Electrical Level 4

Advanced Controls 26407-14

Objectives

When trainees have completed this lesson, they should be able to do the following:

1. Select and install solid-state relays for specific applications in motor control circuits.
2. Install non-programmable/programmable motor circuit protectors (solid-state overload relays) in accordance with the manufacturer’s instructions.
3. Select and install electromechanical and solid-state timing relays for specific applications in motor control circuits.
4. Recognize the different types of reduced-voltage starting motor controllers and describe their operating principles.

Objectives and Performance Task

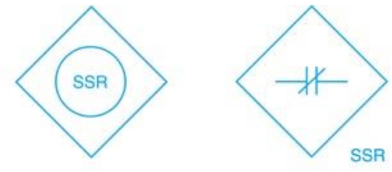
5. Connect and program adjustable frequency drives to control a motor in accordance with the manufacturer's instructions.
6. Demonstrate and/or describe the special precautions used when handling and working with solid-state motor controls.
7. Recognize common types of motor braking and explain the operating principles of motor brakes.
8. Perform preventive maintenance and troubleshooting tasks in motor control circuits.

Performance Task

Identify and connect various control devices.

Introduction; Solid-State Relays

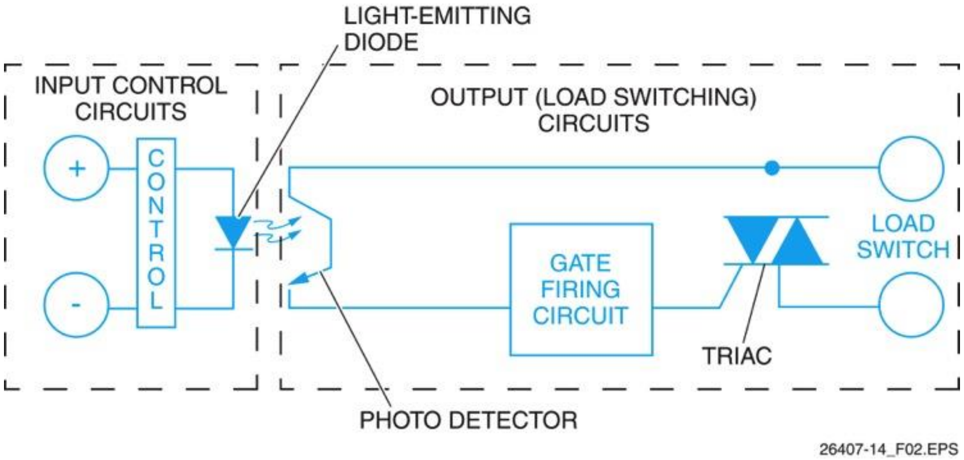
- Solid-state relays (SSRs) have many advantages over electromechanical relays, including faster switching and superior service life, reliability, and shock/vibration resistance.
- An SSR is activated by an AC or DC voltage applied to its input terminals. DC inputs are normally less than 32VDC and applied from digitally controlled motor inputs.



SCHEMATIC SYMBOLS

Block Diagram of an Optically Isolated Solid-State Relay

- An SSR consists of an input control circuit and an output control circuit.
- The input control circuit senses the input control signal and provides coupling between the input and output circuits using a light-emitting diode (LED) and photo detector.



Comparison Chart for EMR and SSR Technology

Comparable or Equivalent Terminology for Electromechanical and Solid-State Relays	
Electromechanical Relays (EMRs)	**Solid-State Relays (SSRs)**
1. *Coil voltage:* The minimum voltage necessary to energize or operate the relay. This value is also referred to as the pickup voltage.	1. *Control voltage:* The minimum voltage required to gate or activate the control circuit of the solid-state relay. Generally a maximum value is also specified.
2. *Coil current:* In conjunction with the coil voltage, the amount of current necessary to energize or operate the relay.	2. *Control current:* The minimum current required to turn on the solid-state control circuit. Generally a maximum value is also specified.
3. *Hold current:* The minimum current required to keep a relay energized or operating.	3. *See control current.*
4. *Dropout voltage:* The maximum voltage at which the relay is no longer energized.	4. *See control voltage.*
5. *Pull-in time:* The amount of time required to operate (open or close) the relay contacts after the coil voltage is applied.	5. *Turn-on time:* The elapsed time between the application of the control voltage and the application of the voltage to the load circuit.
6. *Dropout time:* The amount of time required for the relay contacts to return to their normal unoperated position after the coil voltage is removed.	6. *Turn-off time:* The elapsed time between the removal of the control voltage and the removal of the voltage from the load circuit.
7. *Contact voltage rating:* Maximum voltage rating that the contacts of a relay are capable of switching safely.	7. *Load voltage:* The maximum output voltage handling capability of a solid-state relay.
8. *Contact current rating:* Maximum current rating that the contacts of a relay are capable of switching safely.	8. *Load current:* The maximum output current handling capability of a solid-state relay.
9. *Surge current:* Maximum peak current that the contacts of a relay can withstand for short periods of time without damage.	9. *Surge current:* Maximum peak current that a solid-state relay can withstand for short periods of time without damage.
10. *Contact voltage drop:* Voltage drop across relay contacts when relay is operating (usually quite low).	10. *Switch-on voltage drop:* Voltage drop across a solid-state relay when operating.
11. *Insulation resistance:* Amount of resistance measured across relay contacts in open position.	11. *Switch-off resistance:* Amount of resistance measured across a solid-state relay when turned off.
12. *No equivalent.*	12. *Off state current leakage:* Amount of current leakage through a solid-state relay when turned off but still connected to the load voltage.
13. *No equivalent.*	13. *Zero current turn-off:* Turn-off at essentially the zero crossing of the load current that flows through an SSR. A thyristor will turn off only when the current falls below the minimum holding current. If input control is removed when the current is at a higher value, turn-off will be delayed until the next zero current crossing.
14. *No equivalent.*	14. *Zero voltage turn-on:* Initial turn-on occurs at a point near zero crossing of the AC line voltage. If input control is applied when the line voltage is at a higher value, initial turn-on will be delayed until the next zero crossing.

EMR and SSR Performance

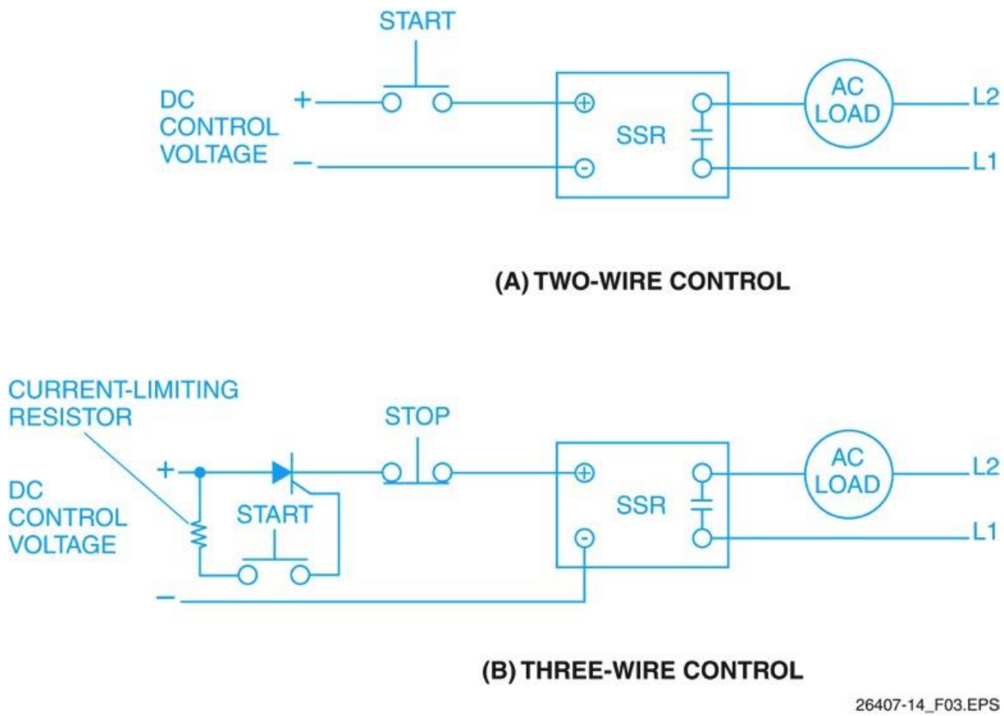
Plus (+) indicates advantages; minus (–) indicates disadvantages.

Advantages and Disadvantages of Electromechanical and Solid-State Relays

General Characteristics	EMR	SSR
1. Arcless switching of the load	–	+
2. Electronic (IC, etc.) compatibility for interfacing	–	+
3. Effects of temperature	+	–
4. Shock and vibration resistant	–	+
5. Immunity to improper functioning because of transients	+	–
6. Radio frequency switching	+	–
7. Zero voltage turn-on	–	+
8. Acoustic noise	–	+
9. Selection of multipole, multithrow switching capability	+	–
10. Contact bouncing	–	+
11. Ability to stand surge currents	+	–
12. Response time	–	+
13. Voltage drop in load circuit	+	–
14. AC & DC switching with same contacts	+	–
15. Zero current turn-off	–	+
16. Leakage current	+	–
17. Minimum current turn-on	+	–
18. Life expectancy	–	+
19. Initial cost	+	–
20. Real cost-lifetime	–	+

Two-Wire and Three-Wire SSR Control

- SSRs can be connected for either two-wire or three-wire control.
- In the two-wire circuit shown here, the SSR activates the load for as long as the Start pushbutton is pressed. In the three-wire circuit, the SSR activates a gate that maintains current flow when the pushbutton is released.



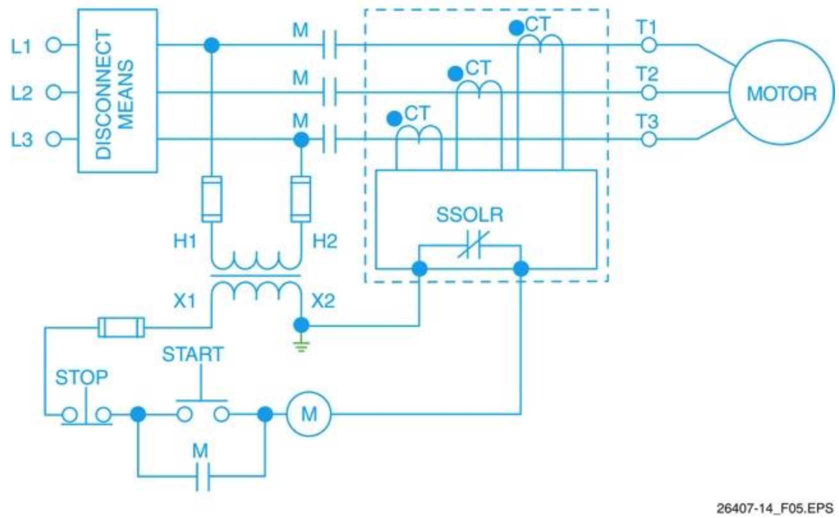
Next Session…

Multiple SSRs Connected in Parallel and Series to Control a Three-Phase Load

- A single SSR can be designed for multiple switched outputs or the inputs of two or more single-output SSRs can be series- or parallel-connected to obtain the desired outputs.
- In the circuits shown here, three SSRs are controlled by a single switch to

Solid-State Protective Relays

Solid-State Protective Relays



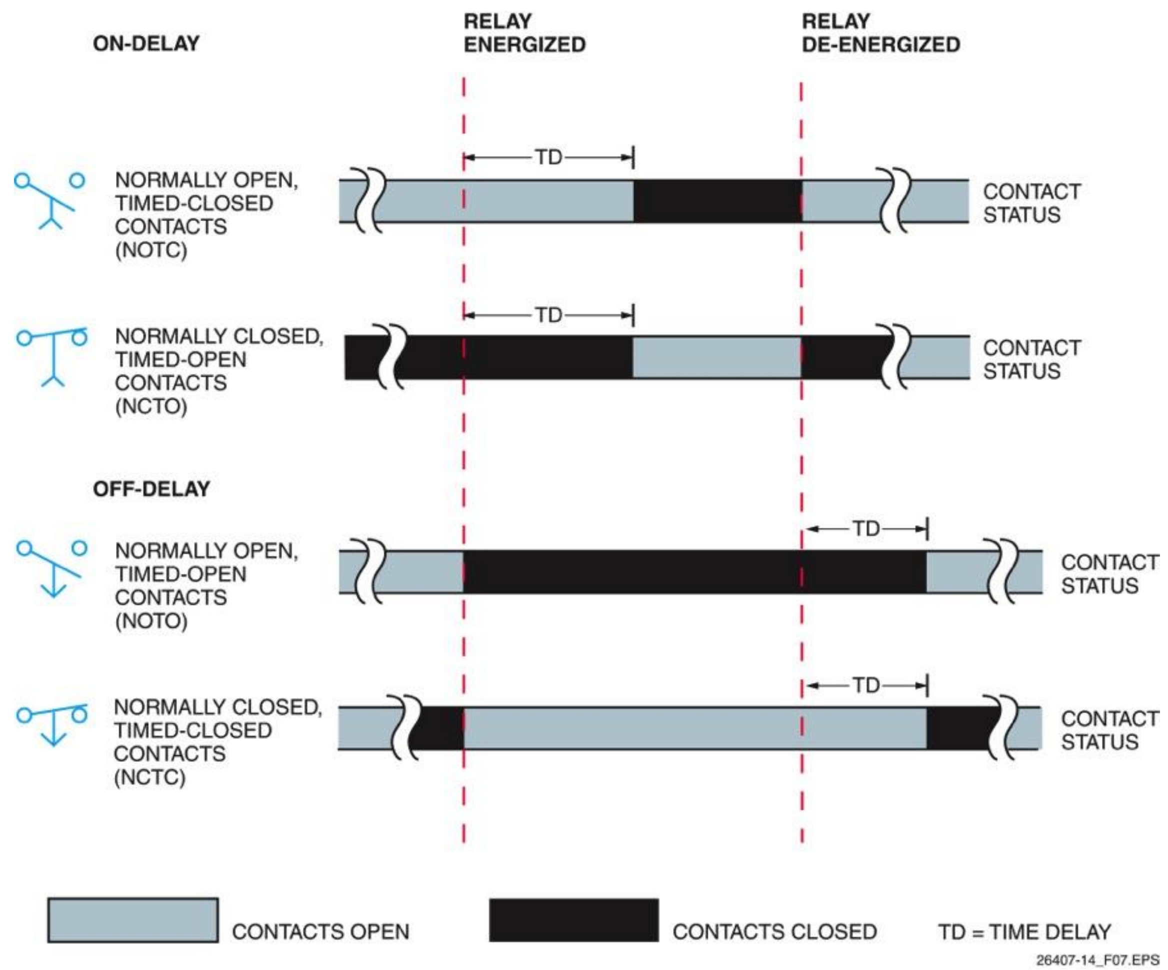
26407-14_F05.EPS

Typical Programmable Solid-State Overload Relay

- SSOLR programming is usually done using the front panel controls on the unit. Some units can be controlled using a personal computer (PC) connected via a communications network.
- The control parameters typically include various trip points and delay times. Refer to the manufacturer's instructions for the relay in use.

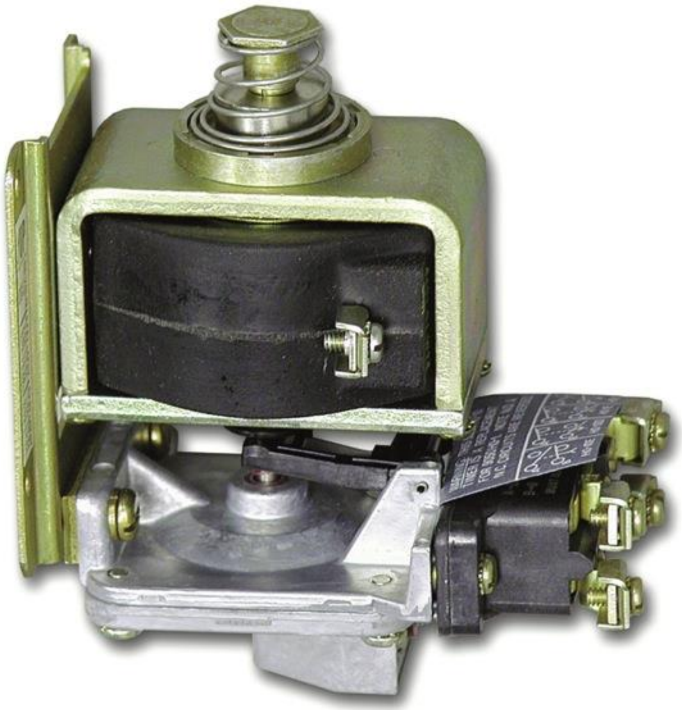
26407-14_F06.EPS

Timing Relays



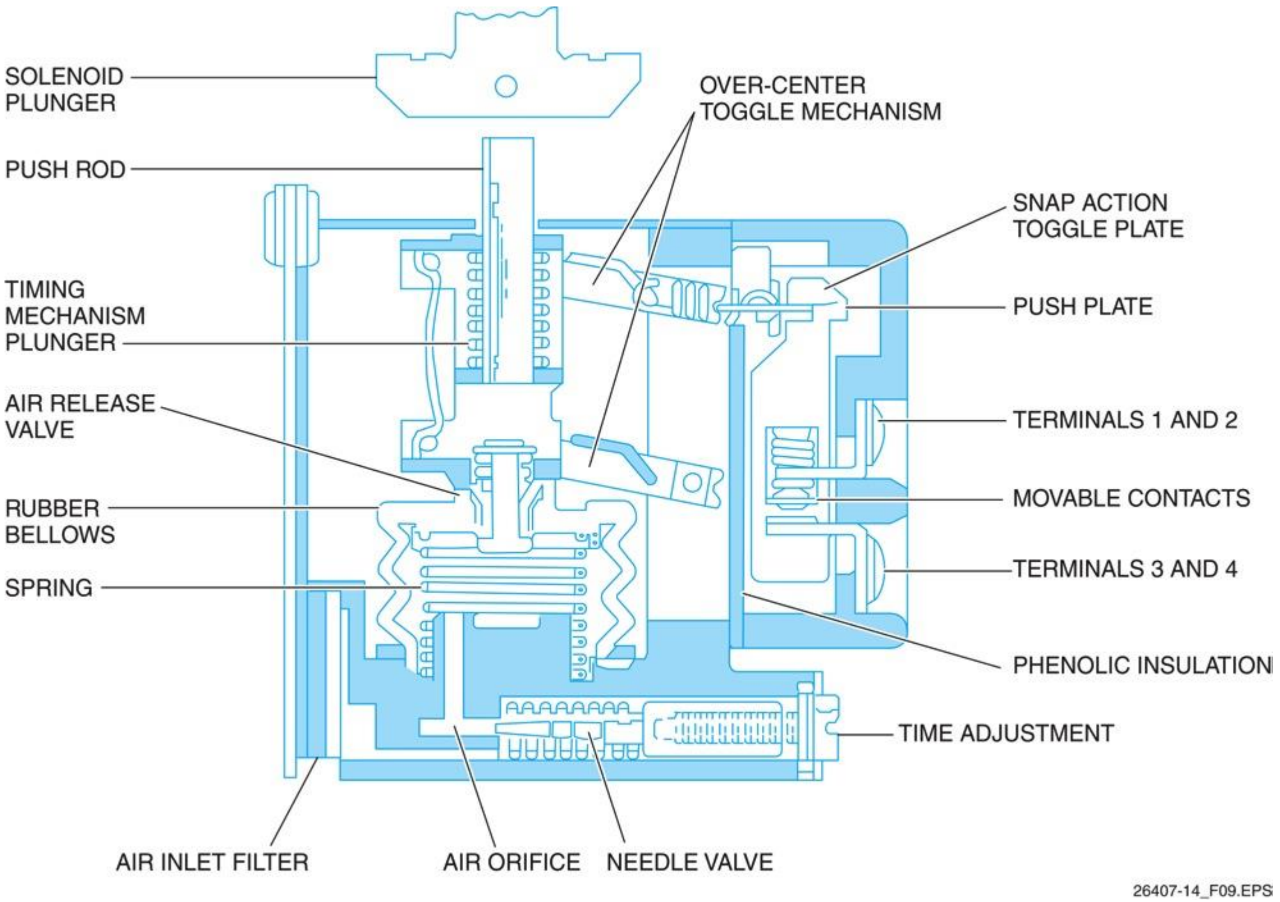
Pneumatic Time Delay Relay

- Pneumatic timing relays are electromechanical relays that use air power to retard the movement of the relay contacts.
- The pneumatic relay shown here has one normally open (NO) contact and one normally closed (NC) contact.



26407-14_F08.EPS

Cutaway View of Pneumatic Relay Contact Unit and Timing Mechanism

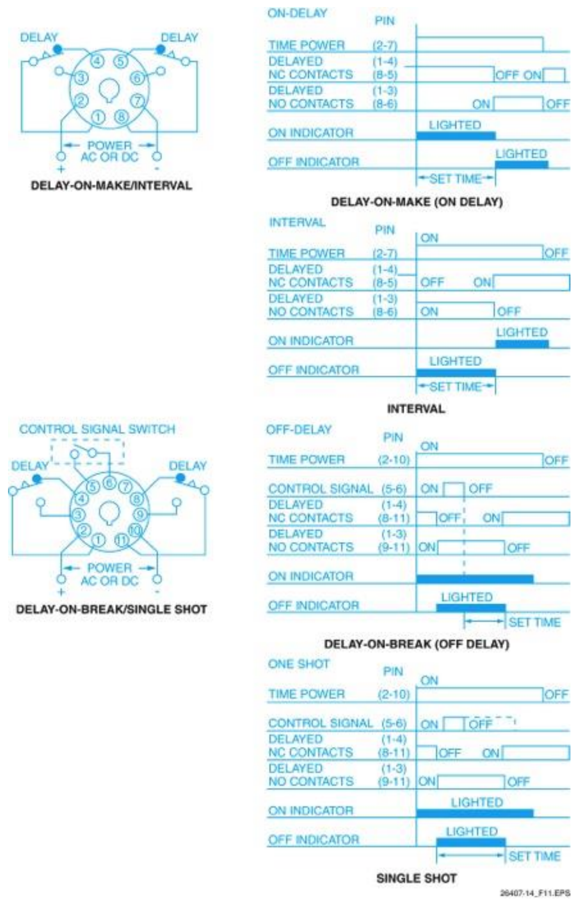


Typical Solid-State Plug-In Timing Relay

- Solid-state timing relays are used where high repeat accuracy is required and the time delay must be frequently changed.
- The solid-state timing relay shown here can provide several fixed timing ranges that are selected using controls on the top of the relay.

26407-14_F10.EPS

Plug-In Solid-State Relay Connection Diagrams and Operation Charts

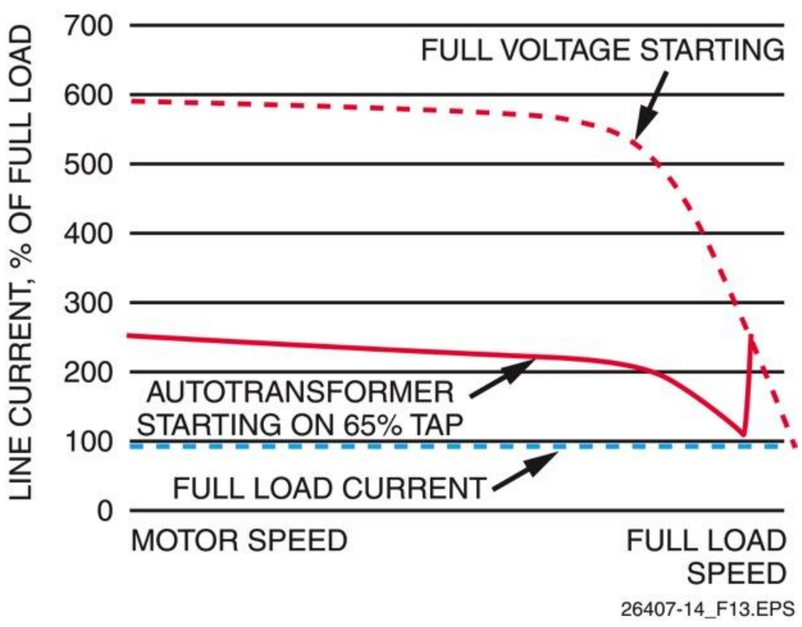


Next Session…

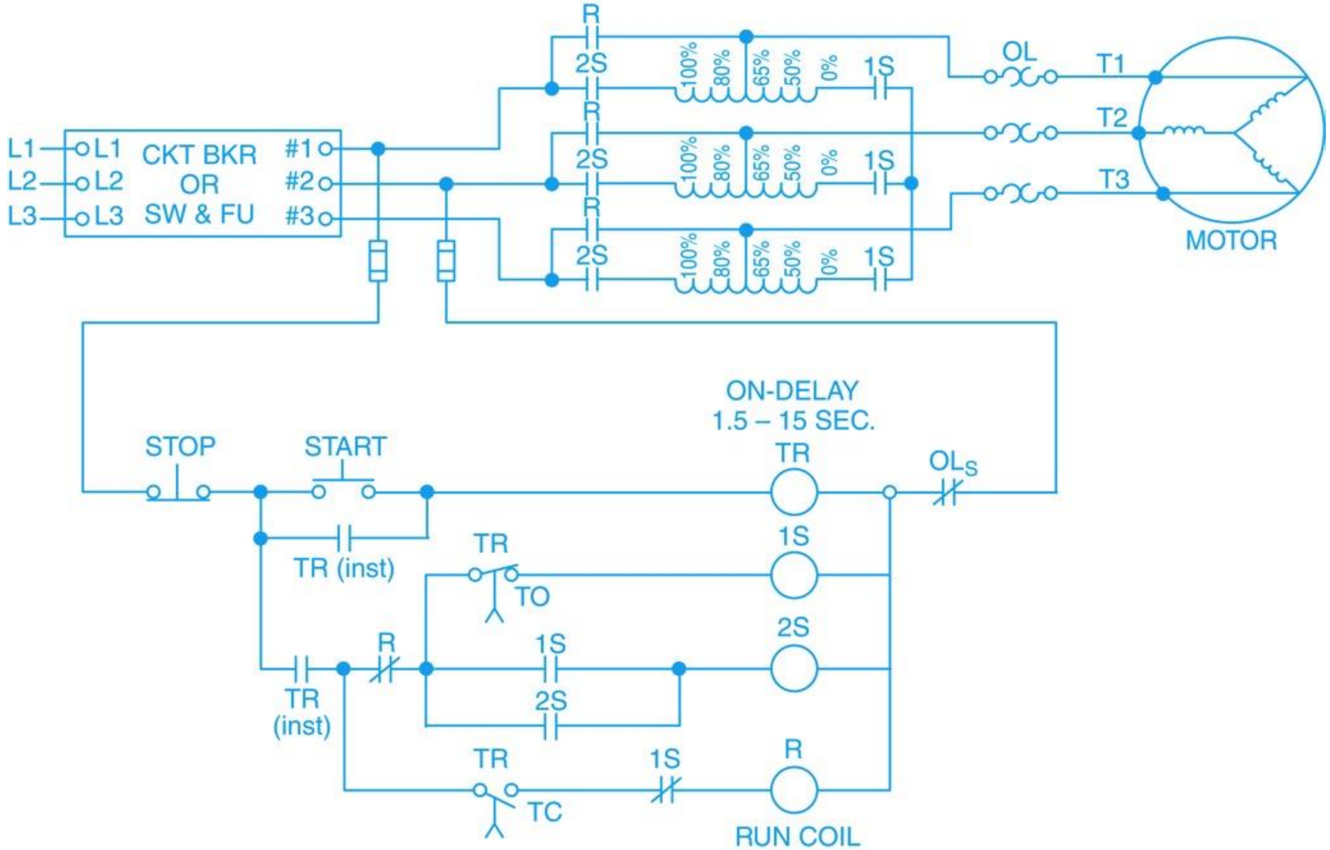
Reduced-Voltage Starting Motor Control

Reduced-Voltage Starting Motor Control

- Autotransformer reduced-voltage starting circuits allow for adjustment of the starting torque and inrush current to help accelerate the load.
- Autotransformers are typically used with high-torque loads such as reciprocating compressors, grinding mills, and pumps.



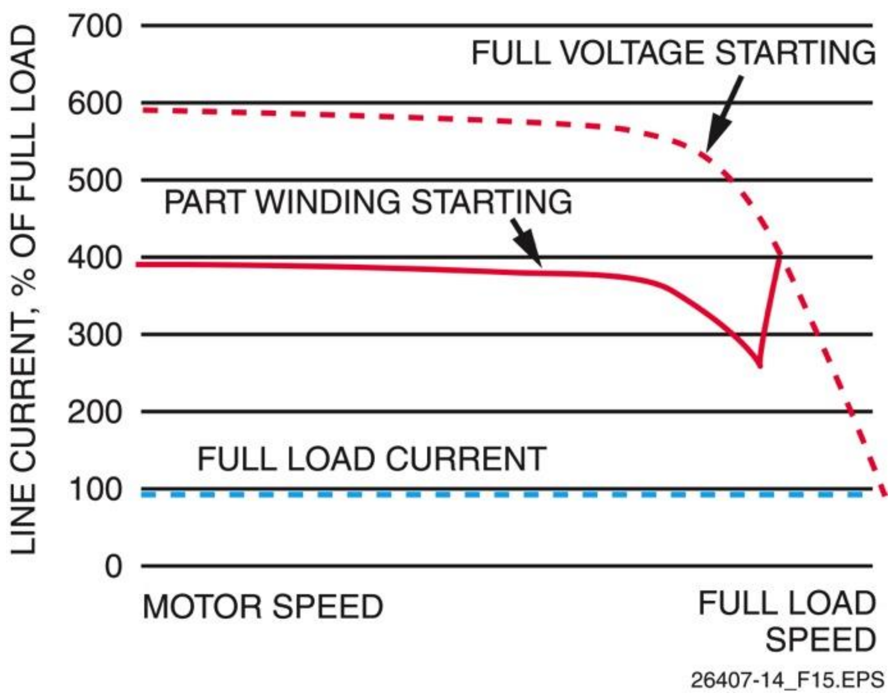
Typical Autotransformer Reduced-Voltage Starting Circuit



26407-14_F14.EPS

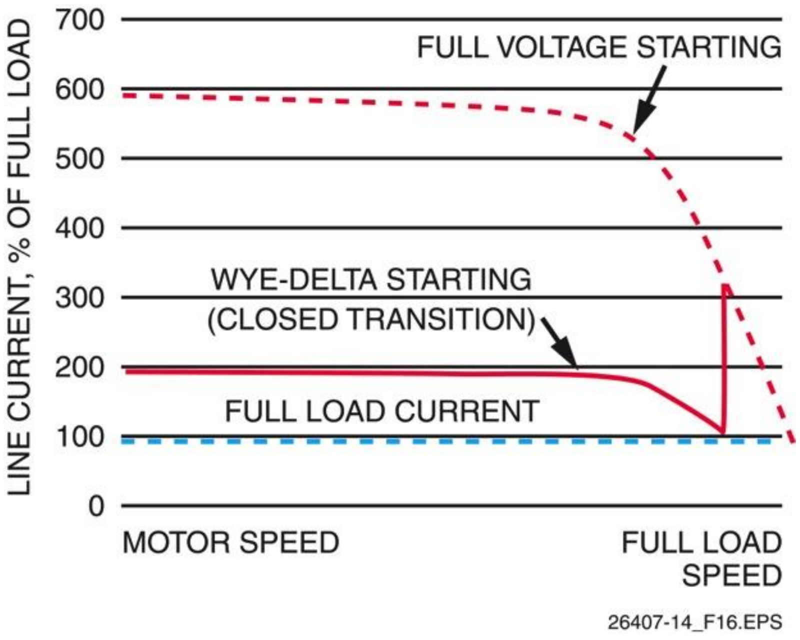
Part-Winding, Reduced-Voltage Starting Characteristics

- Part-winding, reduced-voltage starting motor control is an older method of motor control used with part-winding induction motors.
- The induction motor is started by applying power to part of the motor's coil windings for starting, then the remaining windings for normal running.



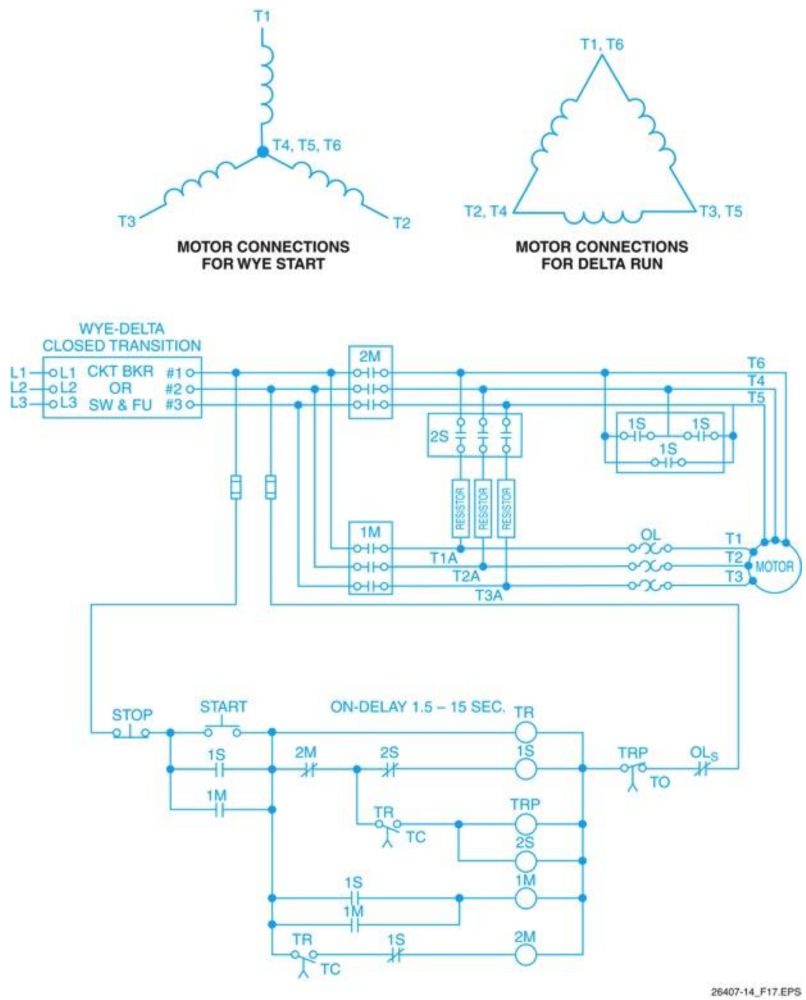
Wye-Delta, Reduced-Voltage Starting Characteristics

- Wye-delta, reduced-voltage starting operates by first connecting the leads in a wye configuration for starting, then connecting them in a delta configuration for running.
- Wye-delta starters are used to control high-inertia loads with long acceleration times, such as centrifugal compressors, centrifuges, and similar loads.



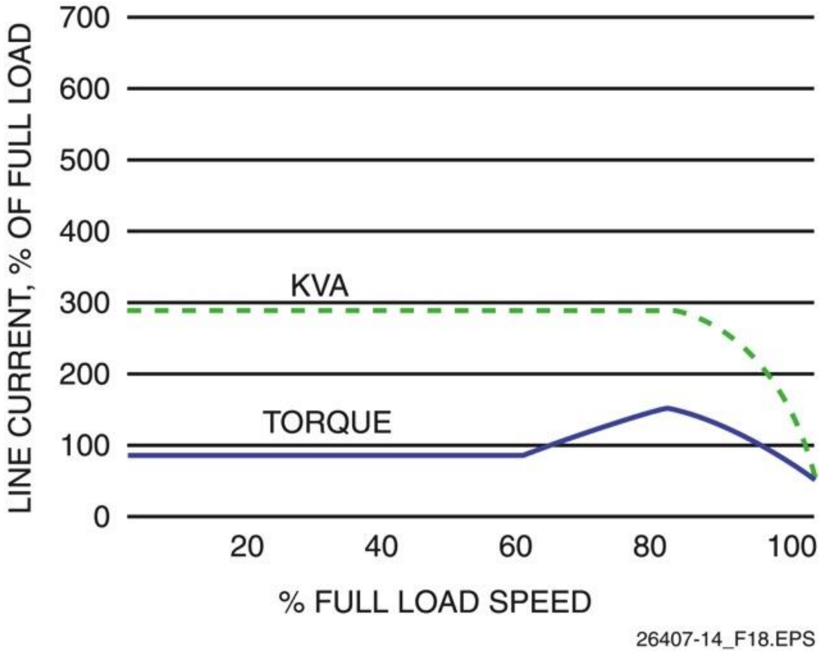
5.0.0 – 5.5.0

Typical Wye-Delta, Reduced-Voltage Starting Circuit

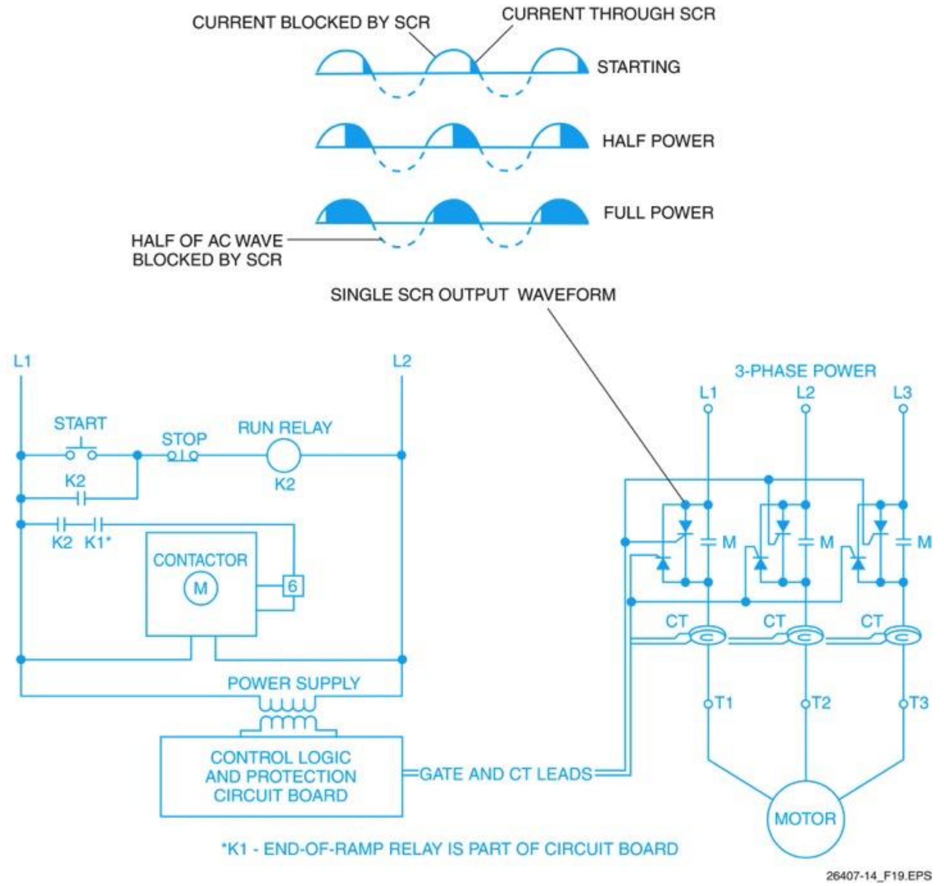


Solid-State, Reduced-Voltage Starting Characteristics

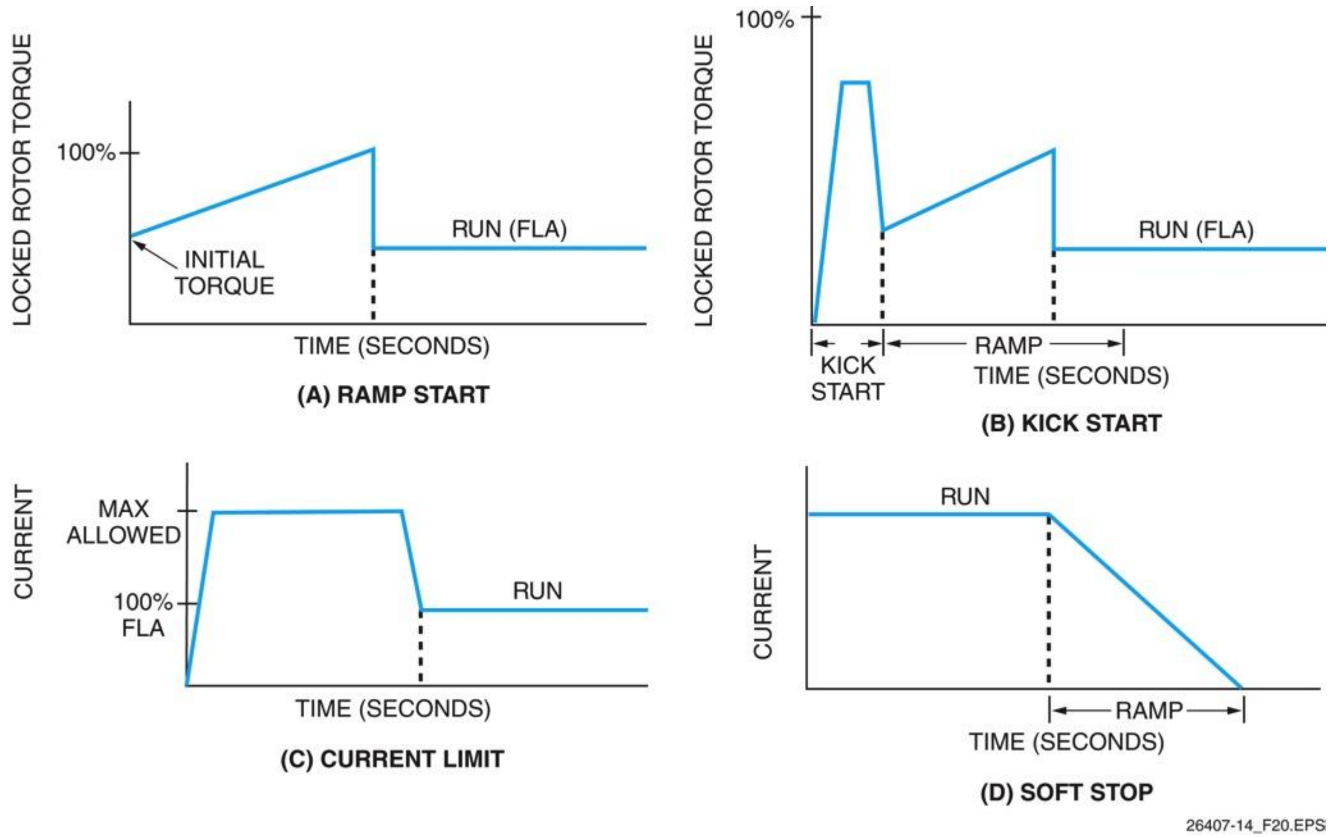
- Solid-state, reduced-voltage starters provide the same functions as electromechanical starters but supply a smoother start/acceleration. They are often referred to as soft-start controllers.
- Soft-start controllers are used with conveyors, compressors, and pumps.



Simplified Solid-State, Reduced-Voltage Starting Circuit



Starting Characteristics of Solid-State, Reduced-Voltage Controllers



Comparison of Reduced-Voltage Controllers

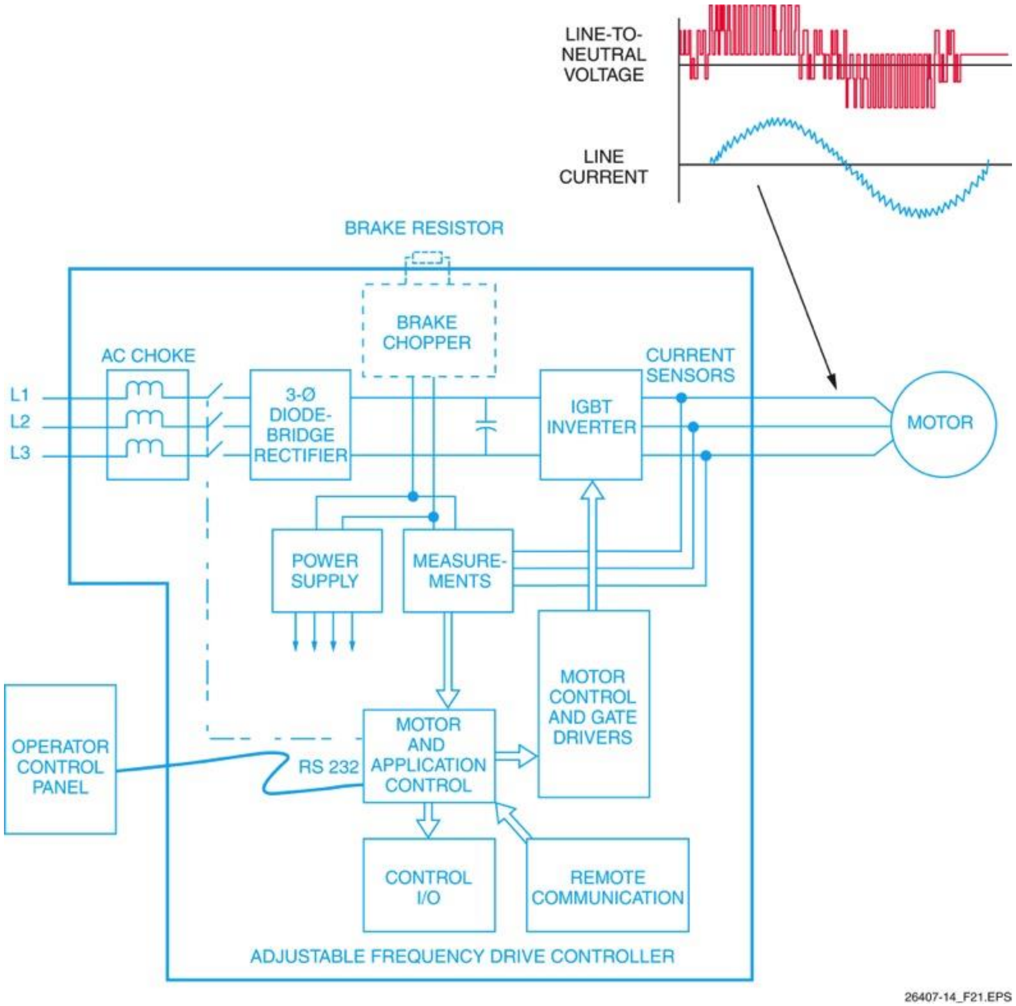
Type of Reduced-Voltage Controller	Starting Characteristics: Voltage at Motor (%)	Line Current (%)	Torque (%)	Remarks
Autotransformer	80	64	64	*Applications*–Blowers, pumps, compressors, conveyors
	65	42	42	
	50	25	25	
				Advantages • Provides maximum torque per ampere of line current • Starting characteristics easily adjusted • Different starting torques available through auto-transformer taps • Suitable for relatively long starting periods • Motor current greater than line current during starting
				Disadvantages • Most complex of reduced-voltage controllers because proper sequencing of energization must be maintained • Large physical size • Low power factor • Expensive in lower hp ratings

5.0.0 – 5.5.0

Next Session…

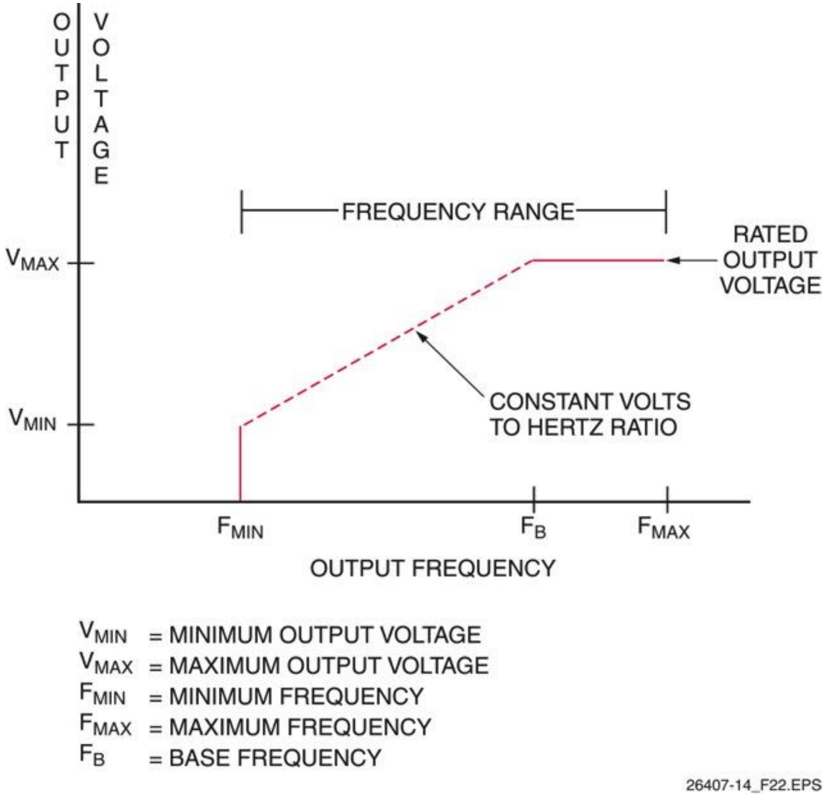
Adjustable Frequency Drives

Adjustable Frequency Drives



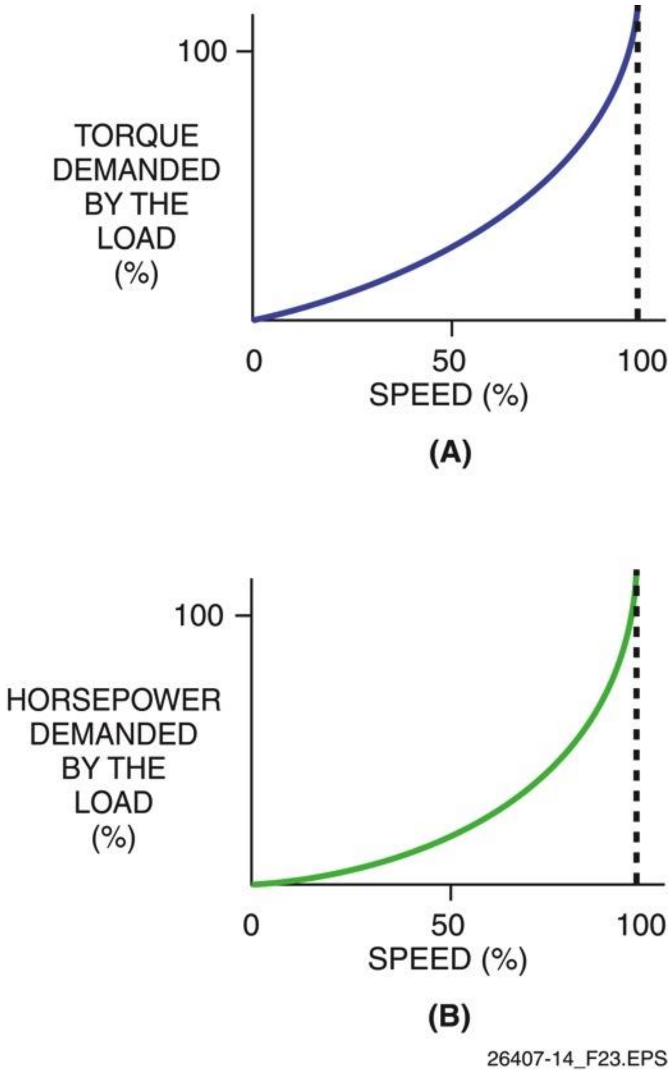
AFD Operating Frequency Range

- AFDs usually have one range of output frequencies over which the ratio of volts to hertz remains constant and another range of output frequencies over which the voltage remains constant but the frequency varies.
- The frequency at which this transition occurs is known as the base frequency.



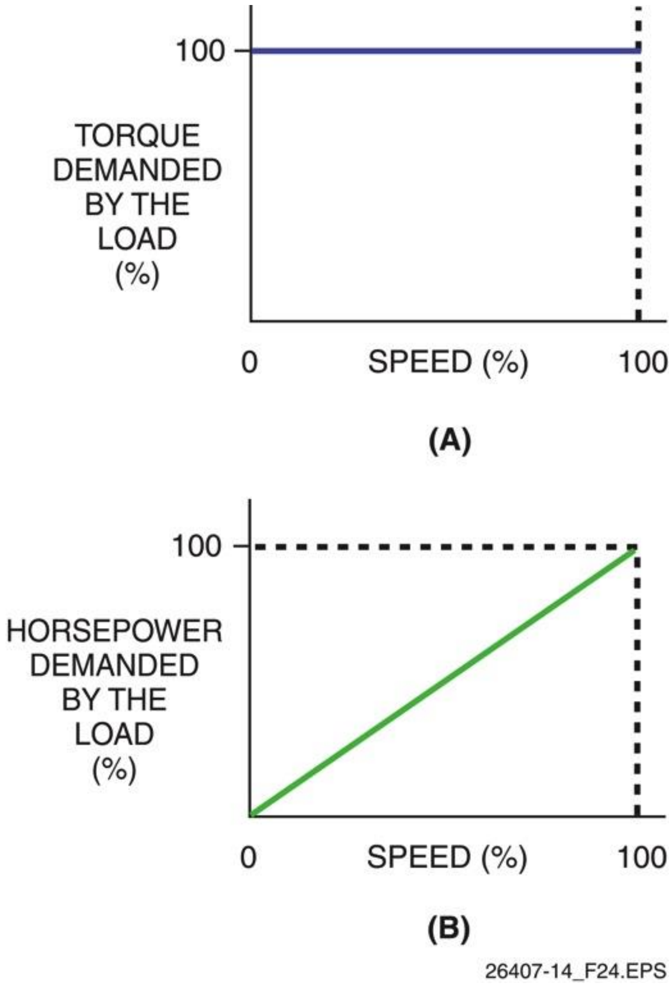
Variable Torque Load

- A variable torque load requires a much lower torque at low speeds.
- This type of load is found in machines with high-inertia loads, such as those with flywheels, centrifugal fans, pumps, blowers, and punch presses.



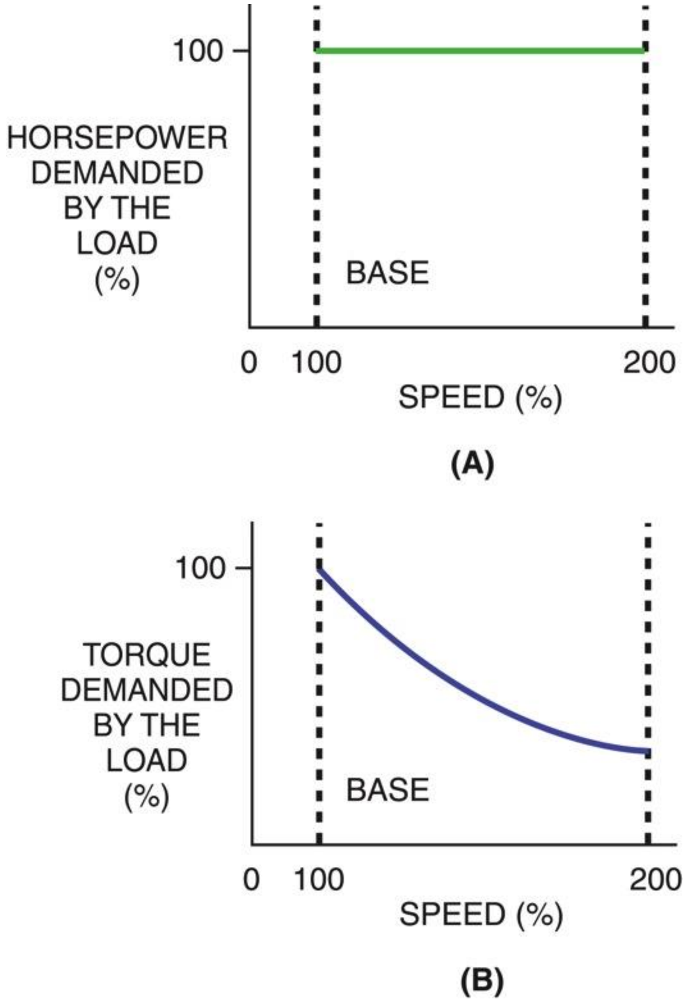
Constant Torque Load

- Constant torque loads require high torque to overcome friction. These loads require the same amount of torque at all speeds.
- This type of load is found in hoists, conveyors, printing presses, positive displacement pumps, and extruders, as well as for shock loads, overloads, and high-inertia loads.



Constant Horsepower Load

- Constant horsepower loads require constant horsepower at all speeds.
- This type of load is found in multi-speed metal cutting equipment, mixers, center-driven winders, and some extruders.



26407-14_F25.EPS

AFD Application Checklist

AFD APPLICATION CHECKLIST

Motor

New______ Existing ______ Horsepower: ______ Base Speed: ______ Voltage: ______

FLA: ______ LRA: ______ NEMA Design: ______ Gearbox/Pulley Ratio: ______

Service Factor:______

Load

Application: ______

Load Type: Constant Torque ______ Variable Torque ______ Constant Horsepower ______

Load inertia reflected to motor: ______

Required breakaway torque from motor: ______

Running load on motor: ______

Peak torques (above 100% running): ______

Shortest/longest required accel. time: ______ / ______ secs up to ______ Hz from zero speed

Shortest/longest required decel. time: ______ / ______ secs down to ______ Hz from max. speed

Operating speed range: ______ Hz to ______ Hz

Time for motor/load to coast to stop: ______ secs

AFD

Source of start/stop commands: ______

Source of speed adjustment: ______

Other operating requirements: ______

Will the motor ever be spinning when the AFD is started? ______

Is the load considered to be high inertia? ______

Is the load considered to be hard to start? ______

Distance from AFD to the motor: ______ feet

Type of AFD (V/Hz, Flux Vector, Closed Loop Vector): ______

Options desired: ______

______

______

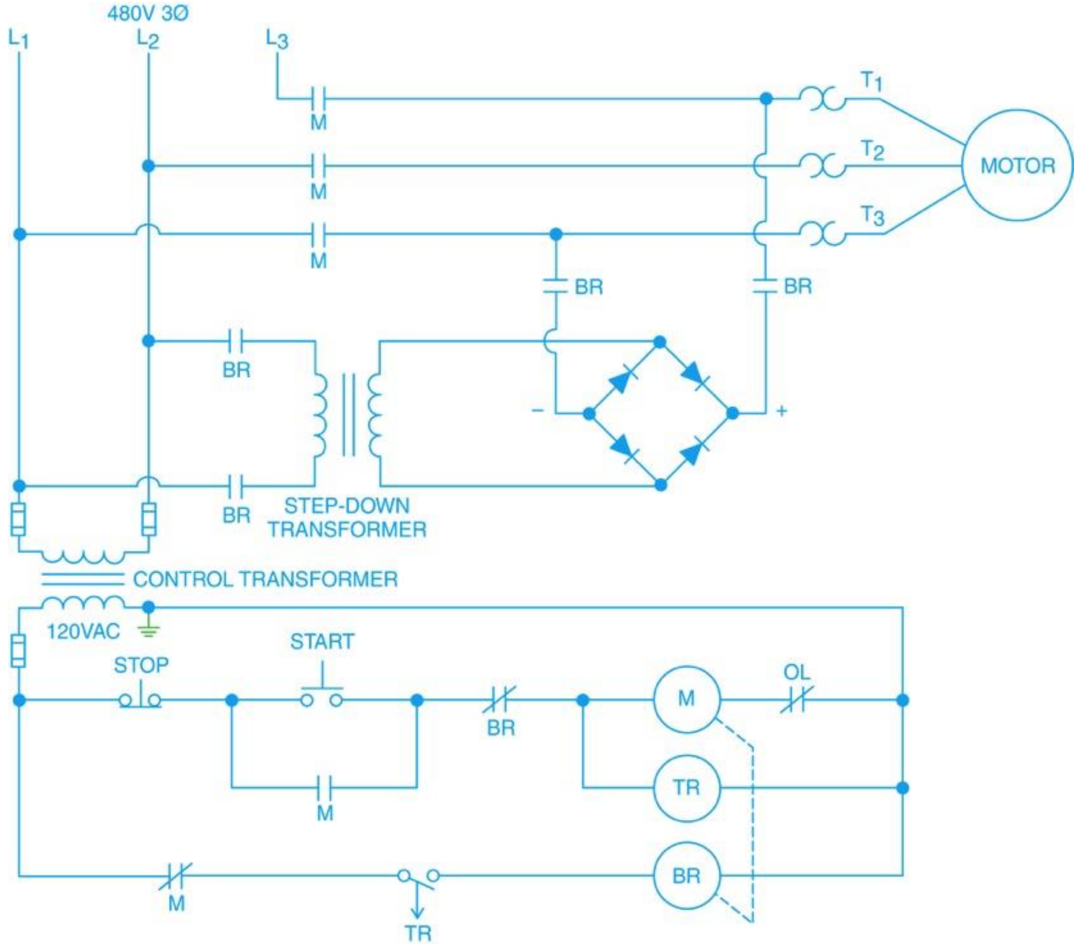
Other special requirements/conditions: ______

26407-14_F26A.EPS

Next Session…

Motor Braking Methods

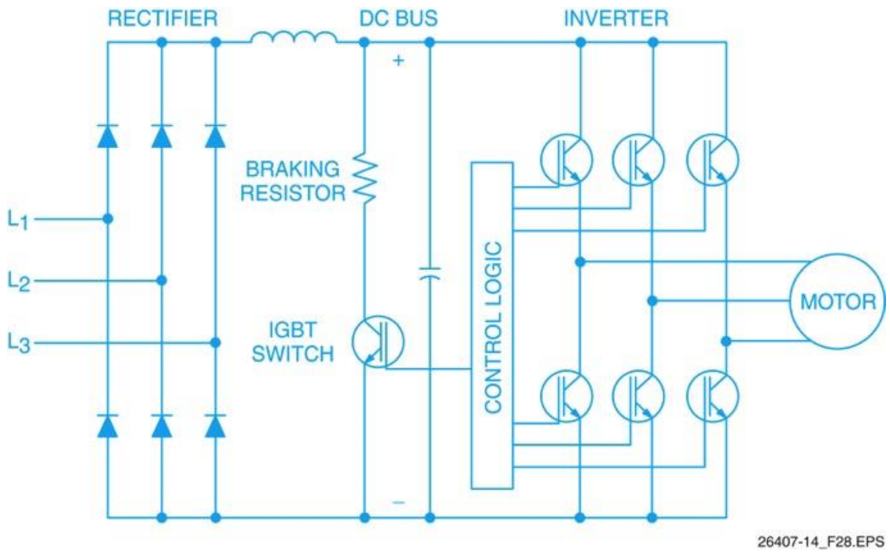
Motor Braking Methods



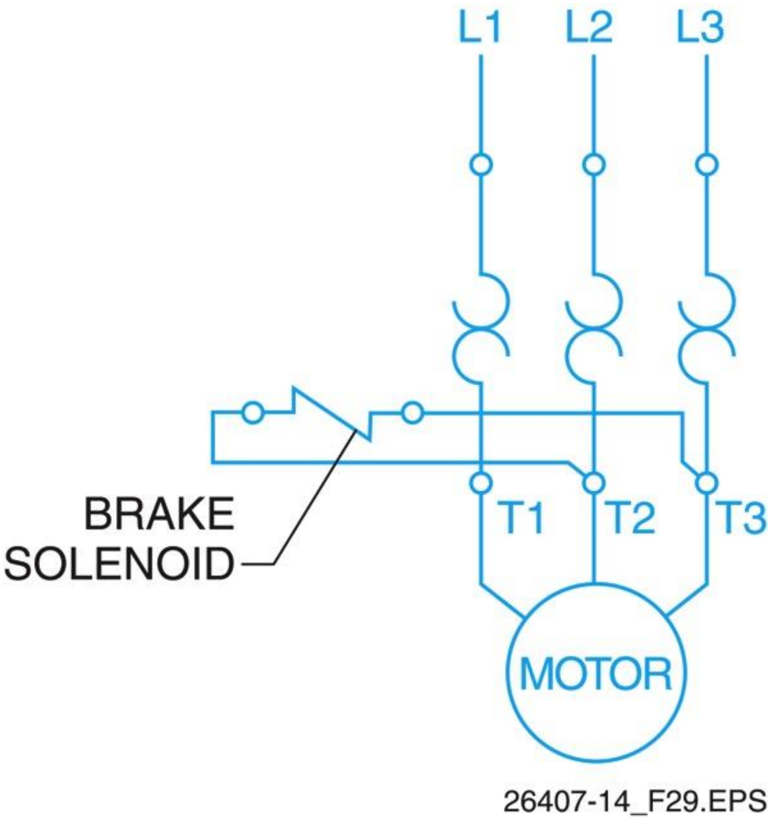
26407-14_F27.EPS

Simplified Schematic of an AC Drive Using Dynamic Braking

- In an AC drive unit, the electrical energy returned by the motor can cause an increase in the voltage to the DC bus, possibly resulting in damage to the drive components.
- A braking resistor can be used to dissipate this excess energy, as shown here.



Friction Brake Solenoid Connection



- Motor braking can also be accomplished using solenoid-operated friction brakes similar to those used on vehicles.
- The solenoid is energized while the motor is running, moving the brake shoes/pads away from the wheel. When the motor is de-energized, the brake shoes/pads contact the wheel to provide friction braking.

7.0.0 – 7.3.0

Next Session…

Motor Control Maintenance; Motor Control Troubleshooting

Precautions When Working with Solid-State Controls

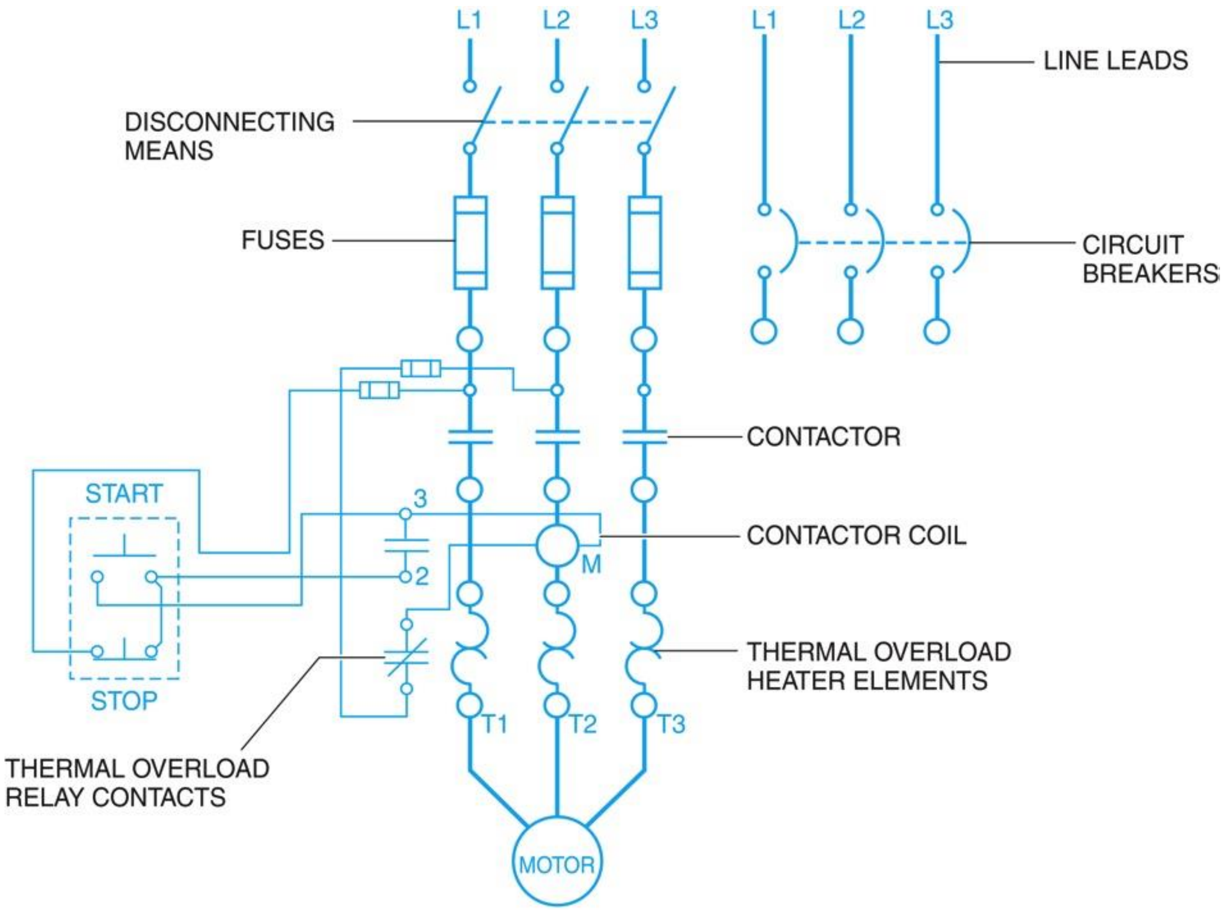
- Solid-state equipment is very sensitive and easily damaged by reversed polarity, excess heat, and electrostatic discharge.
- Always ground yourself before handling a circuit board and wear a grounding strap if supplied. Store unused boards in a shielding bag or conductive tote box.

Motor Control Maintenance; Motor Control Troubleshooting

FAULT CODES	FAULT	POSSIBLE CAUSES	CHECKING
F1	OVERCURRENT	FREQUENCY CONVERTER HAS MEASURED TOO HIGH A CURRENT IN THE MOTOR OUTPUT: – SUDDEN HEAVY LOAD INCREASE – SHORT CIRCUIT IN THE MOTOR CABLES – UNSUITABLE MOTOR	CHECK THE LOAD CHECK THE MOTOR SIZE CHECK THE CABLES
F2	OVERVOLTAGE	THE VOLTAGE OF THE INTERNAL DC-LINK OF THE FREQUENCY CONVERTER HAS EXCEEDED THE NOMINAL VOLTAGE BY 35%: – DECELERATION TIME IS TOO FAST – HIGH OVERVOLTAGE SPIKES AT UTILITY	ADJUST THE DECELERATION TIME
F3	GROUND FAULT	CURRENT MEASUREMENT HAS DETECTED THAT THE SUM OF THE MOTOR PHASE CURRENT IS NOT ZERO: – INSULATION FAILURE IN THE MOTOR OR THE CABLES	CHECK THE MOTOR CABLES
F4	INVERTER FAULT	FREQUENCY CONVERTER HAS DETECTED FAULTY OPERATION IN THE GATE DRIVERS OR IGBT BRIDGE: – INTERFERENCE FAULT – COMPONENT FAILURE	RESET THE FAULT AND RESTART AGAIN; IF THE FAULT OCCURS AGAIN, CONTACT YOUR DISTRIBUTOR
F5	CHARGING SWITCH	CHARGING SWITCH IS OPEN WHEN THE START COMMAND IS ACTIVE: – INTERFERENCE FAULT – COMPONENT FAILURE	RESET THE FAULT AND RESTART AGAIN; IF THE FAULT OCCURS AGAIN, CONTACT YOUR DISTRIBUTOR
F6	UNDERVOLTAGE	DC-BUS VOLTAGE HAS GONE BELOW 65% OF THE NOMINAL VOLTAGE: – MOST COMMON REASON IS FAILURE [illegible] UTILITY SUPPLY	IN CASE OF TEMPORARY SUPPLY VOLTAGE BREAK, RESET THE FAULT AND [illegible]

26407-14_F31.EPS

Basic Motor Control Circuit



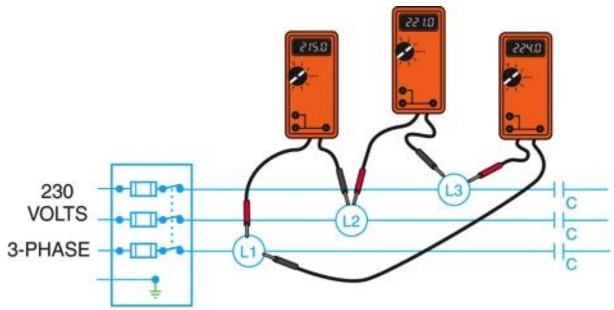
Motor Control Troubleshooting Chart

Malfunction	Possible Cause	Corrective Action
Constant chatter	Broken pole shader	Replace.
	Poor contact in control circuit	Improve contact or use holding circuit interlock (three-wire control).
	Low voltage	Correct voltage condition; check momentary voltage dip during starting.
Contactor welding or freezing	Abnormal inrush of current	Use larger contactor or check for grounds.
	Rapid jogging	Install larger device rated for jogging service.
	Insufficient contact pressure	Replace contact springs; check contact carrier for damage.
	Low voltage preventing magnet from sealing	Correct voltage condition; check momentary voltage dip during starting.
	Foreign matter preventing contacts from closing	Clean contacts with approved solvent.
	Short circuit	Remove fault and check to be sure fuse or breaker size is correct.
Short contact life or tip overheating	Filing or dressing	Do not file silver-faced contacts; rough spots or discoloration will not harm contacts.
	Interrupt excessively high	Install larger device or check currents for grounds, shorts, or excessive motor currents; use silver-faced contacts.
	Excessive jogging	Install larger device rated for jogging.
	Weak contact pressure	Adjust or replace contact springs.
	Dirt or foreign matter on contact surface	Clean contacts with approved solvent.
	Short circuit	Remove fault and check for proper fuse or breaker size.
	Loose connection	Clean and tighten.
	Sustained overload	Install larger device or check for excessive load current.
Coil over-heating	Overvoltage or high ambient temperature	Check application and circuit.
	Incorrect coil	Check rating and if incorrect, replace with proper coil.
	Shorted turns caused by mechanical damage or corrosion	Replace coil.
	Undervoltage, failure of magnet to seal in	Correct system voltage.
	Dirt or rust on pole faces increasing air gap	Clean pole faces.
Overload relays tripping	Sustained overload	Check for grounds, shorts, or excessive currents.
	Loose connection on load wires	Clean and tighten.
	Incorrect heater	Replace relay with correct size heater unit.
Failure to trip causing motor burnout	Mechanical binding, dirt, corrosion, etc.	Clean or replace.
	Wrong heater or heaters omitted and jumper wires used	Check ratings; apply proper heater.
	Motor and relay at different temperatures	Adjust relay rating accordingly.
	Wrong calibration or improper calibration adjustment	Consult factory.
Magnetic and mechanical parts inoperative	Broken shading coil	Replace shading coil.
Noisy magnet humming	Magnet faces not mating	Replace magnet assembly; realign.
	Dirt or rust on magnet faces	Clean and realign.
	Low voltage	Check system voltage and voltage dips during starting.
Failure to pick up and seal	Low voltage	Check system voltage and voltage dips during starting.
	Coil open or shorted	Replace.
	Wrong coil	Check coil number.
	Mechanical obstruction	With power off, check for free movement of contact and armature assembly.

Motor Control Troubleshooting Chart

Malfunction	Possible Cause	Corrective Action
Failure to drop out	Gummy substance on pole faces Voltage not removed Worn or rusted parts causing binding Residual magnetism due to lack of air gap in magnet path	Clean with solvent. Check coil circuit. Replace parts. Replace worn magnet parts.

Three-Phase Input Voltage Checks



1) PHASE — MEASURED READING

PHASE	MEASURED READING
L1	215V
L2	221V
L3	224V

2) AVERAGE VOLTAGE $= \frac{215 + 221 + 224}{3} = 220V$

3) INDIVIDUAL PHASE UNBALANCE FROM AVERAGE
- L1 TO L2 = 220 – 215 = 5V
- L2 TO L3 = 221 – 220 = 1V
- L3 TO L1 = 224 – 220 = 4V

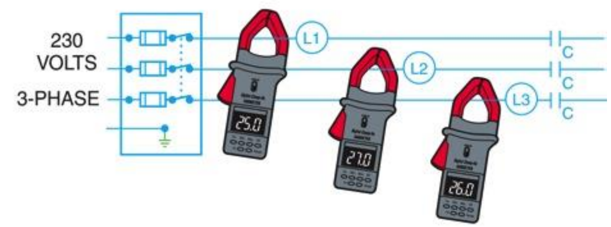
4) 5V = MAXIMUM UNBALANCE

5) % UNBALANCE $= \frac{\text{MAXIMUM UNBALANCE}}{\text{AVERAGE VOLTAGE}} \times 100$

% UNBALANCE $= \frac{5V}{220V} \times 100 = 2.27\%$ (OUT OF BALANCE)

MAXIMUM VOLTAGE UNBALANCE BETWEEN ANY TWO LEGS MUST NOT EXCEED 2%.

(A) CALCULATING VOLTAGE UNBALANCE



1) PHASE — MEASURED READING

PHASE	MEASURED READING
L1	25A
L2	27A
L3	26A

2) AVERAGE CURRENT $= \frac{25 + 27 + 26}{3} = 26A$

3) INDIVIDUAL PHASE UNBALANCE FROM AVERAGE
- L1 TO L2 = 25 – 27 = 2A
- L2 TO L3 = 27 – 26 = 1A
- L3 TO L1 = 26 – 25 = 1A

4) 2A = MAXIMUM UNBALANCE

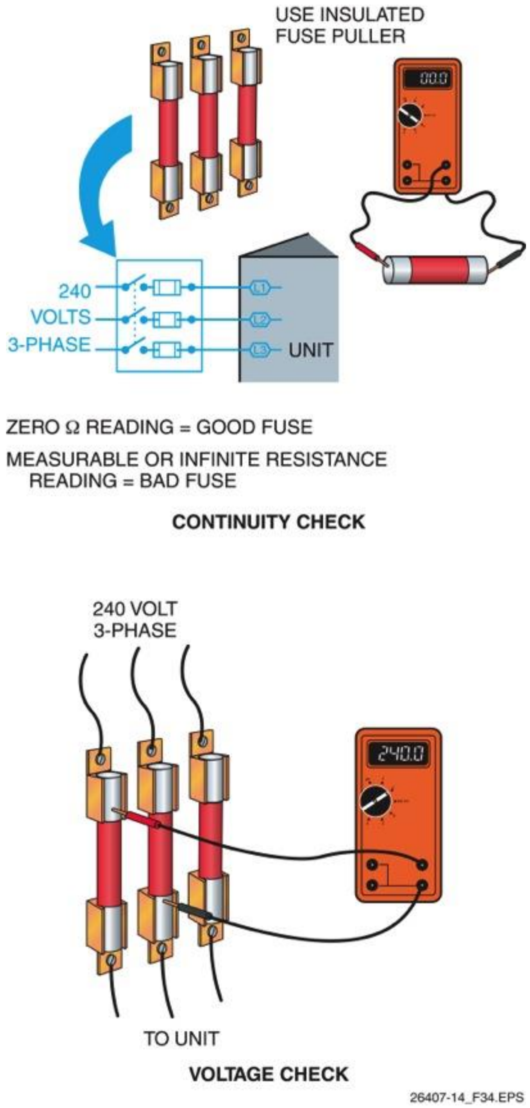
5) % UNBALANCE $= \frac{\text{MAXIMUM UNBALANCE}}{\text{AVERAGE CURRENT}} \times 100$

% UNBALANCE $= \frac{2A}{26A} \times 100 = 7.7\%$ (IN BALANCE)

MAXIMUM CURRENT UNBALANCE BETWEEN ANY TWO LEGS MUST NOT EXCEED 10%.

(B) CALCULATING CURRENT UNBALANCE

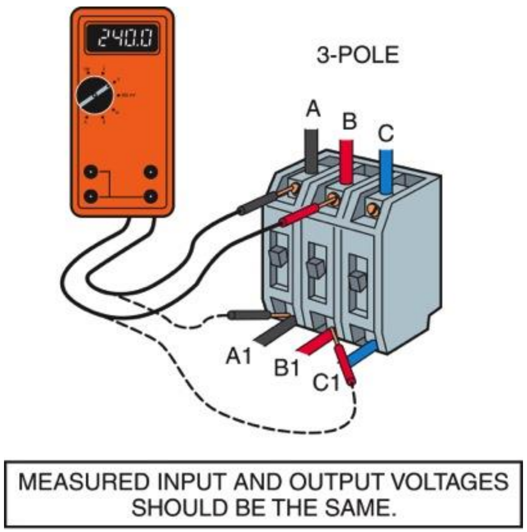
26407-14_F33.EPS



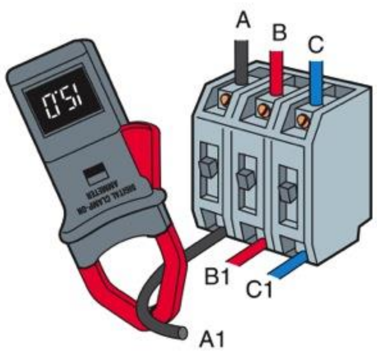
Fuse Checks

- Fuses and circuit breakers are normally the first items checked when a motor is inoperative.
- One way to test a fuse is by measuring continuity using a VOM/DMM. If the fuse shows zero ohms, it is usually good. A blown fuse will indicate infinite resistance.

Circuit Breaker Checks



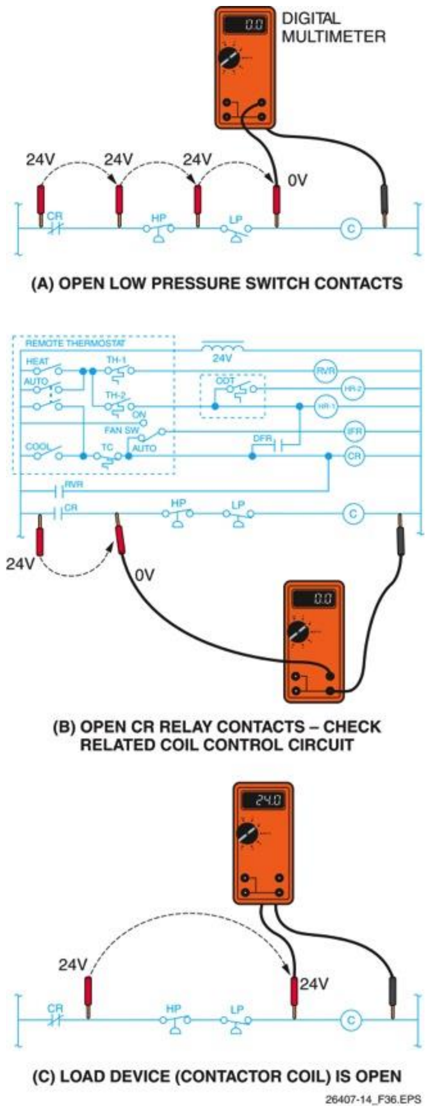
CIRCUIT BREAKER VOLTAGE CHECK



CIRCUIT BREAKER CURRENT CHECK

26407-14_F35.EPS

- To test a circuit breaker, measure the voltage between A1 to B1, B1 to C1, and C1 to A1. A good breaker will show equal voltages on all input and output terminals.
- If a circuit breaker is overheating, measure the current at A1, B1, and C1. A breaker that trips at a current below its rating or is not tripping at a higher current should be replaced.

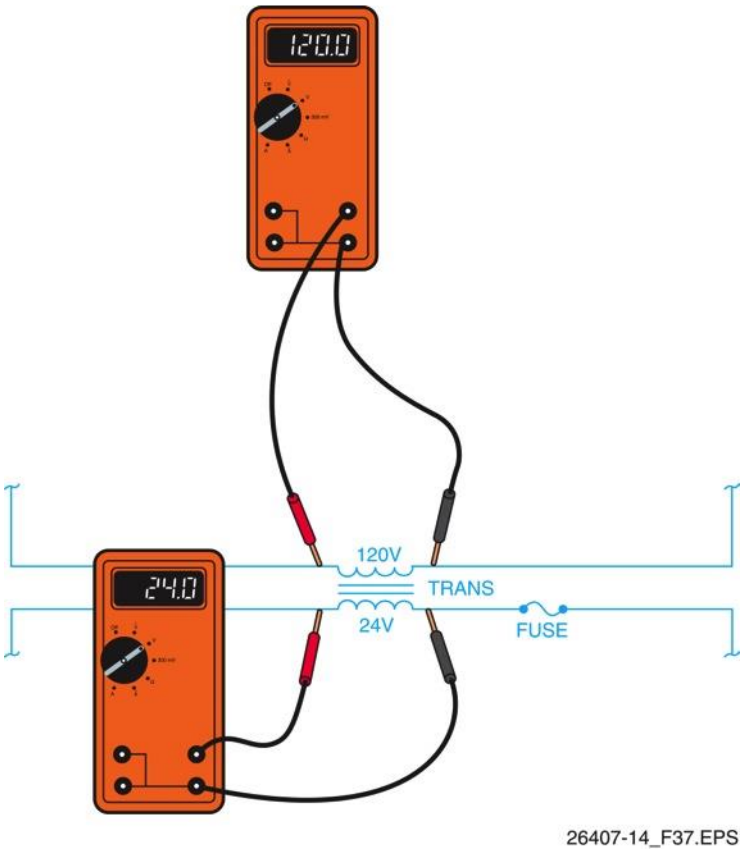


Isolating a Faulty Control Circuit Component

- A series of voltage measurements can be made across each device in a control circuit to locate a faulty device.
- Start from the line or control voltage side and move toward the load side. If a zero reading is found, there is an open set of contacts between the last two measurement points.

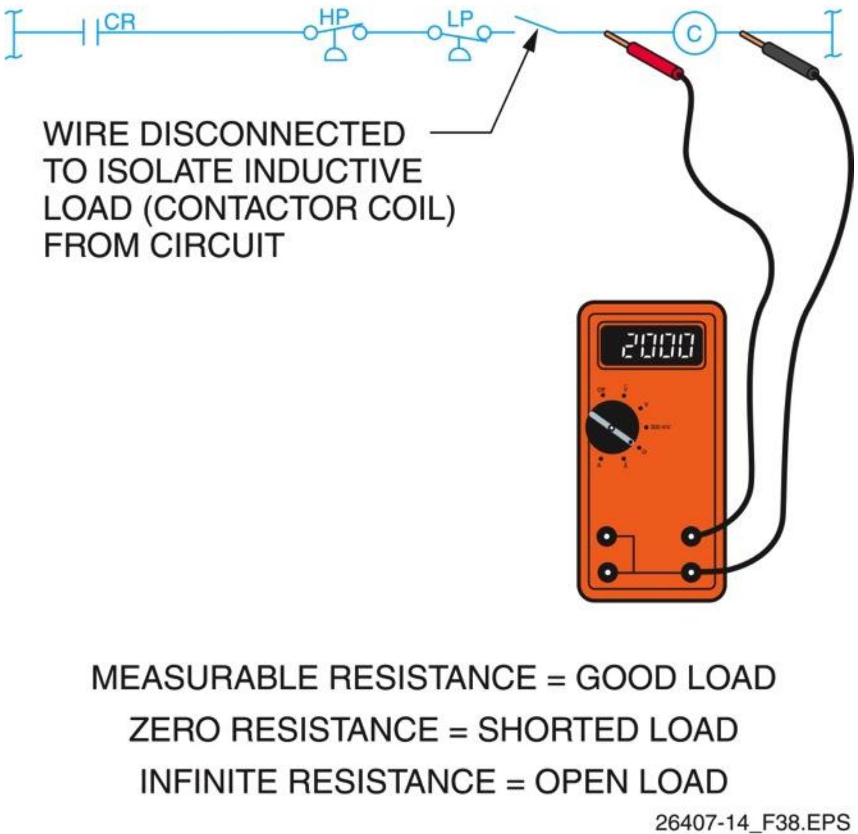
Control Transformer Checks

- Control transformers can be checked by measuring the voltage across the primary and secondary windings.
- The secondary winding is usually measured first. If it is within 10% of the required voltage, the transformer is good.



Coil Resistance Checks

- The best way to test a coil is to electrically isolate the coil and then measure the resistance across its terminals.
- A reading of zero ohms indicates a shorted coil and a reading of infinite resistance indicates an open coil.



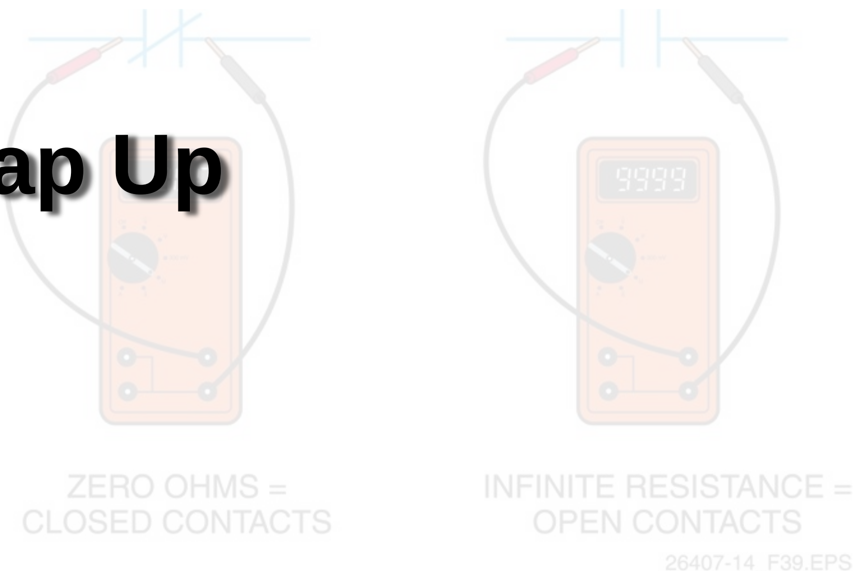
9.0.0 – 10.6.8

Next Session…

Checking the Continuity of Contactor/Relay Contacts

- With power to the circuit turned off, contacts can be tested by making a continuity measurement to determine whether the contacts are open or closed.
- If the contacts are open, the VOM/DMM will show a reading of infinite resistance.

Wrap Up



Wrap Up

3-2-1

3 – Write 3 important things learned during class

2 – Write 2 questions you have about the material

1 – Write 1 thought you had about the material

Next Session…

MODULE EXAM

Review the complete module to prepare for the module exam. Complete the Module Review as a study aid.