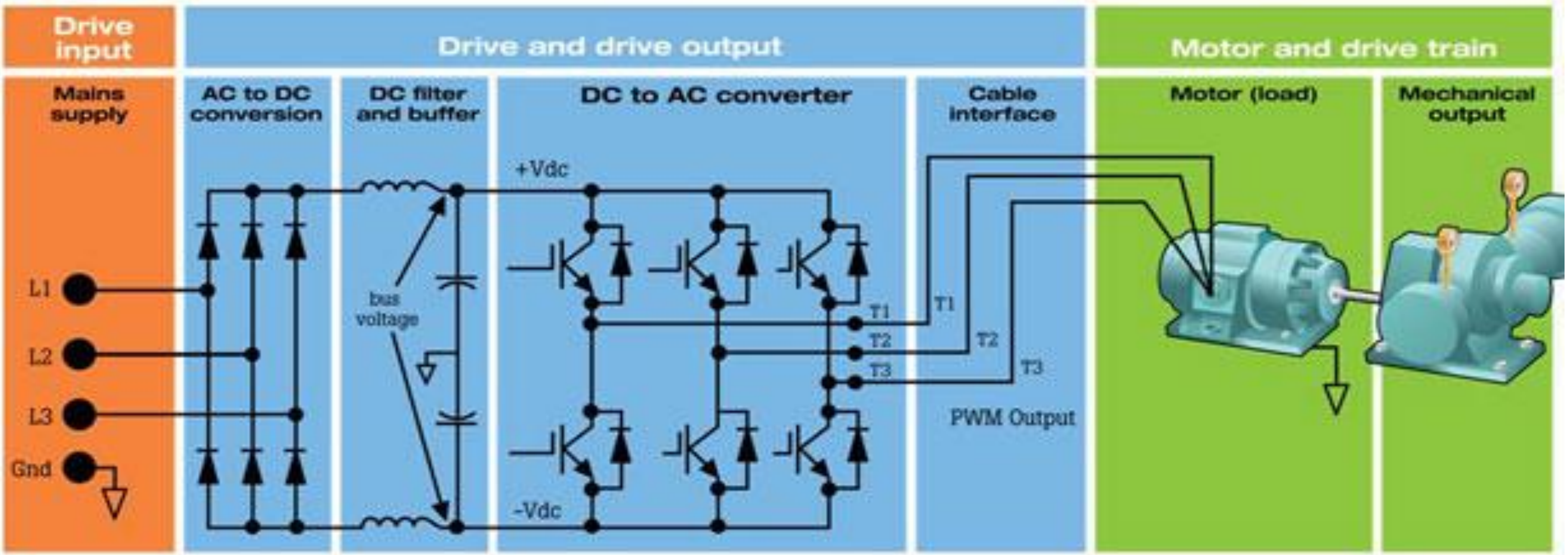
# Power Stage



Diode Bridge
IGBT Transistor Stage
M
Pre-Charge
Relay
Charging Limiting
Current
Measurement




## Problems

| Drive input | Drive and drive output | Motor and drive train |
| --- | --- | --- |
| Nominal supply voltage | Voltage Unbalance | Motor Overload |
| Voltage unbalance | Current Unbalance | Single Phasing |
| Transients | Sigma Current and PE Current | Bearing Failures |
| Harmonics | Control Signal | Misalignment |
| Power factor | Output Transients | Imbalance |
| | Disturbances | Looseness |
| | Harmonics | Insulation Breakdown |
| | Volt to Hertz Ratio | Shaft Voltage and Bearing Current |
| | Diagnostic Shutdown | |

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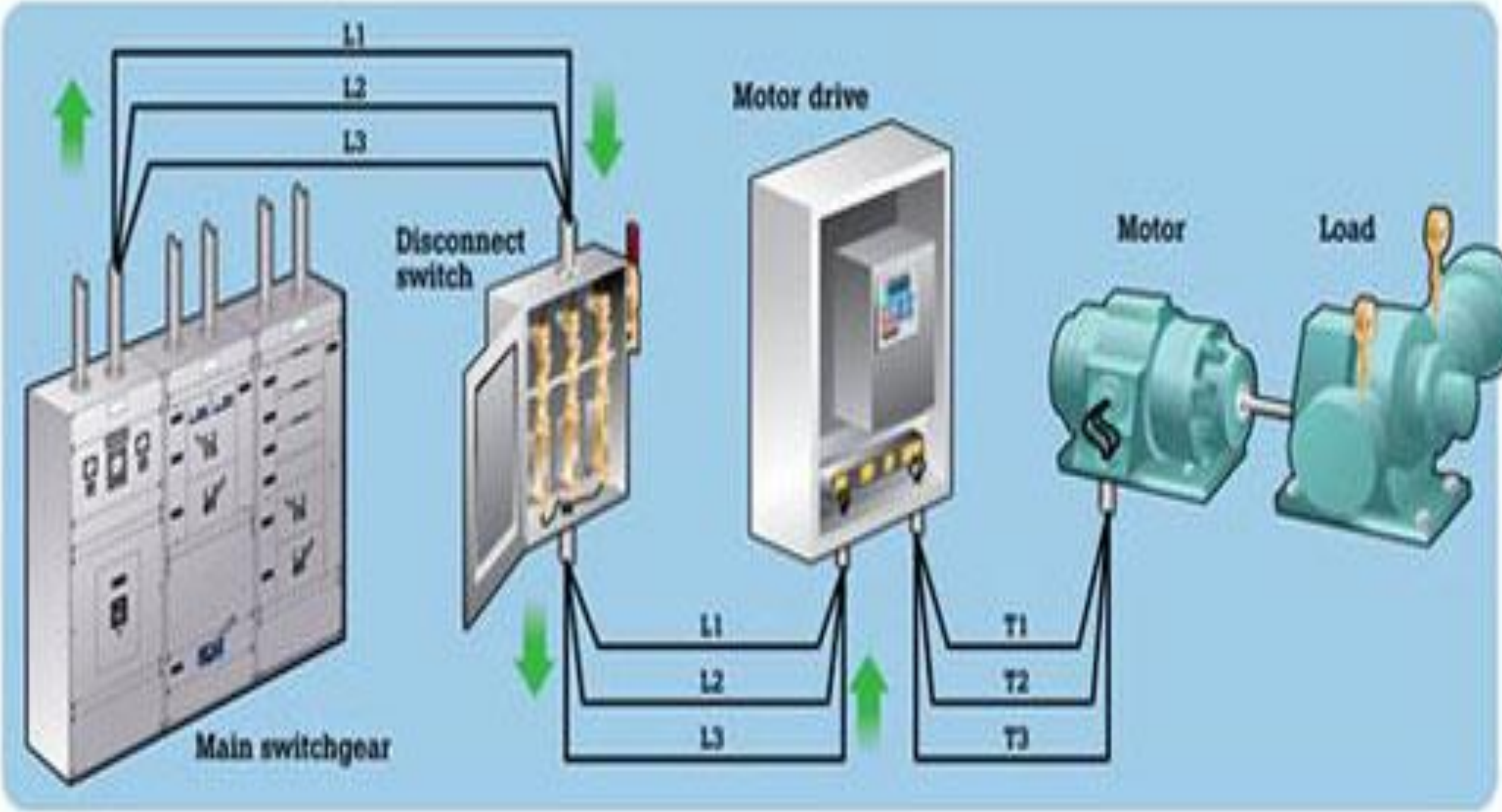


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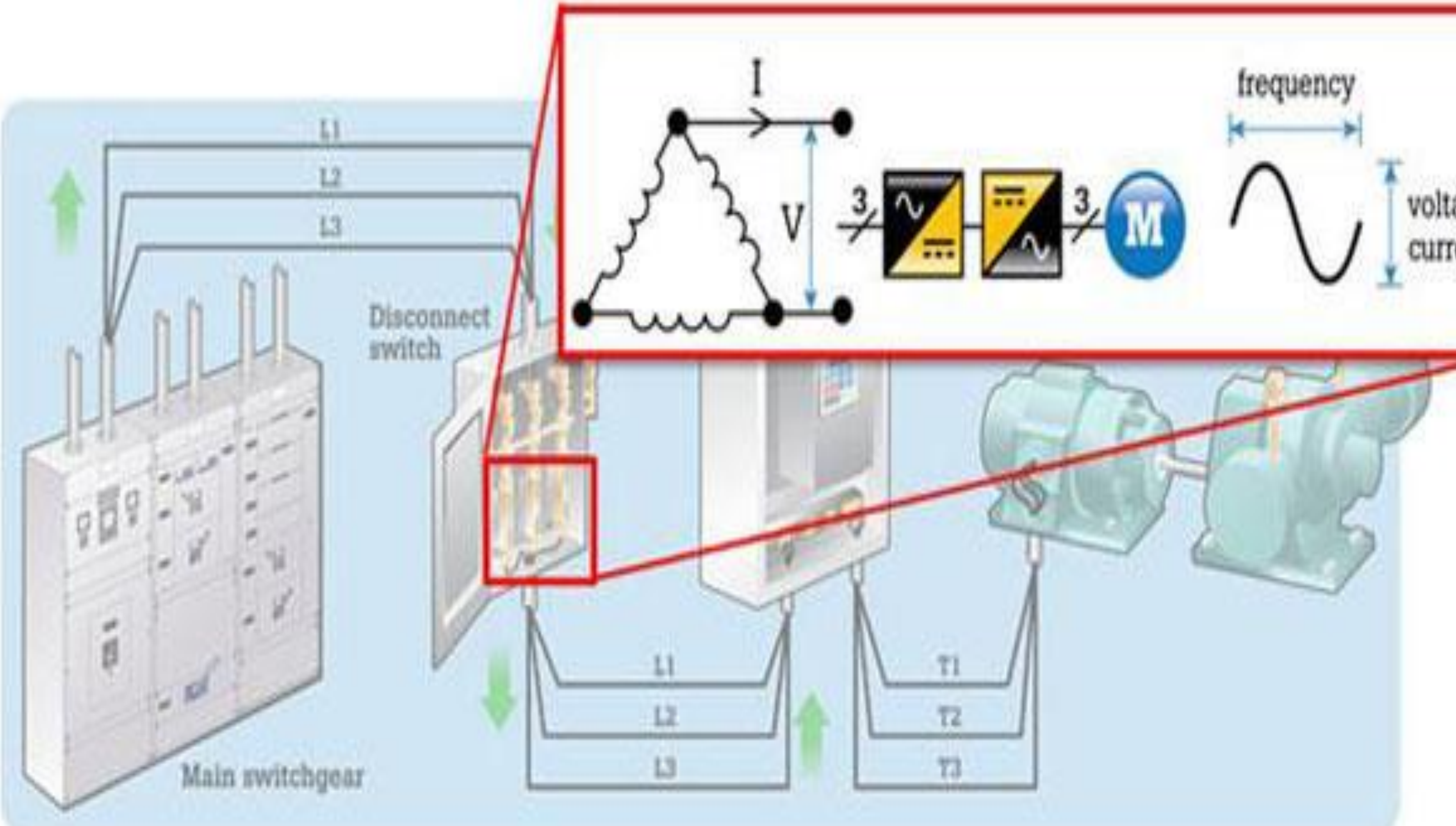


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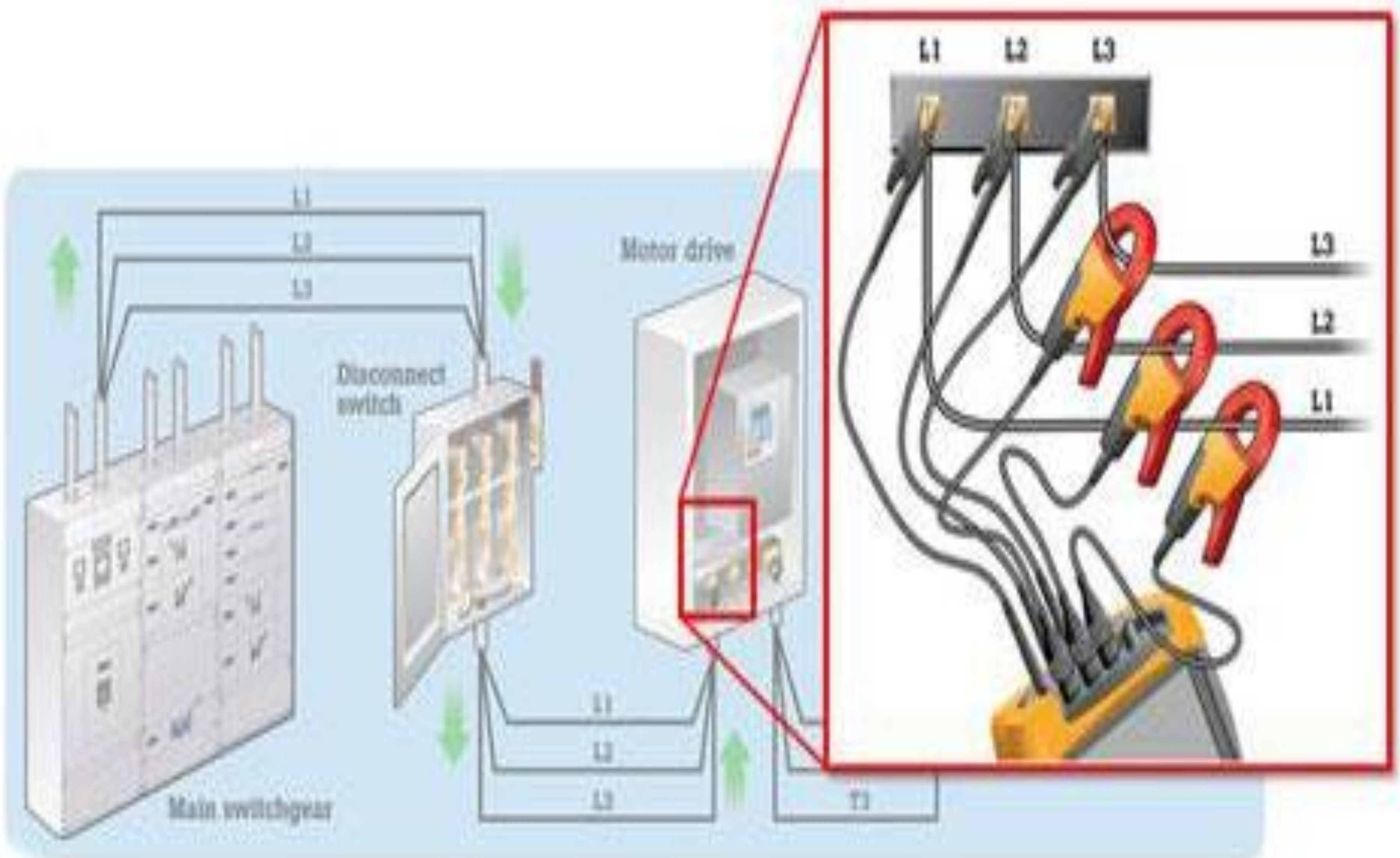


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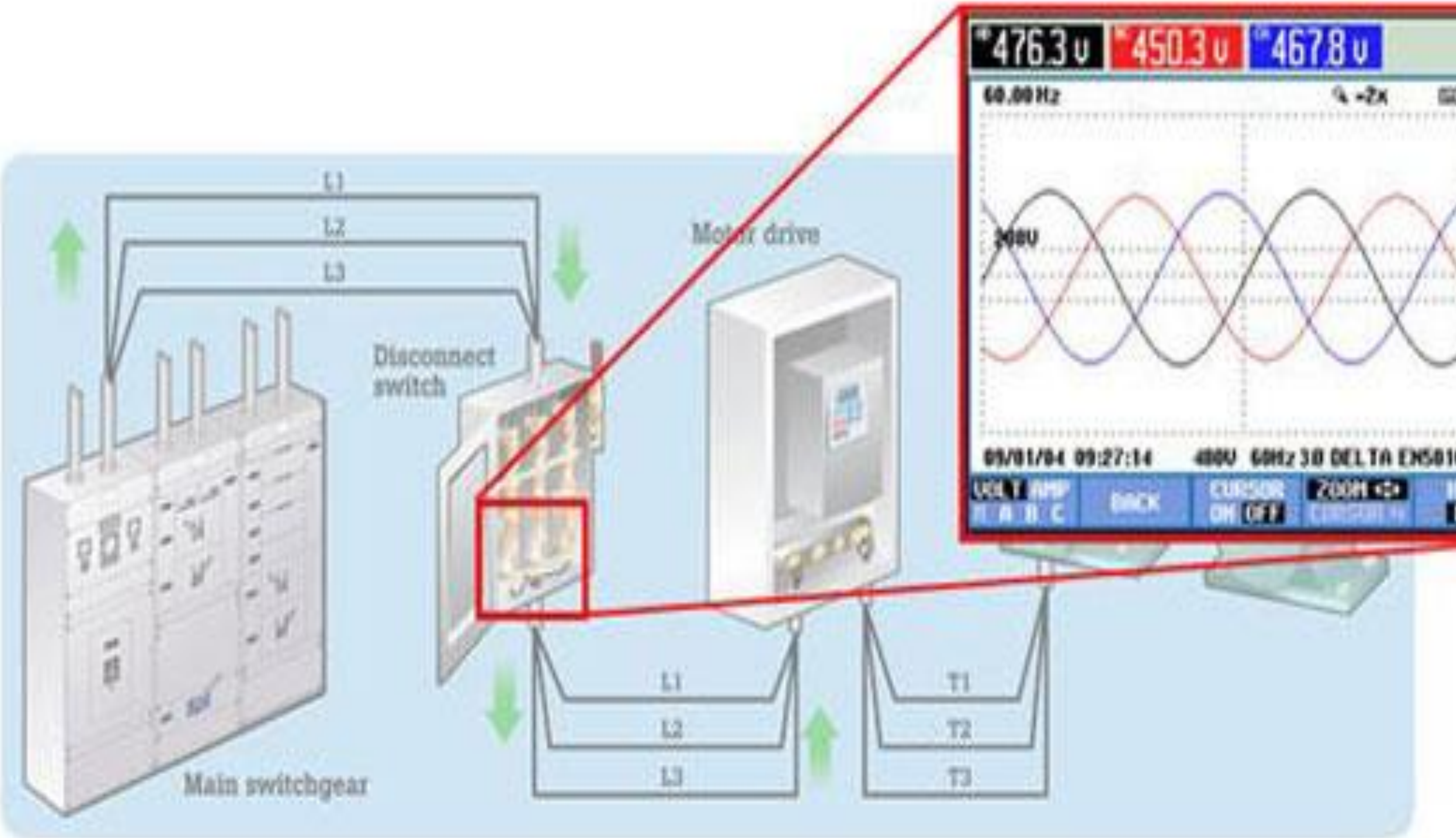


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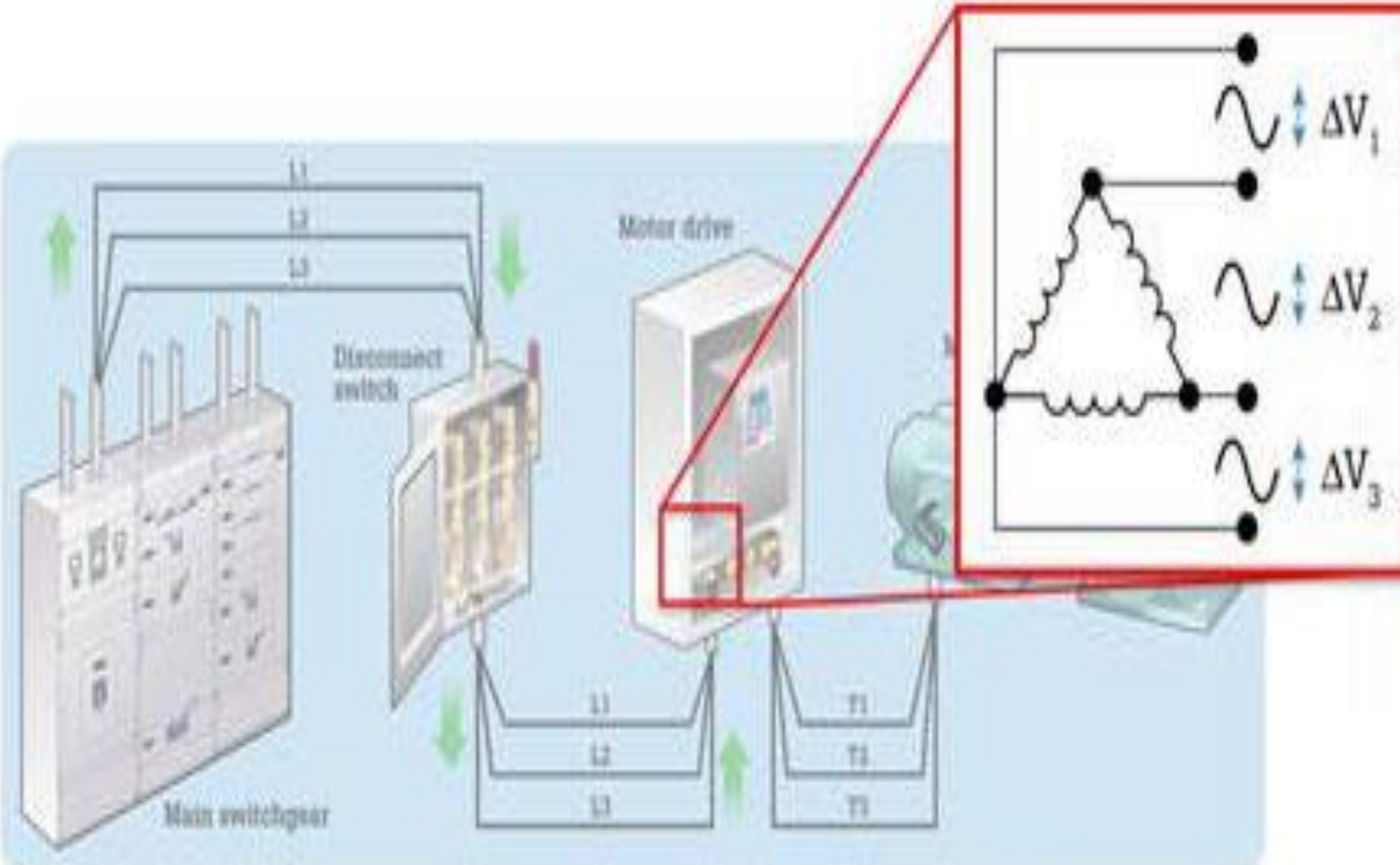


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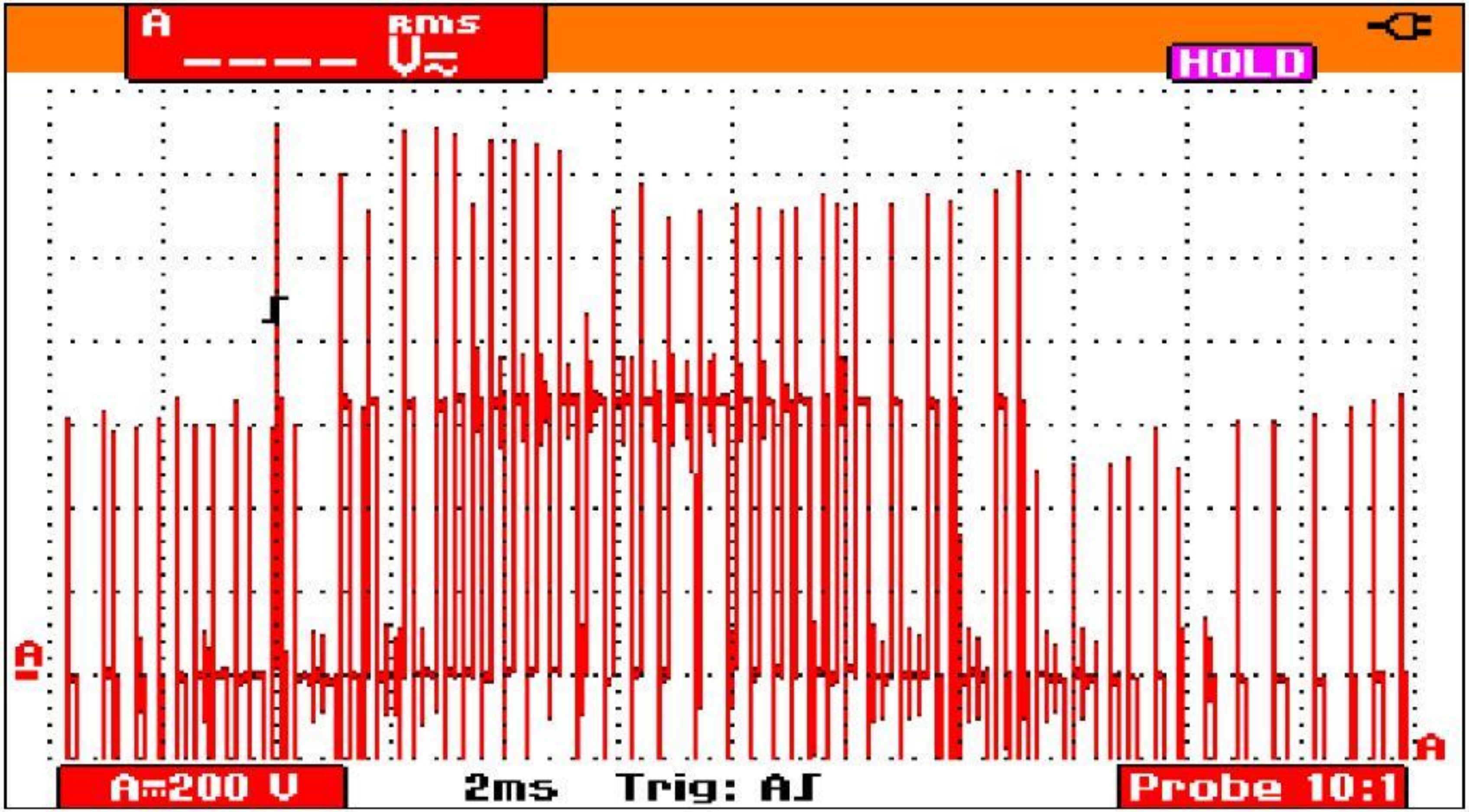
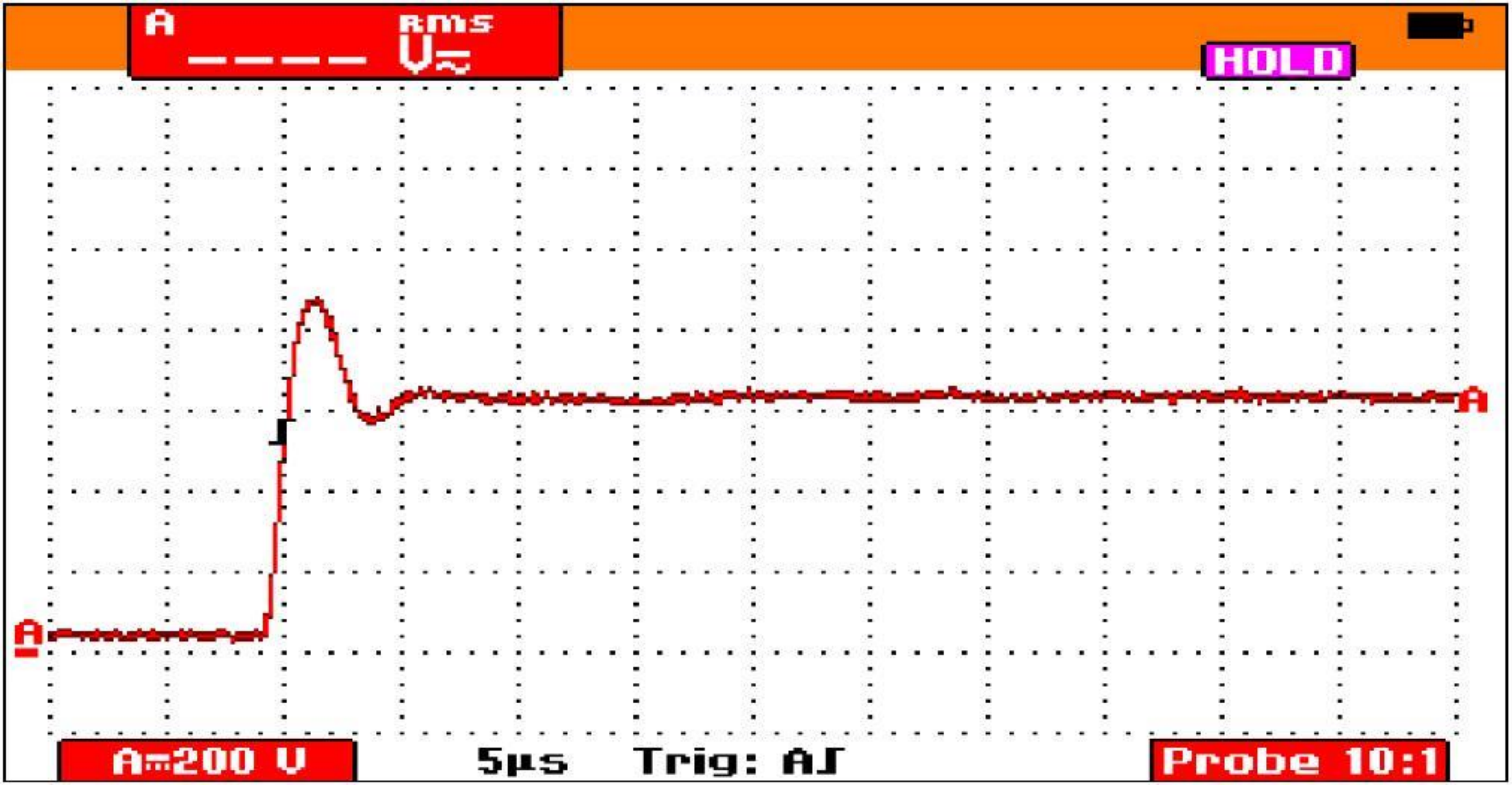
# No Output Filter Present

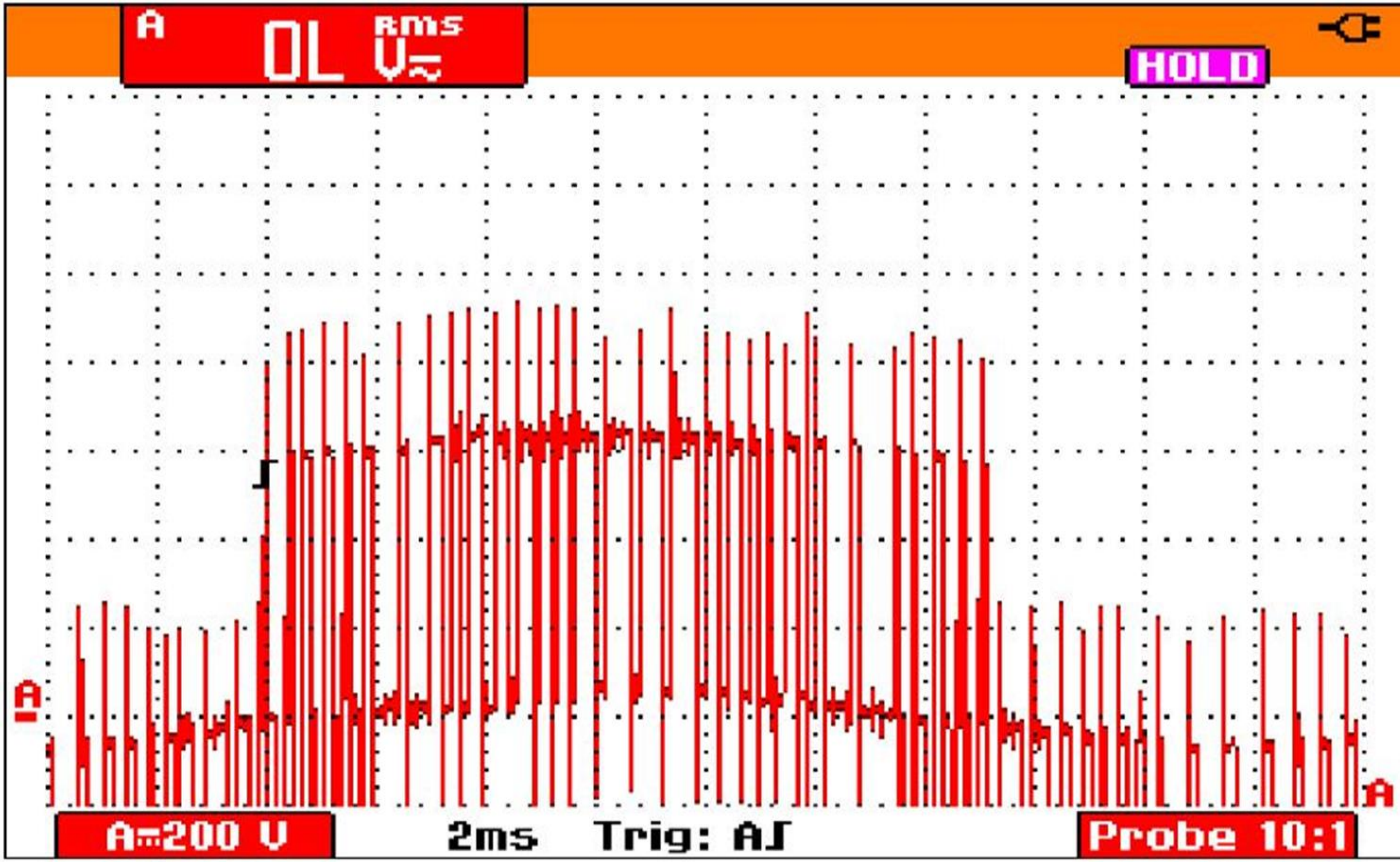



1320Vpk

# Pulse Rise Time




3.5usec

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# Motor Problems

VFD Motor Fault Frequencies VFD Motor Fault Frequencies
Electric Motor Fault Conditions:
Rolling element bearing faults
Imbalance
Misalignment
Looseness
Soft foot conditions
Rotor winding failure
Stator winding Failure
Air gap issues
VFD Carrier Frequencies
Sleeve bearing faults
Audible Noise
Mechanical Resonances
Note: these are not all possible failures, but the most typical

Common Causes of Electric Motor Failures
There are six main causes of electric motor failures:
Over-Current
Low Resistance
Over heating
Dirt
Moisture
Vibration


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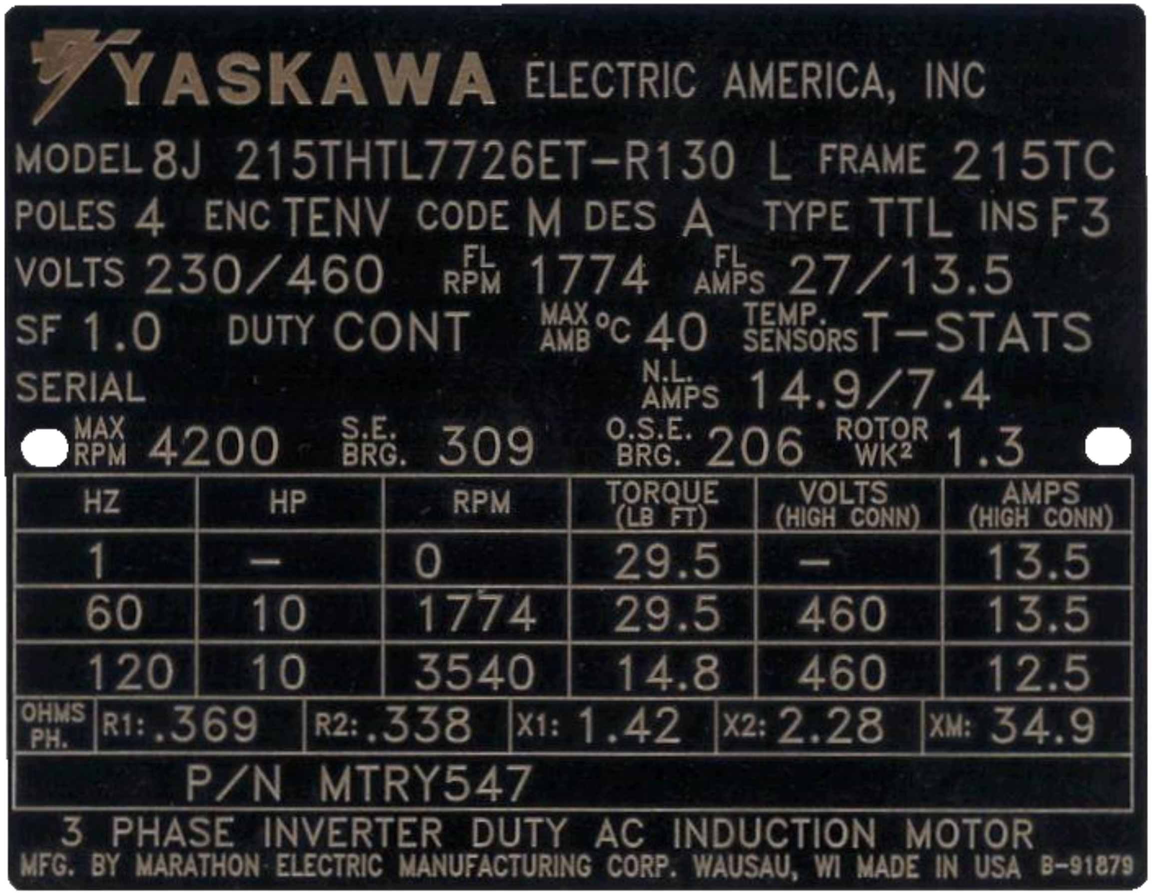


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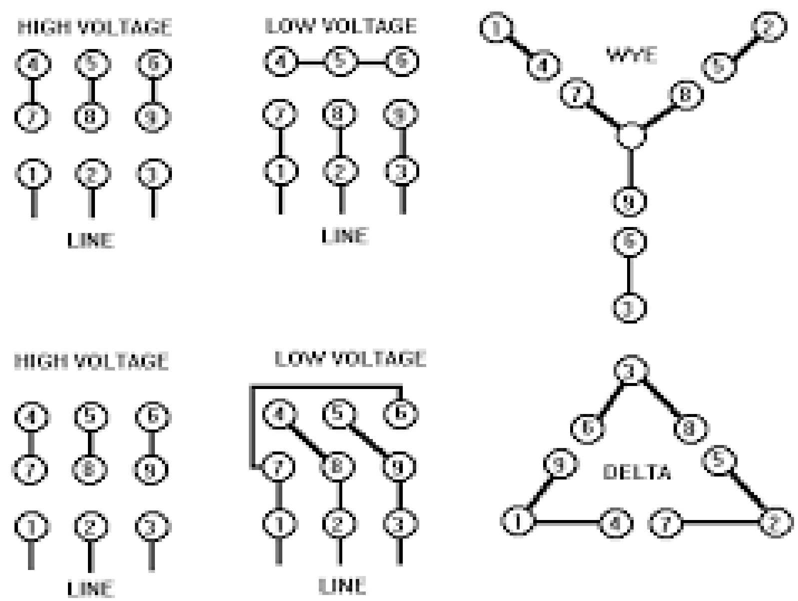


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Caution: 1. Disconnect power to the motor before performing service or maintenance.

2. Discharge all capacitors before servicing motor.

3. Always keep hands and clothing away from moving parts.

4. Be sure required safety guards are in place before starting equipment.

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## Visual and Mechanical Inspection:

An important aspect of large machine maintenance is the visual and mechanical inspection;

1. Inspect the machine's physical and mechanical condition.
2. Check for signs of oil or water leakage.
3. Check for abnormal sounds or smells.
4. Check the surroundings for any environmental issues that may affect performance or service life.
5. Check for appropriate lubrication and lubrication systems.
6. Verify the bearing oil level.
7. Look for dirty oil or old oil ( should be replaced or tested)
8. Check for poor alignment

1. Resistance measurements taken through bolted connections with a low resistance ohmmeter.

2. Phase to phase stator resistance tests.

3. Insulation – resistance tests on insulated bearings.

4. Testing and inspection of surge protection devices.

5. Testing and inspection of motor starters.

6. Resistance tests on resistance temperature detector (RTD) circuits.

7. Vibration testing of motor after it has started running.

8. Insulation power factor or dissipation – factor tests.

9. Surge comparison tests.

10. Power factor tip up tests.

11. Verification of machine space heater operation, if applicable

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An Electric Research Institute (ERPI) study of electric motor failures indicated that 53% of electric motor failures are related to mechanical components and 47% to electrical faults.

Bearing failures are the root cause for the great majority of electric motor downtime

Bearings fail well before they serve their theoretical life

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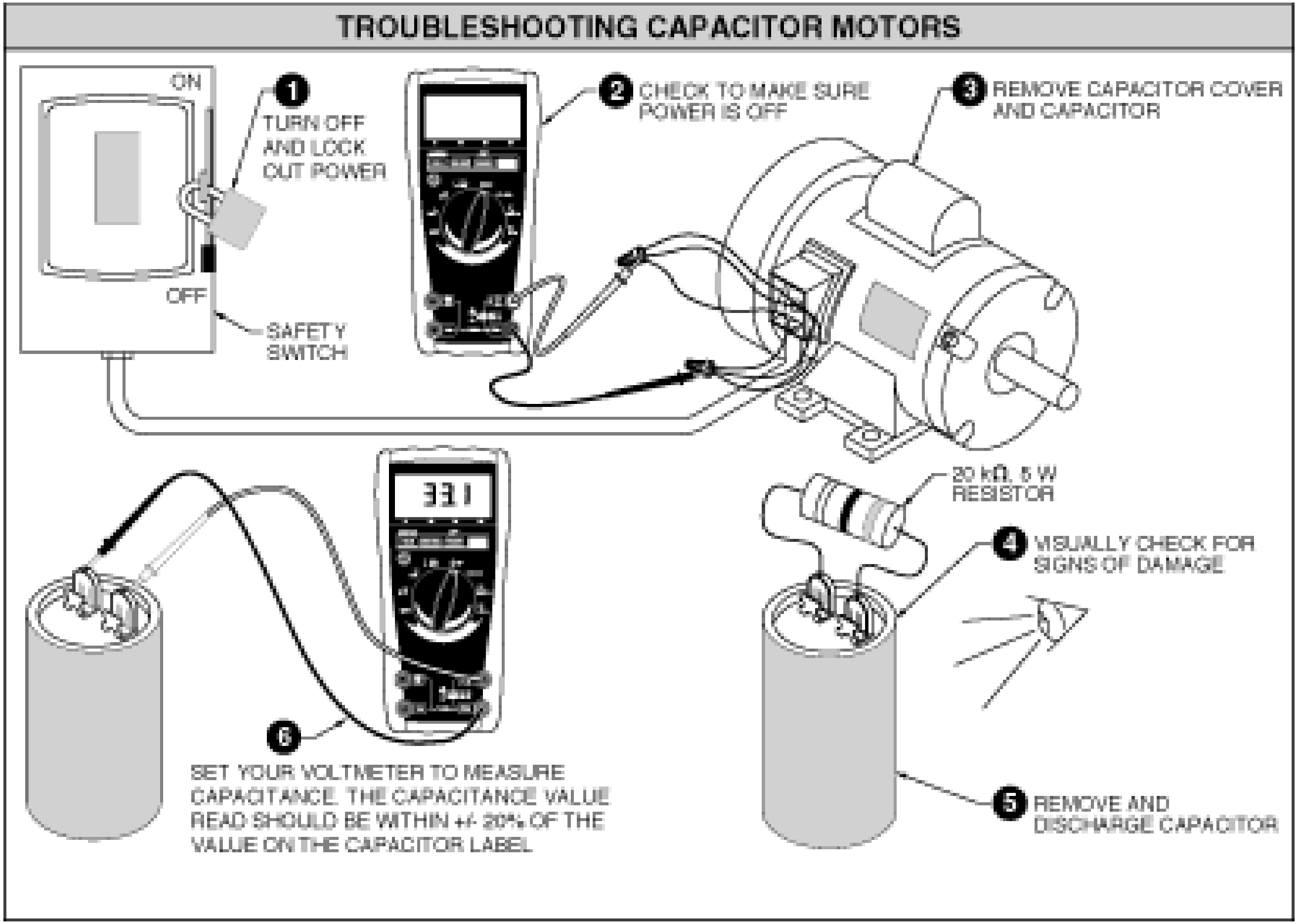


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Meg Ohm Meter. A megaohm meter is a special type of ohm meter. Instead of using the little 1.5 volt battery to check for ohms like a traditional meter, it has circuitry that checks the ohms is the presence of either 500 or 1000 volts.

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# Troubleshooting AC Motors

## Problem A - Motor won't start or motor accelerates too slowly

**A1:** Check input power to starter. Is there power on all lines? (Three-phase motors won't start on one-phase.)

NO → Restore power on all lines

YES ↓

**A2:** Check starter. Is overload protection device opened?

YES → Replace or reset device. Does it open again when starting? (YES → A3)

NO ↓

**A3:** Is there power on all lines to motor?

NO → Repair starter

YES ↓

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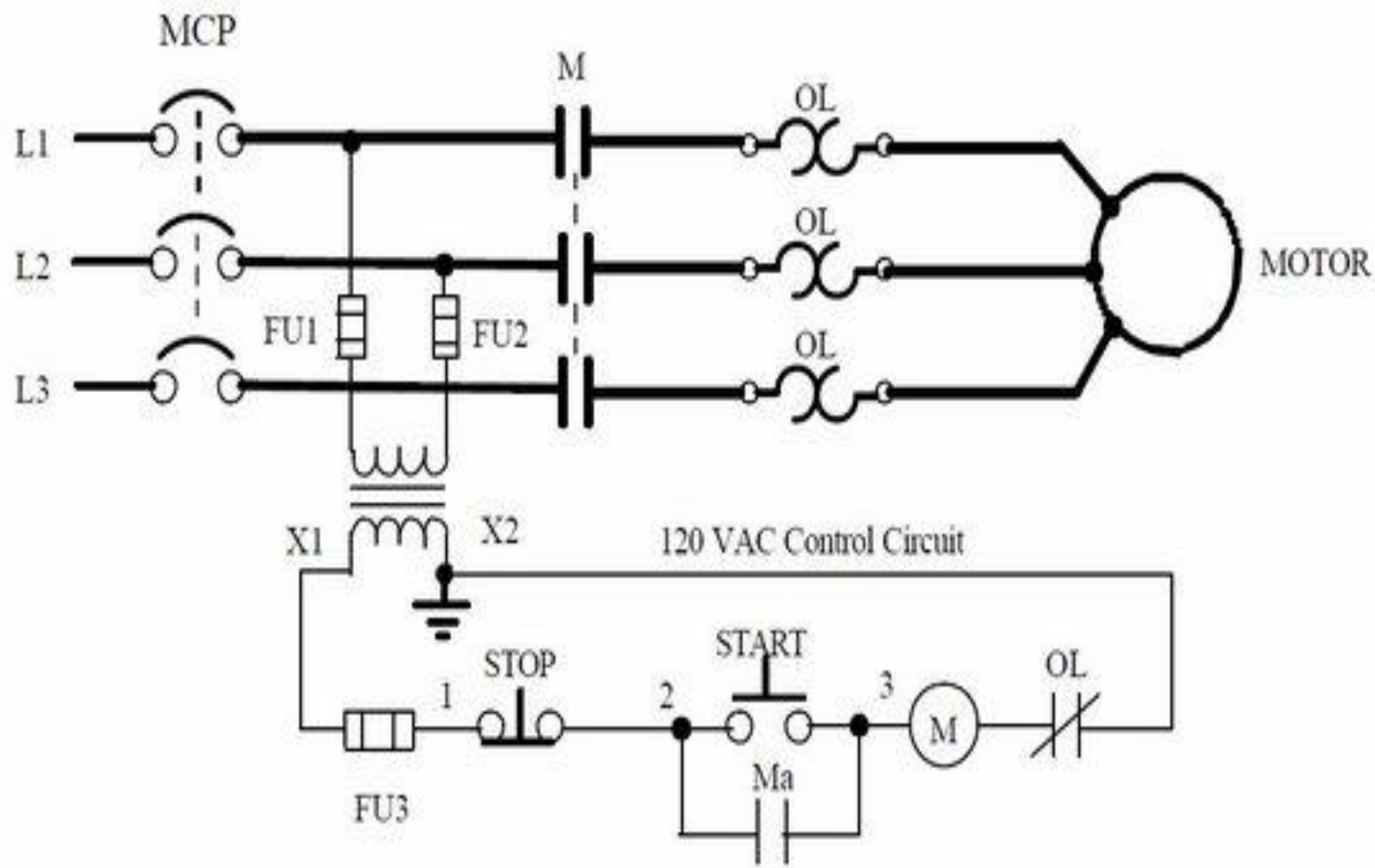
MCP
M
OL
OL
OL
L1
L2
L3
FU1
FU2
MOTOR
X1
X2
120 VAC Control Circuit
STOP
START
OL
1
2
3
M
Ma
FU3

**A4:** Is voltage to motor more than 10% below nameplate voltage? — YES → Restore proper voltage.

NO ↓

**A5:** Check motor terminal connections. Are any loose or broken? — YES → Repair connections.

NO ↓

**A6:** May be wrong motor for application. Is starting load too high? — YES → Install Design C or Design D motor. Install larger motor.

NO ↓

**A7:** Is driven machine jammed or overloaded? — YES → Remove jam or overload.

NO ↓

**A8:** Are misalignments, bad bearings or damaged components causing excessive friction in driven machine or power transmission system? **YES** → Repair or replace component.

NO ↓

**A9:** Are bad bearings, bent shaft, damaged end bells, rubbing fan or rotor or other problem causing excessive friction in the motor? **YES** → Repair or replace motor.

NO ↓

**A10:** Check stator. Are any coils open, shored or grounded? **YES** → Repair coil or replace motor.

NO ↓

**A11:** Check commutator. Are any bars or rings broken? **YES** → Replace rotor.

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# Problem B - Motor runs noisy

**B1:** Are vibrations and noise from driven machine or power transmission system being transmitted to motor?

YES → Locate source of noise and reduce. Isolate motor with belt drive or elastomeric coupling.

NO ↓

**B2:** Is a hollow motor foundation acting as a sounding board?

YES → Redesign mounting. Coat foundation underside with sound dampening material.

NO ↓

**B3:** Check motor mounting. Is it loose?

YES → Tighten. Be sure shaft is aligned.

NO ↓

**B4:** Is motor mounting even and shaft properly aligned?

NO → Shim feet for even mounting and align shaft.

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YES ↓

**B5:** Is fan hitting or rubbing on stationary part or is object caught in fan housing? — YES → Repair damaged fan, end bell or part causing contact. Remove trash from fan housing.

NO ↓

**B6:** Is air gap no uniform or rotor rubbing on stator? — YES → Recenter rotor rubbing on worn bearings or relocate pedestal bearings.

NO ↓

**B7:** Listen to bearings. Are they noisy? — YES → Lubricate bearings. If still noisy, replace.

NO ↓

**B8:** Is voltage between phases (three-phase motors) unbalanced? — YES → Balance voltages.

NO ↓

**B9:** Is three-phase motor operating on one-phase? (Won't start on single-phase.) — YES → Restore power on three-phases.

# Problem C - Motor overheats

**C1:** Is ambient temperature too high? — YES → Reduce ambient, increase ventilation or install larger motor.

NO ↓

**C2:** Is motor too small for present operating conditions? — YES → Install larger motor.

NO ↓

**C3:** Is motor started too frequently? — YES → Reduce starting cycle or use larger motor.

NO ↓

**C4:** Check external frame. Is it covered with dirt which acts as insulation and prevents proper cooling?

YES → Wipe, scrape or vacuum accumulated dirt from frame.

NO ↓

**C5:** Feel output from air exhaust openings. Is flow light or inconsistent indicating poor ventilation?

YES → Remove obstructions or dirt preventing free circulation of air flow. If needed, clean internal air passages.

NO ↓

**C6:** Check input current while driving load. Is it excessive indicating an overload?

NO → Go to Step C11.

YES ↓

**C7:** Is the driven equipment overload?

YES → Reduce load or install larger motor.

NO ↓

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**C8:** Are misalignments, bad bearings or damaged component causing excessive friction in driven machine or power transmission system?

YES → Repair or replace bad components.

NO ↓

**C9:** Are motor bearings dry?

YES → Lubricate. Does motor still draw excessive current?

YES → (to C10)

NO ↓

**C10:** Are damaged end bells, rubbing fan, bent shaft or rubbing rotor causing excessive internal friction?

YES → Repair or replace motor.

NO ↓

**C11:** Are bad bearings causing excessive friction?

YES → Determine cause of bad bearings (See Problem D).

NO ↓

**C12:** Check phase voltage. Does it vary between phases?

YES → Restore equal voltage on all phases.

↓ NO

**C13:** Is voltage more than 10% above or 10% below nameplate?

YES → Restore proper voltage or install motor built for the voltage.

↓ NO

**C14:** Check stator. Are any coils grounded or shorted?

YES → Repair coils or replace motor.

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# Problem D - Motor bearings run hot or noisy

**D1:** Check loading. Is excessive side pressure, end loading or vibration overloading bearings?

YES → Reduce overloading.* Install larger motor.

NO ↓

**D2:** Is sleeve bearing motor mounted on a slant causing end thrust?

YES → Mount horizontally* or install ball bearing motor.

NO ↓

**D3:** Is bent or misaligned shaft overloading bearings?

YES → Replace bent shaft or align shaft.*

NO ↓

**D4:** Is loose or damaged end bell overloading shaft?

YES → Tighten or replace end bell.*

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NO ↓

**D5:** Are bearings dry? — YES → Lubricate.*

NO ↓

**D6:** Is bearing lubricant dirty, contaminated or of wrong grade? — YES → Clean bearings and lubricate with proper grade*

NO ↓

**D7:** Remove end bells. Are bearings misaligned, worn or damaged? — YES → Replace.

**Bearings may have been damaged. If motor still runs noisy or hot, replace bearings.*

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# Three types of drive faults

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# No VFD Display, keypad is dark

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# VFD Keypad displays fault information

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# VFD is ready but does start

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