1/c Electrical Training Lab Manual
Cruise 2016

Name ____

Partner ____

Required STCW Assessments

	Date	Assessor
OICEW 3-1C Detect Location of Grounds	__________	__________
OICEW 3-1D Measure Insulation Resistance	__________	__________
OICEW 3-1E Determine Phase Rotation	__________	__________

Lab Exercises

Single Phase Motor Controller	__________	__________
Programmable Variable Frequency Drive	__________	__________
Programmable Logic Controllers	__________	__________

1/c Electrical Training Final Exam Study Guide.

To help you prepare for the exam, I am providing this study guide. If you can answer these questions, you should be OK.

The questions on the final exam will be multiple-choice. All the questions are based on the questions listed here, and the answers can be found in the attached handout or during the exercises. Some of the questions will be simple: common sense, definitions, recall of facts, etc.; others will require you to demonstrate your understanding or draw conclusions based on things you have learned. For best results, prepare for the exam by studying this material and paying attention to the material covered in the exercises.

Exercise 1 Electrical Safety

Reread the discussion, basic electrical safety rules, and shipboard electrical safety sections and answer the following questions.

1. What do you think was the primary cause of Erickson's death? Identify one link in the chain of errors, which if broken would have prevented the accident.
2. What is the OSHA BASIC RULE for electrical safe practice?
3. How do you achieve and verify an electrically safe working condition?
4. Is it possible to be killed by low voltage (< 115 V)?
5. What hazard is associated with charging wet-cell batteries?
6. What is the function of grounding connections on metal cased portable electric tools?
7. What three factors determine the severity and effect of electric shock on the human body?
8. What common situations can reduce the resistance of the human body?
9. What is the most important thing to consider when attempting to rescue a victim of electric shock?

Exercise 2 Insulation Resistance Measurement

Read the handout *Understanding Insulation Resistance Testing*, by AEMC.

10. What are the three components which make up the insulation resistance test current?
11. How long should the test voltage be applied when conducting an insulation resistance spot test?
12. Why should you record the winding temperature when conducting a spot test?
13. What is the indication of good insulation?
14. What is the indication of insulation which contains moisture or contaminates?
15. What is a polarization index, and do you want a large or small value?

Exercises 3 Phase Rotation

16. Why is it important to have the correct phase sequence when connecting a motor to power?

Exercises 4 Ground Fault Detection

17. What harm could come from ignoring ground faults?

Exercise 5 Single Phase Motor Controller

Understand the operation of a Capacitor Start Motor and study Figures to be prepared to answer questions about the motor, its control circuit and operations such as:

18. Describe the operation of the Single Phase Reversing Starter when the forward button is pressed.
19. Describe how the motor is protected during an overload condition.
20. Describe how the motor controller provides Low Voltage Protection.
21. What are the two windings utilized by a Capacitor Start Motor?
22. How do you reverse a capacitor start motor?
23. What is the purpose of the Centrifugal Switch and when does it open?
24. How can you use a multimeter to verify the correct functioning of pushbutton switch?

Exercise 6 Programmable Variable Frequency Drive

Read the lab introduction and *Cutler-Hammer AC Drive Theory and Application* from the lab handout and answer the following questions.

25. What are some of the benefits of using a variable frequency drive?
26. What are the three main functional components of a VFD?
27. What is the formula which determines the synchronous speed of an induction motor?
28. Why is it important for a VFD to maintain a constant V/Hz ratio?
29. What does IGBT stand for, and what is an IGBT?
30. What is “Pulse Width Modulation” (PWM) and how is it used to control VFD output voltage and frequency?
31. Be familiar with the Torque-Speed relation for Design B motors shown in Figure 5.
32. Referring to Figure 13 in the Cutler-Hammer handout, why does the output torque decrease once the motor speed exceeds 100% of rated frequency?
33. What are some issues relating to operating a motor below its rated speed?

Exercise 7 Programmable Logic Controller

Re-read the introduction section and be prepared to answer the following questions:

34. What is a PLC?
35. What is Ladder Logic?
36. How can you implement basic logic functions such as AND, OR, NOT using ladder logic?
37. Draw a basic “Latch” circuit in Ladder Logic and describe how it operates.
38. Be able to read and understand timing diagrams.
39. Be able to read, understand and describe the operation of simple ladder programs.

Exercise 1 Electrical Safety

Objective

To discuss the hazards associated with electrical maintenance and methods to reduce risk. Demonstrate safe operation of an electrical test bench.

Discussion

On January 7, 2009 Third Assistant Engineer Christopher Erickson, a 2007 Massachusetts Maritime Academy graduate and former Cadet Chief Engineer was working in the electrical shop aboard the chemical tank ship *Sea River Wilmington*[1]. Erickson and the First Assistant Engineer were in the ship's electrical shop to test the operation of a solenoid operated shunt trip on a replacement circuit breaker. A shunt trip is a control device which opens a circuit breaker when power is lost to the shunt trip's solenoid. The intention was to supply power to the solenoid and then de-energize it in order to to verify that the breaker would automatically trip.

In the electrical shop, the engineers had electrical meters, a workbench with a test panel capable of supplying various voltages, and a test lead consisting of a six foot long insulated wire with a four prong plug on one end and bare wires on the other. The test panel had circuit breakers to control power to several test receptacles of different voltages. The test lead was to be used to connect from the 440 V receptacle on the test panel and the solenoid of the shunt trip device.

The first engineer noticed that the breaker on the test panel was in the "tripped" position, midway between open and closed positions, and wanted to determine whether the receptacle was live by measuring the voltage at the bare end of the test lead. Erickson, on the other hand was concerned with connecting the test lead to the solenoid. Erickson picked up the bare ends of the test lead to connect them to the solenoid after the the first engineer plugged the test lead into the receptacle to perform the voltage test. The wires were live, and Erickson received a fatal electric shock. The investigation showed that he had burn marks on the palm of his left hand and the back of his right hand, so current traveled completely through his torso.

After the accident, the Coast Guard identified a number of unsafe conditions and safety failures, including:

- Briefings, training and personal protective equipment missing or inadequate.
- Unnecessary hazards in the workshop.
- Failure to perform a job hazard analysis.
- Failure to heed safety warnings posted on the test bench.
- Failure to communicate a hazard to Erickson.
- Use of a makeshift test lead which did not have insulated alligator clips.
- Failure to verify that the 480 V Receptacle was dead before inserting the test lead.
- Erickson placed himself in a hazardous situation by not treating a circuit as live, until proven otherwise.

Safety when working with electrical equipment is critical. It is your personal responsibility to be aware of the hazards and follow all safety precautions whenever you are working on electrical equipment. Your life may depend on it.

[1] Report of Investigation into the Electrocution of a licensed third engineer onboard the S/R WILMINGTON offshore Galveston, Texas On 01/07/2009; MISLE Activity Number: 3390690

Basic Electrical Safety Rules

According to the Occupational Health and Safety Administration[2], electrical safe practices depends on two very important basic points. The first is that live parts shall be de-energized before working on or near them. The second point is that even after the exposed parts have been de-energized, they shall still be treated as energized until they are locked out and/or tagged out. That is why the **BASIC RULE** for electrical safe practices procedure is stated as follows:

> **ALL ELECTRICAL CIRCUIT CONDUCTORS, BARE OR INSULATED, ARE ASSUMED TO BE ENERGIZED UNTIL PROVEN OTHERWISE. THEY SHALL BE DE-ENERGIZED, LOCKED OUT AND TESTED FOR THE ABSENCE OF VOLTAGE BEFORE WORKING ON THEM OR WORKING NEAR THEM. WORK ON ELECTRICAL CIRCUIT CONDUCTORS MAY ONLY BE PERFORMED BY QUALIFIED PERSONNEL WHO HAVE BEEN AUTHORIZED TO DO THE WORK.**

The safest way to avoid electrical hazards is to de-energize the conductors to be worked on or near, and, assure that they cannot be re-energized. This is known as putting the conductors in an electrically safe work condition and should always be your first consideration.

An electrically safe work condition will be achieved and verified by the following process:

1. Determine all possible sources of electrical supply to the specific equipment. Check applicable up-to-date drawings, diagrams and identification tags.
2. After properly interrupting the load current, open the disconnecting device(s) for each source.
3. Where it is possible, visually verify that all blades of the disconnecting devices are fully open or that drawout type circuit breakers are withdrawn to the fully disconnected position.
4. Apply lockout/tagout devices in accordance with a documented and established policy.
5. Use adequately rated voltage detector to test each phase conductor or circuit part to verify they are de-energized. Before and after each test, determine the voltage detector is operating satisfactorily.
6. Where the possibility of induced voltages or stored electrical energy exists, ground the phase conductors or circuit parts before touching them. Where it could be reasonably anticipated that the conductors or circuit parts being de-energized could contact other exposed energized conductors or circuit parts, apply ground connecting devices rated for the available fault duty.

[2] OSHA ELECTRICAL SAFETY HAZARDS AWARENESS, http://www.lanl.gov/safety/electrical/docs/elec_hazard_awareness_study_guide.pdf

Shipboard Electrical Safety

The following discussion is adapted from US Navy Recommendations.

Need for Safety

Safety precautions must always be observed when you work around electric circuits and equipment to avoid injury from electric shock and short circuits.

The danger of shock from the 450-volt A.C. ship's service system is reasonably well recognized by operating personnel. Relatively few reports of serious shock are received from this voltage despite its widespread use. On the other hand, a number of shipboard fatalities have been reported due to contact with 115-volt circuits. Despite a fairly widespread but totally unfounded popular belief to the contrary, low voltage (115 volts and below) circuits are very dangerous and can cause death where the resistance of the body is lowered by moisture and especially when current passes through the chest. Aboard ship, the body is likely to contact the ship's metal structure and the body resistance to electric current may be low because of perspiration or damp clothing. Extra care and awareness of the hazard is therefore needed.

Short circuits can be caused by accidentally placing or dropping a metal tool, rule, flashlight case, or other conducting article across an energized line. The arc and fire which results on even relatively low voltage circuits may cause extensive damage to equipment and serious injury to personnel.

Ship service power distribution systems are designed to be ungrounded. Many persons believe it is safe to touch one conductor since no electrical current would flow. This is not true. If one conductor of an ungrounded system is touched while the body is in contact with the ship's hull or other metal equipment enclosure, a fatal electric current may pass through the body.

> **All live electric circuits must be treated as potential hazards at all times.**

Alertness to Danger Signals

You should constantly be on the alert for any indication of malfunction of equipment. The senses of sight, hearing, smell, and touch all serve to alert you to possible electrical malfunctions. Examples of signs which shipboard personnel must be alert to are: an unusual sound from an electric motor, fire, smoke, sparks, or arcing; frayed or damaged cords of plugs; receptacles, plugs, and cords which feel warm to the touch; slight shocks felt on handling electrical equipment; odor of burning or overheated insulation; electrical equipment which either fails to operate or operates irregularly; electrical equipment which produces excessive vibration.

If any of the above signs are noted, report it immediately. Do not delay. Do not operate suspect equipment until it has been repaired. Stand clear of any suspected hazard and instruct others to do likewise.

Warnings

Heed all warning signs. They have been installed for your protection. To disregard them is to invite personal injury as well as possible damage to equipment.

> **Switches and receptacles with a temporary warning (DANGER/CAUTION) tag, indicating work is being performed, are not to be touched.**

Authorized Personnel Only

Because of the danger of fire, damage to equipment and injury to personnel, all repair and maintenance work on electrical equipment shall be done only by authorized persons, with approval of the Chief Engineer. Keep hands off all equipment which you have not been specifically authorized to work on. In particular, stay clear of electrical equipment open for inspection, test or servicing.

Keep Covers Closed

Covers for all fuse boxes, junction boxes, switch boxes, and wiring accessories should always be kept closed. Any cover which is not closed or is missing should be corrected immediately. Failure to do so may result in personnel injury or damage to equipment in the event accidental contact is made to expose live parts within.

Circuit Breakers and Fuses

Unauthorized operation of circuit breakers and insertion or removal of fuses may endanger personnel as well as damage equipment.

Open switches before removing fuses. Never remove a fuse from a circuit when the circuit is carrying current. Use an approved fuse puller to remove fuses, never use pliers.

Operating Switches

Never energize a circuit or start a piece of equipment, until you know that doing it will not endanger other personnel.

Use only one hand for switching when operating power and lighting circuits. Keep the other hand clear. Open and close all switches completely. Switches left in a partly open position can cause an arc or flashover, or start a fire.

Batteries

Wet cell batteries generate highly explosive hydrogen gas while being charged. Flames and sparks of all kinds must be kept away from batteries. Don't smoke in the area.

Be sure to ventilate the battery compartment if it has been sealed, before entering the compartment, turning on any lights, starting engines or equipment, making or breaking any electrical connections, or doing any work in a battery storage or charging compartment.

When using tools near a battery, be careful not to short circuit the battery terminals. Never store conducting materials on or above a battery where they could fall upon and short out battery terminals.

Charge batteries only in accordance with the approved procedures. Charging rates especially for Nickel Cadmium batteries are critical to prevent resultant explosions.

Primary batteries especially mercury and lithium batteries should never be punctured, incinerated or recharged.

Remove batteries from equipment before shipment or storage. Cover terminals of batteries with an insulating material to prevent short circuits.

Store batteries in an adequately ventilated and cool fireproof area.

Use appropriate eye and skin protection when working with wet batteries.

Fluorescent Lamps

Fluorescent lamps contain mercury vapor which is poisonous. No danger arises from unbroken lamps, whether in use or not, because the mercury vapor is sealed inside. However, injury could result from cuts from broken glass or from breathing the mercury vapor or powder liberated when lamps are broken. To prevent contamination mercury contamination of the oceans, **fluorescent lamps shall never be discarded at sea.** Store them in their original shipping containers until they can be off loaded ashore for disposal in a safe and ecologically acceptable manner.

Flammable Liquids and Other Hazardous Materials

When working with flammables (including flammable aerosols) such as insulating varnish, paint, lacquer, turpentine, kerosene, and other materials producing flammable vapors, always provide ample ventilation to prevent accumulation of fumes. Flammable cleaning fluids must never be used on or near energized electrical apparatus.

Portable Cables

Portable cables should be visually examined for any signs of an unsatisfactory condition, such as tears, chafing, exposed insulated conductors, and damage plugs and receptacles. They shall be of the proper length and cross-sectional area. Spliced portable cables are prohibited.

Always support portable cables above decks, floor plates, and gratings. Never place them where they can be damaged by falling objects, by being walked on, by contact with sharp corners or projections in the ship's hull, or other objects. Where portable cables are passed through doorways or hatches, stops should be provided to protect the cables from being pinched by a door or hatch cover.

Use only three-wire extension cords which have three-prolonged plugs and three-slot receptacles.

Because a metal hull ship is a hazardous location, personnel who must use portable electric devices connected in extension cords should take the time to plug the device into the extension cord before the extension cord is inserted into a live bulkhead receptacle. Likewise, the extension cord should be unplugged from the bulkhead receptacle before the device is unplugged from the extension cord.

Use proper care when using extension cords:

1. Take care that cords do not come in contact with sharp objects; they should not be allowed to kink, nor be left where they might be damaged by vehicle/foot traffic. When it is necessary to run electrical leads through doors and hatches, protect the cord against accidental closing of the door/hatch.
2. Cords must not come in contact with oil or grease, hot surfaces or chemicals. If they do clean, and carefully inspect the cord before use.
3. Replace damaged cords. They should not be spliced or patched with tape.
4. Store power tools in a clean, dry place where the cord can be loosely coiled.
5. Cords extending through walkways should be elevated or taped down so they do not become a tripping hazard or interfere with safe passage.
6. Extension cords should be no longer than 25 ft. in length and no more than two such cords should be connected together for the operation of portable equipment.
7. Stow cords neatly.

Portable Electric Tools

Inspect portable electrical tools for safety before each use. Visually examine the attached cable with plug and any extension cords for any cracks, breaks or exposed conductors and damaged plugs. If any defects are noted, do not use the equipment until it has been repaired. Before plugging in any tool, be sure the tool is turned off.

Personnel using portable electric tools shall wear **safety glasses/goggles**, and if the tool produces hazardous noise levels **wear proper ear protection**.

Only explosion-proof portable electric tools shall be used where flammable vapors, gases, liquids, or exposed explosives are present.

Rubber gloves must be worn when using portable electric tools under hazardous conditions, i.e., wet decks, bilge areas, working over the side, in boats, etc.

Leather glove shells should be worn over rubber gloves when the work being done, such as sheet metal work, could damage the rubber gloves.

Grounding Connections

Metal cased portable electric tools (except those rated "Double Insulated") must be fitted with three prong plugs having a grounding connector.

Double insulated portable tools are designed to be electrically safe without the use of a three-pronged plug. A two conductor flexible cable and a two- pronged plug suitable for use with the grounded type receptacles shall be used on double insulated tools.

Grounding circuits on tools should be checked to ensure that the circuit between the ground and the ground power conductor has resistance which is low enough to permit sufficient current to flow to cause the fuse or circuit breaker to interrupt the current.

Never disable the ground connection on portable electrical equipment or extension cords.

Metal cases and parts of motors and other stationary electrical equipment must be grounded by direct contact with a metal hull. This will protect you from shock in case of a short circuit in the equipment. If the equipment is isolated from the hull by resilient shock mounts, ground straps are used to maintain ground continuity. Never remove or tamper with ground straps.

Working on Electrical Equipment

When work must be performed on electric equipment, check with an electrician or the equipment's manual for any potential hazards of which you may not be aware. Electrical devices may have multiple voltage sources, high voltage capacitors, etc. Open the disconnect switches or remove the fuses before examining, repairing or working on power circuits. Notify the watch engineer before shutting down equipment for maintenance.

Never work on live equipment. All electrical circuits, outlets, lights, motors, etc., should be assumed to be live until proven otherwise with a voltmeter or test lamp. Even so, treat "dead" circuits as though they are live, because a circuit may be accidentally energized by another person.

Deenergize, lock out all sources of voltage, and verify that no voltage is present before working on any electrical equipment.

Electrical Fires

Carbon dioxide (CO_2) is to be used in fighting electrical fires because it is nonconductive, thereby providing the highest degree of personnel safety and because it offers the least likelihood of doing equipment damage. However, if the discharge horn of a CO_2 extinguisher is allowed to accidentally touch an energized circuit, the horn may transmit a shock to the person handling the extinguisher.If CO_2 is not available, a dry chemical extinguisher should be used.

Electrical Fire Fighting

1. Deenergize circuit
2. Report fire to the quarterdeck/bridge or fire department
3. Secure ventilation
4. Attack fire with available Class C fire fighting equipment
5. Provide self-contained breathing apparatus for fire fighters to prevent smoke inhalation or suffocation from CO_2 or Halon fire extinguishing agents

Electrical Fire Prevention

1. Keep electric motors clean
2. Ensure proper maintenance is performed on electrical equipment, i.e., motors, bearings, etc.
3. Report overheating or arcing electrical equipment.
4. Keep air filters clean.

Electric Shock

Electrical shock occurs when electrical current flows through the body. The effects of the shock on the body will depend on the amount of current that flows, the path of the current through the body, and the length of time that the victim is subjected to the current. Shock effects range from a mild tingling sensation to death.

Unfortunately, it only takes a very small current through the body to cause death. The following table describes the effects of various currents on the human body.

Current	Effects
below 0.4 ma	No sensation
0.5 to 1.8 mA	Shock is felt, but it is not painful. Victim can let go at will.
1.8 to 9.9 mA	Mild sensation to painful shock. Individual cannot let go.
10 to 16 mA	Painful shock. Muscular control is lost.
17 to 23 mA	Painful shock. Severe muscular contractons. Difficulty breathing.
24 to 100 mA	Ventricular fibrillation. Death is almost certain.
over 100 mA	Severe burns. Muscular contractions will stop the heart, however it may be re-started with CPR.

The resistance of the human body is mostly due to the resistance of the skin. The resistance is very high when the skin is dry and unbroken; however, moisture such as perspiration can reduce the skin's resistance to less than a hundredth of its dry value. Cuts and burns which open the skin can reduce the body's resistance to almost nothing.

It is imperative to recognize that the resistance of the human body cannot be relied upon to prevent a fatal shock from 115 volts or even lower voltage; fatalities from as low as 30 volts have been recorded. Tests have shown that body resistance under unfavorable conditions may be as low as 300 ohms and possibly as low as 100 ohms from temple to temple if the skin is broken.

Volt for volt, D.C. potentials are normally not as dangerous as A.C. as evidenced from the fact that reasonably safe "let-go currents" for 60 hertz alternating current is 9.0 milliamperes for men and 6.0 milliamperes for women while the corresponding values for direct current are 62.0 milliamperes for men and 41.0 milliamperes for women.

Symptoms of Electric Shock

In the event of severe electric shock, the victim could become very pale or "bluish." His/her pulse is extremely weak or entirely absent, unconsciousness is complete, and burns are usually present. The victim's body may become rigid or stiff in a few minutes. This condition can be caused by muscular reaction to shock, and it shall not necessarily, be considered as rigor mortis. Therefore, artificial respiration shall be administered immediately, regardless of body stiffness, as recovery from such a state has been reported. Consequently, the appearance of rigor mortis shall not be accepted as a positive sign of death.

Rescue of Victim

The rescue of electric shock victims is dependent upon prompt administration of first aid.

> **Do not attempt to administer first aid or come in physical contact with an electric shock victim before the power is shut off, or, if the power cannot be shut off immediately, before the victim has been removed from the live conductor.**

When attempting to administer first aid to an electric shock victim, proceed as follows:

1. Shut off the power.
2. If the power cannot be deactivated, then remove the victim immediately, while observing the following precautions: Protect yourself with dry insulating material, and use a dry board, belt, dry clothing, or other available non- conductive material to free the victim (by pulling, pushing, or rolling) from the power-carrying object. **Do not touch the victim.**

3. Immediately after removal of the victim from the power-carrying object, administer CPR.

Procedure

☐ 1. Follow the posted directions to *Safely* check the operation of the provided test lamp, using the *Sea River* Electrical Test Bench mockup.

Exercise 2   Insulation Resistance Measurement

Objective

Understand principles of insulation resistance. Safely measure insulation resistance and correct for temperature. Satisfy requirements of STCW Element OICEW–3–1D *Measure insulation resistance*.

Discussion

Please read the attached handout. Exam questions will be taken directly from it.

Other good sources of information on insulation resistance testing are found here:

- Chapter 24 in *Operating, Testing, and Preventive Maintenance of Electrical Power Apparatus* by Charles I. Hubert. Copies are available in the lab.
- *A Stitch in time…* by Biddle Megger Corporation Available online at http://www.biddlemegger.com/biddle/Stitch-new.pdf and in the lab.
- IEEE Standard 43–2000 *IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery* Available from http://IEEE.org.

Procedure

Using the procedures described in chapter 24 of Hubert, you will test the insulation resistance of a motor supplied by your instructor:

☐ 2. Use the available meggers to measure the insulation resistance of equipment indicated by your instructor and according to the directions in sections 24.4–24.7.

   1. Use table 24.1 to select an appropriate test voltage. Appropriate voltage = __________

   2. De-energise, lock-out, check voltage with a voltmeter.

   3. Disconnect any electronic circuitry, and ground the machine.

   4. Connect the megger to the machine.

   5. Perform a 60 second insulation test. Record Resistance measurement $R_1 =$ __________

☐ 3. Repeat the previous step using another motor or wire spool, and with another megger.

☐ 4. Analyze the results for one of your measurements.

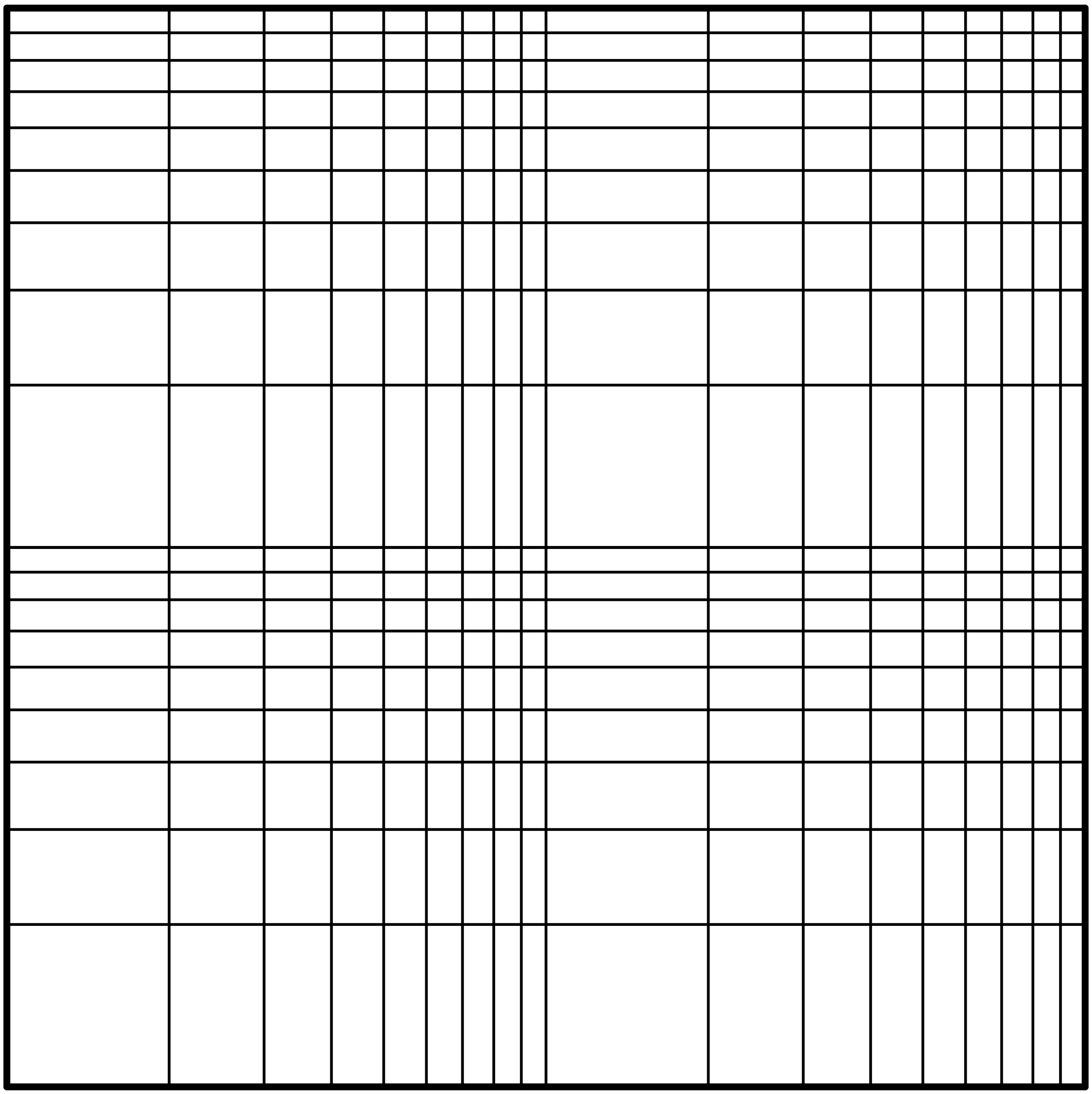
   1. Use table 24.2 to determine an acceptable minimum insulation resistance. Minimum resistance \blank

   2. Estimate the winding temperature to be the same as the ambient temperature in the lab. Winding Temperature __________

   3. Correct the insulation resistance to 40°C with equations 24–2 and 24–3 and assuming a halving factor of 5°C. If your resistance value was nearly infinity, use a value of 640 MΩ for this calculation

      Correction Factor k_t __________

      Corrected Resistance R_{40} __________



☐ 5. Dielectric Absorption Test

The following data was collected during a semi-annual Dielectric Absorption Test of a 240 V motor with Class A insulation, and recorded the in Table 2.1.

1. Plot this data on the Log-Log Paper provided.
2. Calculate the polarization index of the insulation. ___________
3. Would you consider the motor insulation good or bad? ___________ Why?

Table 2.1: Dielectric Absorption Test Data

Test Time	Resistance (MegOhms)
12 sec	200
24 sec	200
36 sec	210
48 sec	220
54 sec	250
60 sec	250
2 min	225
3 min	200
4 min	195
5 min	190
6 min	180
7 min	180
8 min	175
9 min	175
10 min	175

Questions

1. What effect does capacitance have on the indicated values of insulation resistance? Explain
2. What is *dielectric absorption?*
3. What effect does absorbed moisture have on the measured values of insulation resistance?
4. What effect does the temperature of a machine have on the measured values of insulation resistance?
5. Can electrical equipment be damaged as a result of a megger test? Explain?
6. Why should a large machine be grounded for several minutes before an insulation resistance test is made?

Understanding Insulation Resistance Testing

Why have an insulation testing program?
A regular program of testing insulation resistance is strongly recommended to prevent electrical shocks, assure safety of personnel and to reduce or eliminate down time. It helps to detect deterioration of insulation in order to schedule repair work such as: vacuum cleaning, steam cleaning, drying and rewinding. It is also helpful when evaluating the quality of the repairs before the equipment is put back into operation.

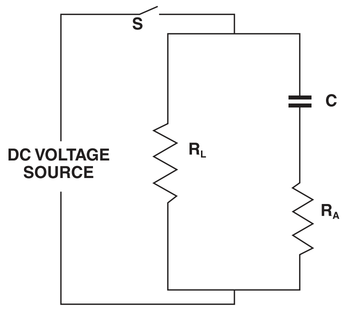
What causes insulation failure?
Some of the more common causes of insulation failure include: excessive heat or cold, moisture, dirt, corrosive vapors, oil, vibration, aging and nicked wiring.

What tests are used to detect insulation deterioration?
There are numerous maintenance tests for assessing insulation quality. The three tests discussed here are used primarily to test motor, generator and transformer insulation.

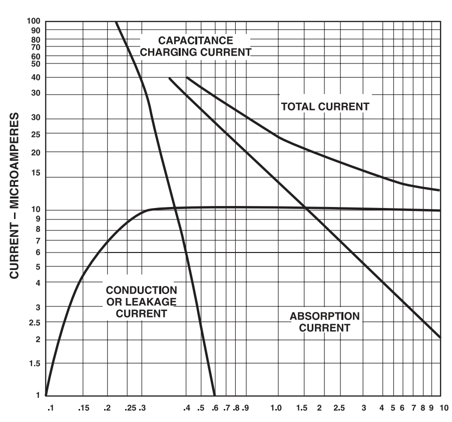
What equipment is necessary for conducting insulation resistance tests?
- Megohmmeter with a timed test function
- Temperature indicator
- Humidity meter (not necessary if equipment temperature is above the dew point)

Test Currents in Insulation
Total current in the body of the insulation is the sum of three components
- Capacitance Charging Current
- Absorption Current
- Leakage or Conduction Current

Test Currents in Insulation One Line Diagram



C = Represents charging current
R_A = Represents absorption current
R_L = Represents volumetric leakage current (dielectric loss)



Insulation Resistance Readings
Readings are time dependent
- at the start, capacitance is what you see first
- at or about one minute, absorption
- at 10 minutes, reading is mainly leakage current

These changing readings are best seen with analog bargraphs on digital instruments or needle movement on analog instruments.

Spot Reading Test

Method
For this test, the megohmmeter is connected across the insulation of the windings of the machine being tested. A test voltage is applied for a fixed period of time, usually 60 seconds and a reading is taken. The spot reading test should only be carried out when the winding temperature is above the dew point[1]. The operator should make a note of the winding temperature, so that it will be possible to correct the reading to a base temperature of 20°C.

Test Duration
To obtain comparable results, tests must be of the same duration. Usually the reading is taken after 60 seconds.

Interpretation of Results
Proper interpretation of spot reading tests requires access to records of results from previous spot reading tests. For conclusive results, only use results from tests performed at the same test voltage for the same amount of time, and under similar temperature and humidity conditions. These readings are used to plot a curve of the history of insulation resistance. A curve showing a downward trend usually indicates a loss of insulation resistance due to unfavorable conditions such as: humidity, dust accumulation, etc. A very sharp drop indicates an insulation failure. See Figure 1.

Exercise 3 Phase Rotation Testing

Objective

To use a phase rotation meter to predict the direction of rotation of a three phase motor. Satisfies STCW requriements OICEW–3–1E *Determine phase rotation*.

Discussion

This discussion is adapted from http://www.electricianeducation.com/electrical/phase_rotation_meter.htm.

While being a fundamental motor installation task, determining rotation direction is critical to the coupled load's operation.

You've just had a motor repaired or purchased a replacement, and you're about to connect it. What critical task must be performed to insure the correct operation of the motor's connected load? That's right: Determining the motor will turn in the correct direction.

We all know that the direction of rotation of a 3-phase motor can be changed by reversing two of its stator leads. This interchanging, reverses the phase sequence of the incoming voltage waves which reverses the direction of the rotating magnetic field within the motor, which reverses the direction of the rotor.

If the connected load will not be affected by the motor's reverse rotation, we can temporarily power the motor and observe its direction of rotation. If it's the wrong direction, we can simply interchange any two line leads.

But what can we do if the connected load would be damaged with the motor's reverse rotation? We have to determine the correct rotation before the motor is connected to its load. We can temporarily uncouple the the motor from its load and while it's uncoupled briefly energize it and observe its direction of rotation. And, after making the lead interchange, if required, the motor then can be re-coupled to its load. There's another option, one that's less time consuming and more efficient: Using a phase rotation meter.

A phase rotation meter can be used to determine the phase sequence of the three phase power supply, and it can be used to determine the phase sequence required to cause the motor to turn in the desired direction. Once these facts are known, it is a simple matter to correctly wire the motor so that it turn in the proper direction on the first try.

Other applications of phase rotation meters are to verify the phase sequence of shore power, so that when the vessel is connected to shore power all motors will operate in the proper directions; and to verify that multiple voltage sources have the same phase sequence, so that they can be paralleled together without damage.

Procedure

- ☐ 1. Read the directions for the *BK Precision Model 302* Phase and motor rotation meter shown below.
- ☐ 2. Follow all safety precautions and determine the phase sequence of the three-phase power supply indicated by your instruction.

  The power leads must be energized in order to conduct this test.
- ☐ 3. Use the phase rotation meter to determine the phase sequence required to cause the motor to turn in the desired direction as viewed from the shaft end of the motor.
- ☐ 4. Use the phase rotation meter to determine the phase sequence of the power supply
- ☐ 5. With power off, connect the motor to the power in such a way as to turn in the desired direction when the motor control FWD button is activated.

BK PRECISION®

Instruction Manual

Model 302 Phase and Motor Rotation Meter

INDEX PAGE

SAFETY RULES

CAUTION **RISK OF ELECTRIC SHOCK**

This tester has been designed with your safety in mind. However, no design can completely protect against incorrect use. Electrical circuits can be dangerous and/or lethal when lack of caution or poor safety practices are used.

Do not carry out field measurements on either the power system grounding, during periods of forecast lightning activity, in areas that encompass the station being measured or of the power network connected to the station being measured. In the event that lightning occurs, stop all testing and isolate any temporarily installed test spikes.

Preparations for testing of power system grounding can leave personnel vulnerable to exposure caused by faults at or fed from the system under test, transferred potentials from remote test grounds, and inadvertent line energisations.

While the probability of the occurrence of one of these events is low, personnel safety will, nevertheless, be enhanced by the following:

When working near high tension systems rubber gloves and shoes should be worn.
Work on clean, dry crushed rock or an insulating blanket.
Avoid bare hand to hand contact between the tester and extended test leads.

When using the tester with test leads, ensure that they are safe and properly authorized

Disconnect the tester from any external circuit when changing the batteries.

CAUTION **READ THE MANUAL**

Follow the instructions in the Manual for every measurement. Read and understand the general instructions before attempting to use this tester

SAFETY CHECK

Before using the tester check the condition of the batteries. This is done by switching the tester ON.
If the BAT OK led does not light up, the battery need replacing.
Battery and fuse replacement are described later in this user's manual..

When changing the battery, fuses, or removing the cover to access the internal circuitry, always disconnect the test leads.

When replacing the fuse use only the type specified, 5 x 20mm, 200mA, 250V fuse, and insert correctly into the fuse holder.

Double check the switch setting, and lead connections before making measurements.

DON'T TOUCH

Don't touch exposed wiring, connections or other "Live" parts of an electrical circuit. If in doubt, check the circuit first for voltage before touching it.

Do not use cracked of broken test leads.

THIS INSTRUMENT SHOULD ONLY BE USED BY A COMPETENT, SUITABLY TRAINED PERSON.

REMEMBER

SAFETY IS NO ACCIDENT

CAUTION RISK OF ELECTRIC SHOCK

CAUTION READ THE MANUAL

GENERAL DESCRIPTION

This Test Instrument is a 3 Phases Presence and Rotation Indicator combined with a 3 Phases Motor Rotation Tester.

It can be utilized on a **3 Phase Powered System** (the supply side) or on a **Three Phases Unpowered Motor** (the load side) without having to worry about damage to the tester.

When utilized on a **3 Phase Powered System,** the instrument is then utilized as a 3 Phases Presence and Rotation Indicator.

When utilized on a **Three Phases Unpowered Motor**, the instrument is then utilized as a 3 Phases Motor Rotation Tester.

When utilized on a 3 Phases Powered System, this instrument is a rotary field indication instrument which display all three phases by lighting up it's corresponding Lamp. It display the rotation (clockwise or anti-clockwise) on a LED.

When utilized on a 3 Phases Unpowered Motor, it is also possible to determine the motor connections U, V, W without a live circuit to avoid subsequent damages of e.g. pumps to reversed motor rotation. It display the rotation (clockwise or anti-clockwise) on a LED.

This instrument represents the quickest and easiest way for servicing, repairing and electrical maintenance of 3 phase rotating machinery.

With this equipment, you can, before connecting Load to Supply:
- On the supply side;
  - Quickly verify the presence of the three Phases on a 3 Phases Power System.
  - Confirm the Phase Rotation on a Powered 3 Phase System.
- On the Motor Side (Load);
  - Confirm the Phase Rotation on a unpowered 3 Phase Motor 3 Phases Alternator.
  - Confirm that each winding is connected to the terminals of the Motor, when the rotation Leds light up.

BRIEF PRODUCT DESCRIPTION

This 3 Phases and Motor Rotation Tester has 3 test leads which connects to the 4 mm female sockets on the tester, on the one side.

These Test leads are color coded:

L1	=	Red	which connects to L1 on the tester.
L2	=	White(or yellow)	which connects to L2 on the tester.
L3	=	Blue(or black)	which connects to L3 on the tester.

On the other side of the test leads are the probes, also color coded.

The tester has three neon lamps which are the Phase Presence indicators:

Neon Lamp for Individual Phase Presence Indication = L1
Neon Lamp for Individual Phase Presence Indication = L2
Neon Lamp for Individual Phase Presence Indication = L3

Please note that any of these Neon lamp will only start to light up if more than 100Vac is present between any 2 phases.

A LED to display clockwise rotary direction.
A LED to display counter clockwise.
A LED to display and confirm operation and battery OK status.
A Push Button to switch the instrument ON.

OPERATING INSTRUCTIONS

Determination of the rotary field direction and phase presence

On a 3 Phase System, the sequence of the 3 phases determine the rotation of a 3 phase motor connected to that system.

The correct 3 Phase Sequence L1, L2, L3 results in a clockwise rotation of the connected motor.

Connect the Test Leads to the sockets of the Instrument, respecting the correct color. Red to L1, White(or yellow) to L2, Blue(or black) to L3.

Clip the test probes to the three mains phases, L1, L2, L3

When connecting to a voltage superior to 100V AC, the corresponding neon lamp will start to glow, indicating the presence of the voltage on it's corresponding lead (L1, L2, L3 lamps).

Press the TEST button to turn the instrument "ON".
The green LED indicates that the instrument is ON and is busy testing. The battery is OK when the green LED is ON.

Should the Green LED not come on while depressing the TEST button, replace the battery (see Battery Replacement).

If the LED (Right arrow) L1-L2-L3 is illuminated, clockwise rotary field is present.

If the LED(Left arrow) L2-L1-L3 is illuminated, a counter clockwise rotary field is present.

Please note that; the phase control is displayed even if the neutral conductor N is connected instead of L1, L2, or L3.

Also refer to table (as indicated on the back of instrument)

Determination of motor connections and rotation of motor
Connect test leads to instrument and to the motor connections.
These are also Color Coded;

U	=	Red	which connects to L1 on the tester.
V	=	White(or yellow)	which connects to L2 on the tester.
W	=	Blue(or black)	which connects to L3 on the tester.

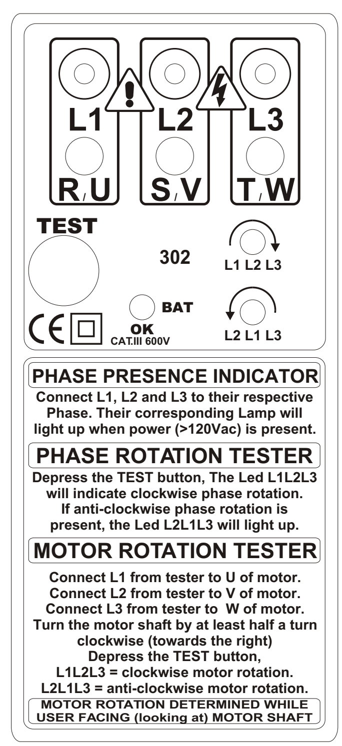
Press button On. The green LED indicates that the instrument is ready for testing.

Turn the motor shaft by at least half rotation towards the right. Look at the Leds while doing that.

It is important to ensure that the user looks from the front side onto the driving shaft and the front side of the tester at the same time, so that motor rotation can be confirmed.

The red LED (Right arrow) L1-L2-L3 indicates clockwise motor rotation if the lines are connected as follows: L1 to U, L2 to V, L3 to W.
The red LED (Left arrow) L2-L1-L3 indicates counter- clockwise motor rotation if the lines are connected as follows: L1 to V, L2 to U, L3 to W.

FRONT PANEL LAYOUT



PRINCIPLE OF HOW IT WORK

The tester has two separate circuits:
The first circuit is the 3 Phase presence indicator, which is shown by the neon lamps and the second circuit is the three phase sequence indicator by LEDs.
A low battery, with a Power On indicator circuitry is also present.

3 Phase Presence Indication circuit:
This circuit uses neon lamps to indicate if a phase is present.
These neon lamps are connected in series with a limiting resistor.
Neon lamps will lights up when the voltage accross any two phases is more than 100Vac.

3 Phase sequence indicator circuit:
This circuit has an analog and a digital part. The analog signals are amplified (so that motor rotation with very low signals can be performed), then compared to a set of references. These results are digitally compared to give the results on the indicating LEDs.

Switch-ON and low Battery detector:
At switch ON, the battery voltage is measured and compared. If the battery voltage is below the threshold, the LED will not light up, thus replacing the battery indication.

PREPARATION FOR USE

Fuses:
In doubt, check the fuses using a ohm meter.
Please note that this instrument will not indicate anything, should the fuses be blown.
Test Leads:
Check the test leads for defects or cracks. Replace if cracked or damaged. Only replace with the same type

Cleaning:
Clean the instrument case with an anti-static cleaner and wipe with dry cloth.

REPLACING THE BATTERIES

Prior to battery replacement always disconnect the instrument from the circuit to which it's connected.
Remove the test leads from the instrument.
Remove the back cover to access the battery compartment.
Remove the bad battery from the battery compartment and dispose properly of that battery (see your local disposal facilities related to disposal of batteries).
Only replace with a new battery of the following type:
9 V, IEC 6 LR61.
Re-insert the (battery) back cover onto the instrument and tighten the screws.

FUSES REPLACEMENT

Unscrew the back cover and replace the faulty fuse(s) with the same type, then screw the cover back into place correctly

SPECIFICATIONS

ELECTRICAL

Determination of the Phase Presence
Nominal Voltage for Phase Presence Indication (the voltage required for the neon lamps L1, L2, L3 to lit up) ... From 100Vac to 600Vac.
Frequency Range ... From 10Hz to 400Hz.

Determination of the Phases Rotary Field Direction:
Direction (the voltage required to have the direction LEDs L1-L2-L3 or L2-L1-L3 to indicates) ... From 1 to 600Vac.
Frequency Range ... From 2Hz to 400Hz.

Determination of Motor Connections (requires > ½ turn)
Direction (the voltage required to have the direction LEDs L1-L2-L3 or L2-L1-L3 to indicates) ... From 1 to 600Vac.
Frequency Range ... From 2Hz to 400Hz.

Protection
Over Load ... 550V (between all terminals)
Over Voltage ... Class III - 600V towards Ground.
Fuses... 5 x 20mm, 200mA, 250V fuse

General
Battery ... 9V, IEC 6LR61
Current Consumption ... Max 18 mA.

MECHANICAL

Size ... 151 x 72 x 35 mm
Material ... Poly carbonate/ABS
Weight (less carrying case) ... 180g (with batteries)
Display ... Neon Lamps and LEDs

ENVIRONMENTAL
Operating temperature Range: -15 C to + 55 C
Storage Temperature: -20 C to + 70 C

LIMITED ONE-YEAR WARRANTY

B&K Precision warrants to the original purchaser that its products and the component parts thereof, will be free from defects in workmanship and materials for a period of one year from date of purchase from an authorized B&K Precision distributor.

B&K Precision will, without charge, repair or replace, at its option, defective product or component parts. Returned product must be accompanied by proof of the purchase date in the form of a sales receipt.

To obtain warranty coverage in the U.S.A., this product must be registered by completing the warranty registration form on www.bkprecision.com within fifteen (15) days of purchase.

Exclusions: This warranty does not apply in the event of misuse or abuse of the product or as a result of unauthorized alterations or repairs. The warranty is void if the serial number is altered, defaced or removed.

B&K Precision shall not be liable for any consequential damages, including without limitation damages resulting from loss of use. Some states do not allow limitations of incidental or consequential damages. So the above limitation or exclusion may not apply to you.

This warranty gives you specific rights and you may have other rights, which vary from state-to-state.

B&K Precision
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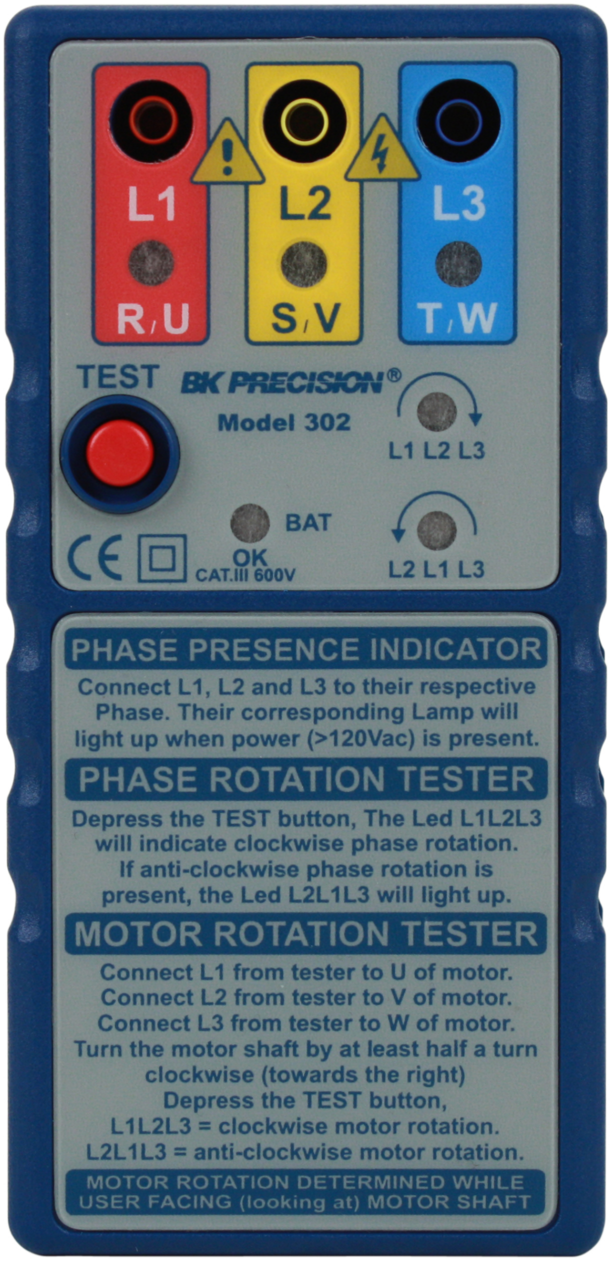


Figure 3.1: BK Precision Model 302 Phase and Motor Rotation Meter

Questions

1. Give three examples of loads which would not work if the motor turned in the wrong direction. Would any of these examples be damaged if they turned in the wrong direction.
2. Is phase sequence A-B-C the same as phase sequence C-A-B? Why or why not.
3. What would it indicate if only two of the three neon lamps illuminates when the meter is connected to a three-phase power supply?
4. Why is it necessary to hand rotate the motor when it is connected to the phase rotation meter?

Exercise 4 Ground Fault Detection

Objective

To understand the importance of detecting ground faults on an ungrounded distribution system. To understand common causes of ground faults. To demonstrate a technique to locate ground faults sufficient to satisfy STCW requirement OICEW–3–1C *Detect location of grounds*.

Discussion

Introduction

Discussion adapted from *Ground Fault Protection on Ungrounded and High Resistance Grounded Systems Application Guide*; Post Glover Resistors, Erlanger KY[1]

The training ship, as do most ships, has an *ungrounded* electrical distribution system. An ungrounded system is defined as a system of conductors with no intentional connection to ground except through potential indicating and/or measuring or other very high impedance devices.

Ungrounded distribution systems are used aboard ship and in some industrial installations because accidental contact between one line and ground does not cause loss of power due to a circuit breaker trip. A single-phase failure to ground does not cause high current to flow, because the current is limited by the capacitance of the other two phases. However, the voltage-to-ground of the other phases can rise by 73%, stressing the insulation of cables and other equipment connected to the system. It is common practice to run a faulted, ungrounded system until it is convenient to shut it down for repairs.

Unfortunately, the ungrounded system is susceptible to a build-up of high voltages (up to six times the nominal system voltage) when the first fault on the system is intermittent. This high transient voltage can initiate a second fault at the weakest insulation point on the system and thus larger, more damaging fault currents can occur. The second phase failure to ground will usually initiate high fault currents flowing between the two insulation failures. Circuit breakers protecting the circuit involved should operate to clear the fault. However, a phase-to-ground-to-phase fault path impedance between them may create a high resistance arcing fault. The magnitude may not be sufficient to operate the breakers, and can cause extended shutdown until the equipment can be replaced.

Locating and repairing the first ground fault as soon as it is indicated is of prime importance, but this is usually not an easy job since some portion of the plant would have to be shut down in order to isolate the problem area.

Effects of Ground Fault

An ungrounded distribution system is, in reality, coupled to ground through the distributed capacitance of conductors and transformer or motor phase windings. In the absence of a ground fault, the line-to-ground voltage of the three phases will be approximately equal because of the equally distributed capacitance of the system.

Theoretically, in a balanced three-phase system, the currents in all three lines are equal and 120° apart see Figure 4.1. The vector sum of the three capacitive phase currents (I_A, I_B and I_C)) is equal to zero at the ground point, which also results in the system neutral being held at ground potential by the balanced capacitive voltages to ground (V_{AG}, V_{BG} and V_{CG}). Thus, although an ungrounded system does not have an intentional connection to ground, the system is actually capacitively coupled to ground.

The ungrounded system can be regarded as a three wire system only, thus the following discussion is valid for both wye and delta transformer secondaries.

[1] http://www.postglover.com/Literature/HR003–05_High_Resistance_Ground_Gde.pdf

If one system conductor, phase C for example, becomes faulted to ground, then phase C and ground are at the same potential, zero volts Figure 4.2. The voltages of the other two phases in the reference to ground are increased to the system phase-to-phase voltage. This represents an increase of 73% over the normal line-to-ground voltage. Furthermore, the voltages to ground are now only 60° out of phase.

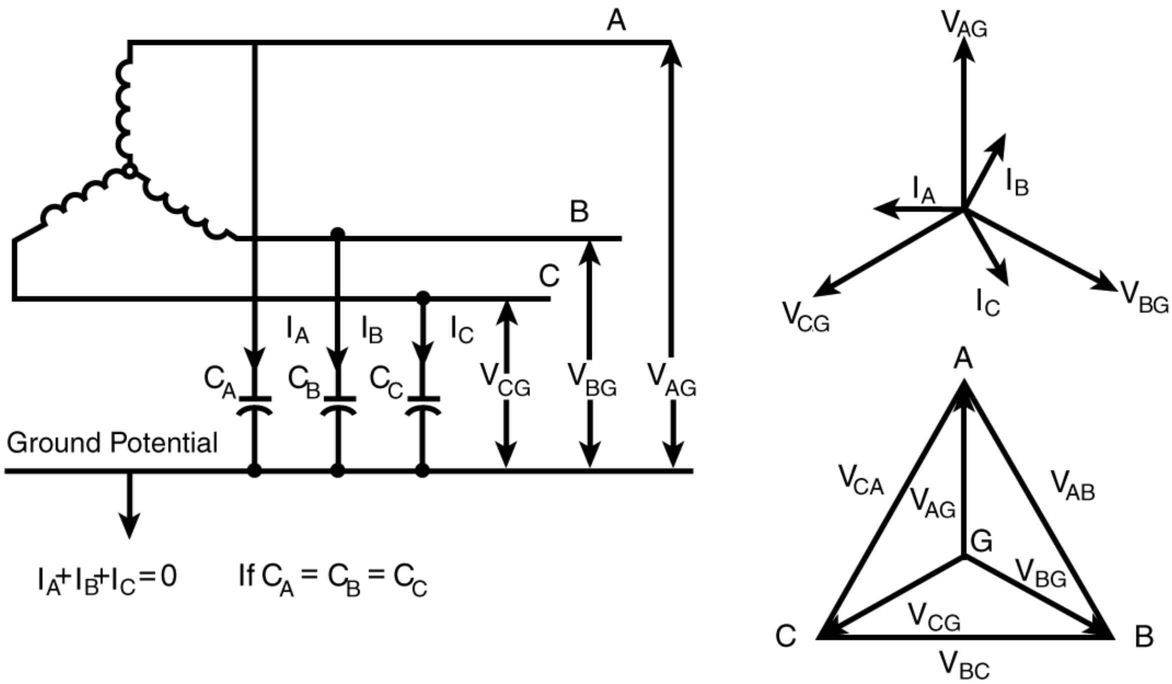


Figure 4.1: Ungrounded System - Normal Condition

Even though the capacitive voltages are unequal during a single line-to-ground fault, the phase-to-phase voltages (V_{AB}, V_{AC} and V_{BC}) have not changed in magnitude or phase relationship and the system remains in service. Ground Current in the fault IG is the vector sum of the two currents I_A, and I_B, (which are 90° ahead of their respective voltages VAG and VBG) where $I_A = V_{AG}/X_A$ and $I_B = V_{BG}/X_B$.

X_A and X_B are the system capacitive reactances calculated from the capacitances of the elements of the distribution system. This ground current value is used to determine the maximum ground resistance for high resistance grounding.

If the ground fault is intermittent such as arcing, restriking or vibrating type, then severe overvoltages can occur. Unless the fault disappears as the phase voltage passes through zero, a DC offset voltage will remain on the system capacitance to ground. When the fault reappears, the system voltage to ground will equal the sum of the DC offset and the AC component, which will depend on the point of wave at which the fault is re-established. In this manner, the intermittent fault can cause the system voltage to ground to rise to six or eight times the phase-to-phase voltage, leading to a breakdown of insulation on one of the unfaulted phases and the development of a phase-to-ground-to-phase fault.

An intermittent type of fault is a very real danger. Therefore, early detection of this condition is of primary importance.

Ground fault Detection and Repair

Ground faults are common aboard ship, and should be repaired as soon as possible, since even one ground causes additional stresses on the insulation.

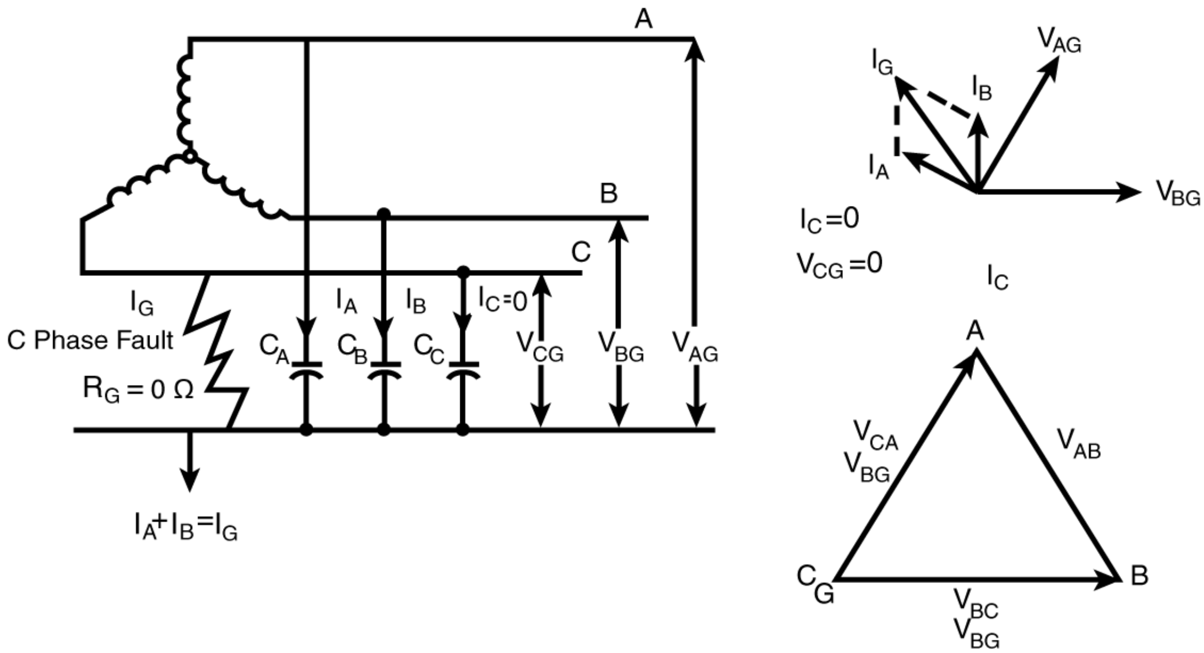


Figure 4.2: Ungrounded System with Fault on Phase C

Common causes of ground faults include buildup of dust and dirt on wiring, which increases the surface leakage currents to ground, and chafing or pinching of conductors which damages the insulation. Probably the most common cause of grounds aboard ship is moisture. Lighting fixtures on deck are a common location of grounds.

The first indication of a ground fault usually appears on the ground indicating lights found on the electrical switchboards, or on the *Kennedy* on the electrical section of the main console and in the AMR. The indicating lights consist of three lamps wired in wye, with the center point connected to ground through a momentary switch, as shown in Figure 4.3. Under normal conditions, all three lamps burn with equal brightness, but a ground on one phase will cause the associated lamp to dim, while the other two become brighter. The dimming effect will be small if the fault has relatively high resistance, while a dead short to ground will cause the lamp to go completely dark.

Grounds are usually located by the process of elimination. Circuit breakers are opened one at a time, until the ground indicating lamps return to normal. This indicates the branch circuit containing the ground. If there are further downstream distribution panels, the process is repeated there. Often, once the fault is localized in this way, the fault is obvious by inspection. Alternately, a megohmmeter can be used to further localize the problem. Obviously, this process must be done with care – and with the permission of the watch – in order to prevent interruption of vital services.

Procedure

- ☐ 1. Investigate the behavior of ground indicating lights using the ground lamp simulator in the lab.
- ☐ 2. Identify the location of the ground in the circuit provided to you by your instructor.

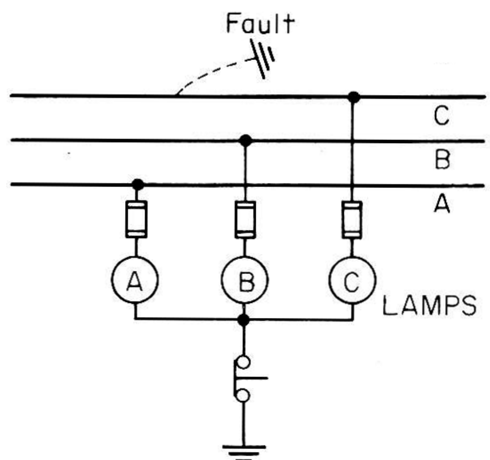


Figure 4.3: Ground Fault Indicating Lights

Exercise 5 Single Phase Motor Controller

Objective

The learning objectives of the single phase reversing controller include:

- Understand the operation of a single phase capacitor start motor
- Understand the significance and operation of using a 24 volt signal to operate high voltage relays
- Demonstrate the use of Lockout - Tagout procedures
- Read and Understand a schematic and wiring diagram for a control circuit
- Understand the operational characteristics of a relay
- Understand the operational characteristics of an Overload Relay Circuit
- Correctly wire a reversing starter for proper operation
- Modify the starter to provide for lighted switches

Discussion

Description

The Single Phase Motor Control Lab is designed to demonstrate the operational aspects of low voltage relays operating high voltage switchgear which in turn operates the electric motor. The single phase 120 volt motor is used in this lab to enable the student to understand the operation of a capacitor start single phase motor.

The control equipment for this motor is identical to one used for three phase motor control, however the wiring of the power circuit would be slightly different for a three phase motor.

Equipment

The equipment for this lab includes the following:

- Meltric 120 volt single phase safety receptacle
- Square D Two Pole Disconnect
- Lockout - Tagout equipment
- 1/2 HP Single Phase Capacitor Start Induction Motor
- Single Phase Type RSXLS Reversing Starter
- Overload Protection Circuit
- 120 - 24 Volt Single Phase Transformer
- Remote Starter Console with lighted FORWARD /REVERSE /STOP pushbuttons

Power

In the lab, power is supplied to the motor through a double pole Meltric disconnect plug known as a *decontactor* and a double pole Square D disconnect switch. The disconnect switch is permanently wired to the terminal block in the Relay Panel. Please do not alter or remove it.

Decontactor plugs and receptacles are designed and rated to safely make and break motor loads and provide protection in the event of overloads or short circuits. Decontactors allow workers to to make and break connections without any special protective equipment or training. The decontactor should be unplugged and locked out at the conclusion of the exercise.

The disconnect switch will be used to de-energize and lock out the motor and control circuit during the lab.

The Disconnect Switch MUST be in the OFF position and LOCKED OUT and TAGGED OUT whenever the Relay Panel is OPEN.

Failure to properly Lock Out equipment is a Safety Violation.

Figure 5.1: Meltric Disconnect Plug

Wiring Diagram

The Wiring Diagram shown in Figure 5.2 illustrates the standard operating methodology for the single phase reversing controller. The student is expected to adapt this schematic to the equipment and operating parameters of this exercise. The diagram shows the portions of the circuit which are typically prewired with solid lines, and the portions that are wired in the field with dotted lines. Also note that the forward and reverse push buttons are mechanically interlocked, as indicated by the dashed lines.

The complexity of this system is not necessarily in the standard wiring connections, but rather how the independent parts of the controls must be connected to form a system. It is important to discuss the system components and their respective relations to other parts.

Motor

The motor used in this lab is a single phase capacitor start motor. The motor utilizes two windings, a **start winding** and a **run winding**. The start winding is wired in series with a capacitor and a centrifugal switch as shown in Figure 5.3. The capacitor causes the current in the start winding to lead the current in the run winding.

The purpose of the start winding is to develop a rotating magnetic field in order that the motor can produce sufficient locked rotor torque to move the attached load from a standstill. The rotating magnetic field is developed because the current in the start winding is out of phase with the current in the run winding, and thus the two winding produce magnetic flux at different points in time. Once the motor has reached about 75% of its nominal speed, the centrifugal switch opens and the start winding is cut out of the circuit.

The run winding is between terminals T1 and T4, while the start winding is between terminals T5 and T8. These leads are permanently connected to the wiring block in the Relay Panel. Please do not alter or remove them.

A capacitor start motor can be reversed by reversing either the start winding or the run winding. The motor control circuit performs this reversal when the FWD or REV button is pressed.

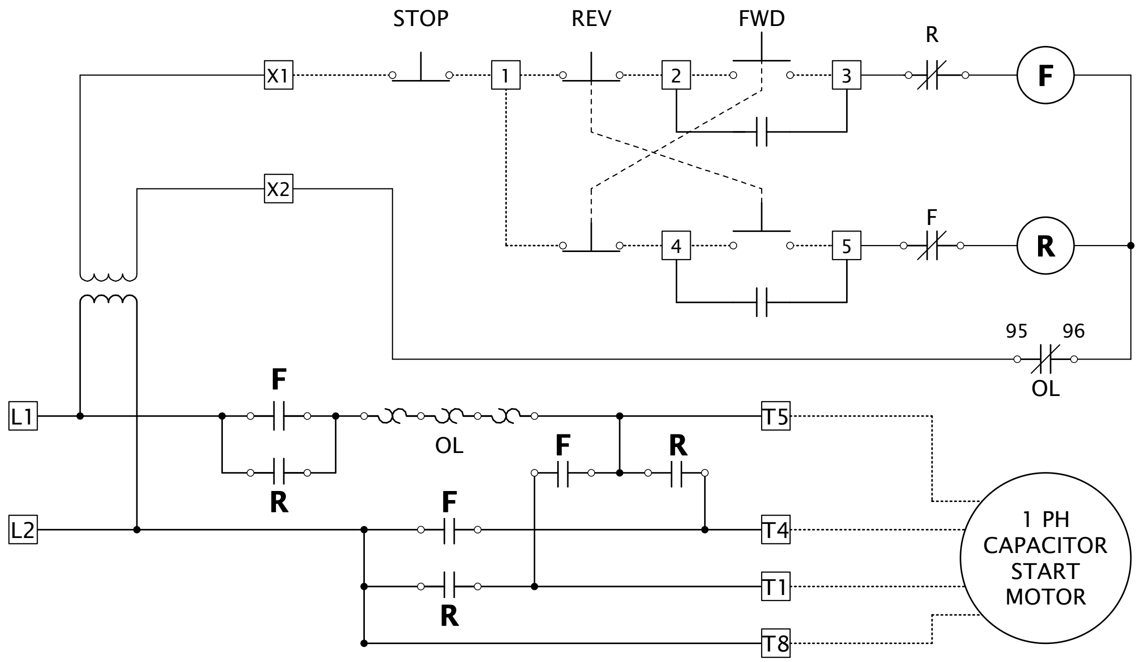


Figure 5.2: 120 Volt Single Phase Reversing Starter with 24 Volt Coil

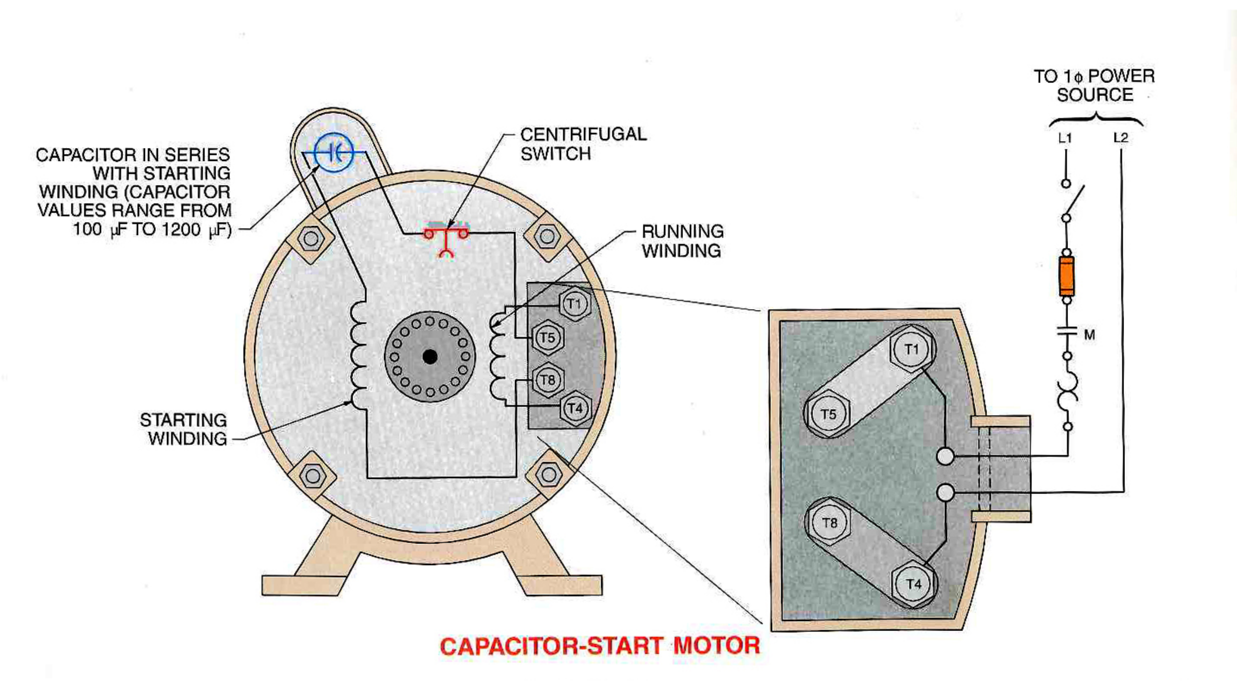


Figure 5.3: Capacitor Start Motor

Relay Panel

The Relay Panel contains the Forward and Reverse relays, the overload relay, and terminal blocks for system connections. The Relay Panel contains HIGH VOLTAGE when in operation. Anytime the Relay Panel is open, the system MUST be properly Locked Out and Tagged Out.

The Relay Panel is also used as the connection point for all of the wire leads for the controls such as the sixteen leads from the Remote Operation Panel. Please note that not all of the leads will be utilized in every procedure, however it is important that unused leads be kept clear of energized equipment.

Remote Operation Panel

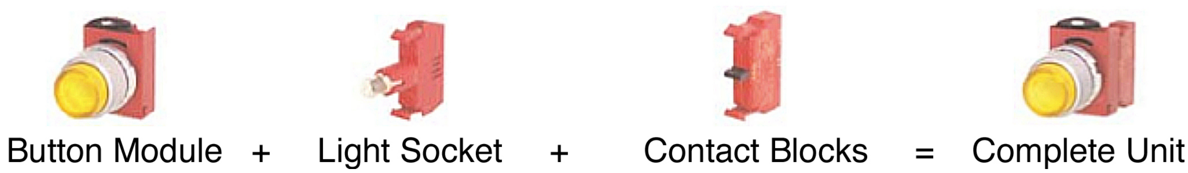


Figure 5.4: Pushbutton Components

The remote operation panel simply contains three lighted pushbuttons: Forward, Reverse, and Stop. A pushbutton is made up of three pieces: the pushbutton & contact block holder, one or more contact blocks, and an optional light socket. Each pushbutton can have up to six contact blocks attached to it. The Stop Button utilizes two: a normally closed (NC) block and a light socket. When depressed, the switch opens. The FWD and REV pushbuttons have three: a NC contact block, a NO contact block, and a light socket. When depressed, the NC switch opens and the NO switch closes.

The remote operation panel is connected to the Relay Panel with eight pairs of wires: 3 pairs for the three lights, one for the NC stop contact, and two each for the FWD and REV switch as each requires a NC and NO pair. The leads are color coded by operation, however the student will be required to determine, through the use of a multi-meter, what each wire pair operates.

In the first lab procedure, the lights are not used. In the second lab procedure, the indicator lights must be correctly wired.

Transformer

The 120 - 24 volt single phase transformer is wired on the primary side to the 120 volt source; on the secondary side to X1 and X2 in the Relay Panel. Connections on the high side are designated **H1** and **H2L**, while the low side are designated **X1** and **X2**.

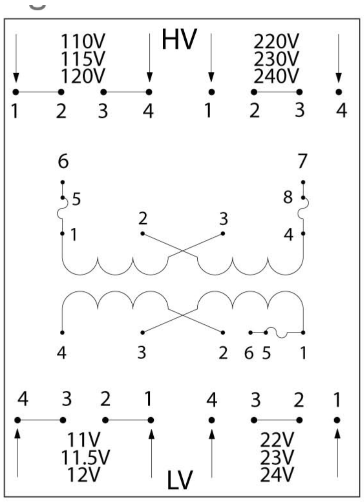
Operational Description

The primary purpose of the control circuit is to cause the motor to start, spin clockwise, spin counterclockwise, or to stop. The secondary purpose of the controller is to stop the motor in the event of a motor overload.

The control circuit uses a 24 volt control power supplied by a *control transformer* to operate forward and reverse contactors (relays) under the control of remote push buttons. Those relays supply 120 volt power to operate the motor. The pushbuttons open and close 24 volt circuits, not 120 volt circuits. Note that the schematic shown has two quasi-independent circuits; the top being the 24 volt *control circuit*, the bottom being the 120 volt *power circuit*.

Forward operation of the motor is accomplished as follows:

FWD is depressed closing the **NO** switch (2–3) and opening the **NC** compliment switch. 24 volts now energizes the **F-coil** in turn closing the *hold-in* or *latching contact* (below 2–3) allowing the **FWD** button to be released. Additionally, the **NC F** contact prior to the **R-coil** is opened to prevent reverse operation.



PH*PG Schematic for 50, 75 and 100VA Units**

High Voltage (HV) (Primary Volts)			Install Supplied Links Between Terminals	Supply Lines Connect To	Install Fuse Clips To
120	115	110	1-2, 3-4	1, 4	Unfused
240	230	220	2-3	1, 4	Unfused
120	115	110	1-2, 3-4	6, 7	1-5, 4-8
240	230	220	2-3	6, 7	1-5, 4-8

Low Voltage (LV) (Secondary Volts)			Install Supplied Links Between Terminals	Load Lines Connect To	Install Fuse Clips To
12	11.5	11	3-4, 1-2	1, 4	Unfused
24	23	22	2-3	1, 4	Unfused
12	11.5	11	3-4, 1-2	4, 6	1-5
24	23	22	2-3	4, 6	1-5

Figure 5.5: Control Transformer Connections

Note 1: The **NC** compliment **FWD** Switch acts as a safety to de-energize the **R-coil** if the motor was operating in the reverse direction. Likewise the complimentary **NC REV** Switch would de-energize the motor if it was running in forward and the reverse switch was pressed. These two complimentary switches eliminate the need to press **STOP** before changing directions.

Note 2: The **NC STOP** button opens the entire 24 volt circuit, de-energizing either the **F-coil** or **R-coil** had they been energized.

Note 3: The **NC OL** contact (95–96) opens on an overload signal from the **OL** coils on the high voltage **L1**.

Note 4: **X1** & **X2** are the 24 volt connections from the secondary side of the transformer.

As soon as the **F-coil** is energized, **ALL F-contacts** will operate; **NO** contacts will close, **NC** contacts will open.

In the 24 volt control circuit, one **NC** contact will open and one **NO** contact (called the hold-in contact) will close.

In the 120 volt motor circuit, the following sequence occurs simultaneously: From **L1**, **NO F** contact closes; From **L2**, **NO F** contact closes; Between **L1** and **L2**, the third **F** contact closes. **L1** is connected to **T5** and **T1**; **L2** is connected to **T4** and **T8**

Note: **T5** and **T8** are connected to **L1** and **L2**, respectively regardless of motor direction. **T1** and **T4** are switched between **L1** and **L2** based on motor direction. **L1** feeds **T1** and **L2** feeds **T4** in **FWD**. In **REV**, **L1** feeds **T4** and **L2** feeds **T1**. This effectively switches the relative polarities of the main and auxiliary windings on startup, causing the rotating field to change direction.

Remember that the centrifugal switch in the motor will disconnect the auxiliary winding when the motor attains approximately 75% of rated speed.

Reverse operation of the motor is accomplished identically to the Forward operation except that the **R-coil** will be energized rather than the **F-coil**.

Reversing Operation

Objective

Using the Single Phase Motor Controller, wire the system such that the motor will operate in the both the forward and reverse direction.

Procedure

> Terminal Blocks in the Relay Panel are *FRAGILE*. Students are requested to please use extreme caution when tightening leads and terminal screws. Very little pressure is required, and they should be just finger tight. The screws in the terminal blocks are rated to be torqued to less than 10 inch-pounds, meaning one pound of force using a 10″ wrench. For comparison, the force require to pull a trigger on a semi-automatic 9-mm pistol is approximately 5 pounds. LESS is MORE!

☐ 1. If you haven't already done it, read the introductory material for this exercise.

☐ 2. Remember the OSHA Basic Safety rule:

> ALL ELECTRICAL CIRCUIT CONDUCTORS, BARE OR INSULATED, ARE ASSUMED TO BE ENERGIZED UNTIL PROVEN OTHERWISE. THEY SHALL BE DE-ENERGIZED, LOCKED OUT AND TESTED FOR THE ABSENCE OF VOLTAGE BEFORE WORKING ON THEM OR WORKING NEAR THEM.

Before you do anything else, check that the motor is locked out, and use your multimeter verify the absence of all voltage. Be sure that your meter leads are connected to the meter properly, that you are on the correct scale, and that the meter works with a known voltage.

What points in the controller should be checked for voltage?

☐ 3. Did you check for voltage between terminals T5 and T8? Why or why not?

☐ 4. Without removing the cover from the Remote Operation Panel, use a multi-meter to determine the purpose of all of the leads coming from the Remote Operation Panel, and record the wire numbers here for future reference. Your instructor has sample push buttons for you inspect if you wish.

What is the function of the third pair on the forward and reverse buttons?

☐ 5. Select the NC Stop leads, the NO and NC FWD leads, and the NO and NC REV leads. Wire these into the motor controller according to the wiring diagram in Figure 5.2. Make all connections at the terminal strip, and do not disturb the factory wiring.

☐ 6. Test the system with a multi-meter to determine that connections are correct.

Do you have continuity between Terminals 2 and 3? ____________ Why?

☐ 7. Request clearance from the Lab Instructor to turn the power on to the motor.

LAB INSTRUCTOR initials here to proceed: ____________

☐ 8. Close Relay Panel, remove Lock-out, and turn on power.

DANGER: Relay Panel is now energized, even if the motor is stopped!

☐ 9. Operate the motor in the forward and reverse directions. Verify that the STOP button operates.

☐ 10. Have your instructor demonstrate the following with the relay panel open:

- Voltage testing
- Break-before-make operation of switches
- Manual operation of the forward and reverse contactors
- Operation of the overload relay

- Setting the overload relay.

☐ 11. Keep the system connected, answer the questions below, and proceed with the next step.

Questions

1. How did you determine what leads were for the light sockets? Without turning on the power or looking inside the remote operating panel, how could you verify your reasoning?
2. How did you determine which leads belonged to the NO and NC switches?
3. What is the voltage at the primary and secondary sides of the transformer?
4. Fill in the following table, and use the results to determine what actually gets switched in order to reverse the motor.

Terminal	FWD	REV
T_1		
T_4		
T_5		
T_8		

5. What happened to terminals T2, T3, T6, and T7?
6. What is the purpose of the jumpers between terminals T1 and T5, and T4 and T8 in the right hand diagram in Figure 5.3.
7. Why does reversing the start winding reverse the motor?
8. Why is it necessary to have both a NC and a NO switch on the FWD and REV pushbuttons.
9. If the complementary NC switches were not used in the FWD and REV pushbuttons, how would that effect the controller operation?
10. What would be the effect of energizing both the FWD and REV coil at the same time?

Motor Indicating Lights

Objective

Using the single phase motor controller, wire the system such that the motor will operate in the both the forward and reverse direction with direction indicating pilot lights.

Procedure

☐ 1. Properly Lockout and Tag-out the system.

☐ 2. Redraw the circuit shown in Figure 5.2 to include pilot lights to indicate when the motor is operating in the Forward and Reverse Directions. We do not have the necessary items to make the stop light work correctly, so just wire it up to be on all the time.

☐ 3. Show your circuit to your instructor to be checked.

LAB INSTRUCTOR initials here to proceed: ____________

☐ 4. After your circuit has been checked, make your modification and test the system with a multi-meter to determine that connections are correct.

☐ 5. Request clearance from the Lab Instructor to turn the power on to the motor.

LAB INSTRUCTOR initials here to proceed: ____________

☐ 6. Close Relay Panel, remove Lock-out, and turn on power.

DANGER: Relay Panel is now energized, even if the motor is stopped!

☐ 7. Operate Motor in the Forward Direction and Reverse Direction. Verify that the STOP button operates and that the indicator lights operate as designed.

☐ 8. How you would wire the stop lamp to function correctly: on when the motor is stopped, and off when the motor is running in either direction. Sketch the circuit on your diagram. What additional equipment would be required to accomplish this?

☐ 9. Keep the system connected and proceed with the next section.

Questions

1. How would you wire in an indicating light that would light when there is an overload condition?

Unidirectional Motor

Objective

Using the Single Phase Motor Controller, wire the system such that the motor will operate in the forward direction only.

Procedure

☐ 1. Properly Lockout and Tag-out the system.

☐ 2. Modify the circuit shown in Figure 5.2 to operate in the forward direction only. Include pilot lights to indicate when the motor is operating and when it is stopped.

☐ 3. Show your circuit to your instructor to be checked.

LAB INSTRUCTOR initials here to proceed: ____________

☐ 4. After your circuit has been checked, wire up and test the system with a multi-meter to determine that connections are correct.

☐ 5. Request clearance from the Lab Instructor to turn the power on to the motor.

LAB INSTRUCTOR initials here to proceed: ____________

☐ 6. Close Relay Panel, remove Lock-out, and turn on power.

DANGER: Relay Panel is now energized, even if the motor is stopped!

☐ 7. Operate Motor in the Forward Direction. Verify that the STOP button operates. Verify that the REV button does not effect the circuit.

☐ 8. Draw a schematic of your final unidirectional motor control circuit.

☐ 9. Deconstruct the system and answer the following questions.

Questions

1. What is a relay?
2. If the unidirectional motor turned Clockwise when running forward, but it should be running counter-clockwise, how would you change the wiring to correct the situation?
3. How would you connect the control transformer to produce a 12 V output from a 240 V supply in Figure 5.5?
4. What is the purpose of the motor's centrifugal switch, and how does it work?

5. The overload relay has two related parts. Describe the purpose of both parts
6. What are the adjustment screw on the overload relay for? How do you determine the correct setting?

Exercise 6 Programmable Variable Frequency Drive

Introduction

Description

The Programable Variable Frequency Drive exercise is designed to demonstrate the operational aspects of Variable Frequency Drives, how the drive can be used as a programmable motor controller, and finally, how the drive functions can be programmed using a command language entered through the keypad.

Learning Objective

At the conclusion of the the Programable Variable Frequency Drive Lab the student should be able to:

- Describe the operation of a variable frequency drive and its effects on a three phase induction motor.
- Recall the input and output signals which can be used with a VFD.
- Operate the VFD as an open loop or sensor-less motor controller.
- Operate the VFD with a closed loop feedback system.
- Program the VFD software to operate VFD and motor using automatic and manual inputs simulating levels, pressures, and temperatures in mechanical systems.
- Understand the relationship that exists between inputs and outputs of the programmable controller.
- Demonstrate the use of Lockout - Tagout procedures
- Read and Understand a schematic and wiring diagram for a control circuit

Equipment

The equipment for this lab includes the following:

- 1 HP Lenze AC Tech Variable Frequency Drive
- “Bud Box” containing four single pole double throw switches, a potentiometer, a green LED indicator, a normally open (NO) momentary pushbutton, and a normally closed (NC) momentary pushbutton.
- Each piece in the Bud Box is connected to a terminal block which can be connected to the terminal block of the AC-Tech Drive
- 1/2 HP Three Phase 4 Pole Induction Motor
- Multimeter
- Screwdriver
- Wire Jumpers

Variable Frequency Drive

The primary purpose of a variable frequency drive such as the Lenze AC Tech Drive is to act as a motor controller – to start, stop and change the speed and direction of the motor and to protect the motor from overloads, phase loss and low voltage. The secondary purpose of the drive is to adjust the motor output based on its operating characteristics, or the characteristics of the system which it is a part of.

The Lenze AC Tech drive uses a single-phase 120 volt 60 hertz power source, and produces 240 volt 3-phase power with a frequency variable from 0 - 500 hertz.

Figure 6.1: Variable Frequency Drive and Motor

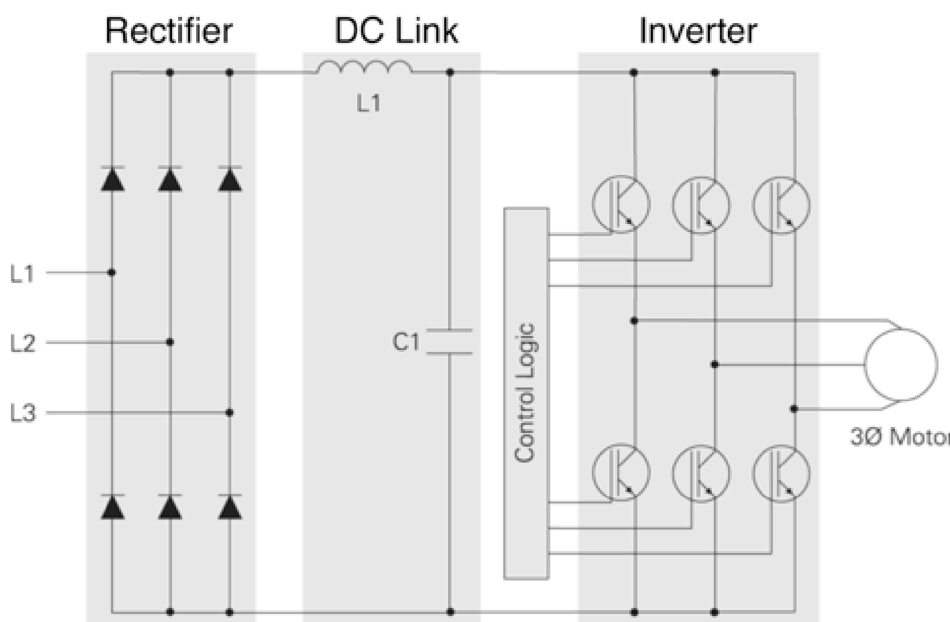


Figure 6.2: VFD Simplified Schematic

The drive operates by first rectifying the 60 hertz AC signal to a DC signal using a bridge rectifier (AC to DC). The DC output is then processed by six IGBTs (insulated gate bipolar transistors), which are essentially computer controlled switches. The IGBTs produce a series of voltage pulses which synthesize three AC sine waves of any desired voltage and frequency, by controlling the duration of the voltage pulses, a method known as *pulse width modulation*.

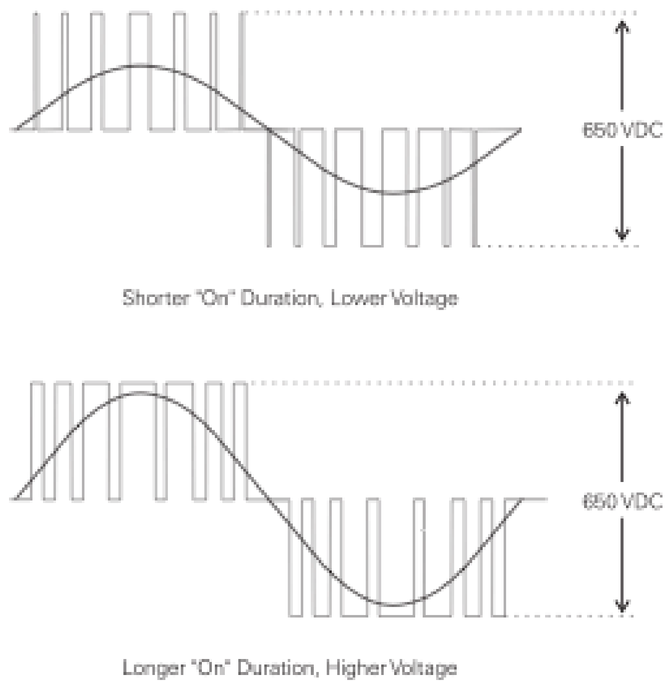


Figure 6.3: Pulse Width Modulation

Basic Operation

The Variable Frequency Drive is pre-wired to both the 120 volt single phase bus and to the three phase 1/2 HP induction motor. The power to the drive originates at the Square D two pole disconnect which is in turn plugged into the Meltric connector and can be locked with an appropriate Lockout when the control system of the drive is being wired.

The drive operators panel, shown in Figure 6.4, provides the basic motor operations. With the drive operating simply as a local motor controller the six control buttons on the faceplate provide on/off, speed adjustment, and reverse/forward control. At this point it should be understood that the VFD and motor, without any additional controls, has more functions and is simpler to wire and operate than standard electro-mechanical motor controllers.

It should be noted that the drive may not function at this point until it is programmed to do so. Although the faceplate has several control functions, any or all of them can be either locked out, or limited – functions can be disabled, speeds can be set to minimums and/or maximums, or ramp up/down times can be defined. Programming the drive is covered in this lab.

VFD Input/Output Connections

The drive has fourteen input/output programmable terminals which will be used to program the control system. The power input and three phase output terminals are permanently connected to the power source and the motor, respectively, and should not be changed.

Figure 6.4: VFD Operator's Panel

The fourteen I/O connections are wired to a 14 point terminal strip mounted on the station board, adjacent to the 18 point terminal strip from the Bud Box.

The use of terminal strips is designed to maintain the life of the fragile miniature screws on the drive itself. However, the terminal strips must be gently tightened – finger tight only. Note also that the screws are not captured screws and should not be removed. Extreme care should be taken so that the terminal strips remain operational.

The fourteen terminals are shown in Figure 6.5 and their functions are given in Table 6.1

Table 6.1: VFD Terminal Functions

Terminal Number	Use
1	Start - With #4 and a NC Switch, starts motor. Used with #11 as a 15 VDC, 50 mA output.
2, 5, 6	Used together as a 0–10 VDC analog input, such as a potentiometer.
2, 25	Used together as a 4–20 mA analog input, such as a transducer, level controller, etc.
4	Selectable Digital Reference. Used with terminal 1, 13A, 13B, 13C
11	15 VDC 50 mA output.
13A, 13B, 13C	These inputs can be programmed for many uses; for example they can be used for stopping, starting, and jogging the motor as well many other functions.
14	Open Collector Output
30	2–10 VDC signal can be converted to 4–20 mA with a total circuit impedance of 500 Ω
16, 17	Programmable NO contact. Can be used to operate relays or other switches.

The schematics and programming options for these I/O terminals are listed in the VFD Manual that you will use during the lab.

The Bud Box

Bud Box is a common name for an electronic enclosure used for electrical assemblies and are sold as blank solid boxes. The Bud Boxes were fabricated specifically for this lab using the training system provided by Lenze

AC Tech. The Bud Box is simply a set of switches that can be wired into the VFD control system providing for simulated analog and digital inputs that will operate the motor via the drive programming language. The box contains three single-pole single-throw (SPST) switches, one single-pole double-throw (SPDT) switch, an LED indicating light, an analog potentiometer, a normally open (NO) momentary switch and a normally closed (NC) momentary switch. Eighteen color coded leads from the Bud Box are permanently connected to one side of a terminal strip allowing them to be then connected to the various input/output positions of the associated terminal trip from the VFD.

Terminal Blocks

As stated earlier, an 18 position terminal block is used for the output connection of the Bud Box. A similar 14 position terminal block is mounted for the 14 I/O terminals of the VFD. An additional 4 position common terminal block is mounted below this block for use when Terminal #4 (digital reference) is required to have more than one connection, such as if it is utilized with all three Programmable Inputs (13A, 13B, and 13C). Students will use jumpers to connect the Bud Box terminals with the VFD terminals.

Terminal Blocks are mounted on the station board are FRAGILE. As stated earlier, students are requested to please use extreme caution when tightening leads and terminal screws. Very little pressure is required, and they should be just finger tight. The screws in the terminal blocks are rated to be torqued to less than 10 inch-pounds, meaning one pound of force using a 10″ wrench. For comparison, the force require to pull a trigger on a semi-automatic 9-mm pistol is approximately 5 pounds. LESS is MORE!

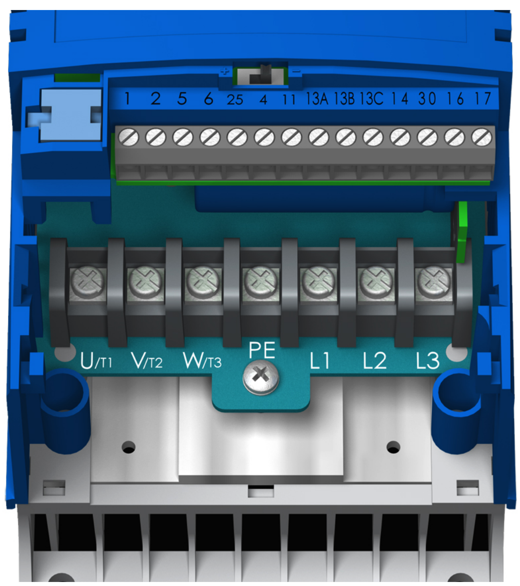


Figure 6.5: VFD Input Terminals

Three Phase Induction Motor

The motor's nine leads are connected at the motor in a low voltage WYE configuration, and are then wired to the three phase outputs of the VFD. These leads are permanently connected to the wiring block in the Relay Panel. Please do not alter or remove them.

Example Connection Diagram

Figure 6.6 shows the VFD connected to four single pole switches, a speed controlling potentiometer, and a output switch contact.

1. Terminals 1–4 are connected as a STOP switch

2. Terminals 2–5–6 are connected with a potentiometer to allow speed control.
3. Terminals 13A - 4 are connected as a RUN FWD Switch.
4. Terminals 13B - 4 are connected as a RUN REV Switch
5. Terminals 13C - 4 are connected as a JOG FWD Switch
6. Terminals 16–17 are connected as a LOSS of LOAD indicating relay. Programmed, this contact will CLOSE when the load on the drive and motor drops below a programmed value of 40%.

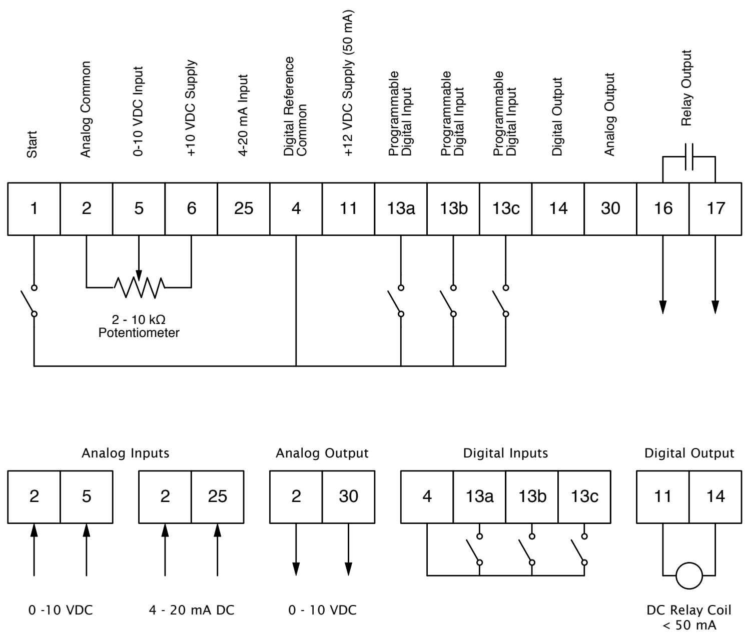


Figure 6.6: VFD Connections

Safety Notes

1. The motor shaft is not protected by a guard so that you can observe the shaft rotation. This is potentially hazardous.
2. The motor may start unexpectedly, particularly if you make an error building the control circuit.

   Always keep your hands away from the motor shaft!

VFD Familiarization

Objective

In this exercise you will investigate the behavior of the Lenze Variable Frequency Drive.

Procedure

☐ 1. Read the introductory material concerning VFDs in this handout.

☐ 2. The manual uses a number of acronyms and abbreviations which you should be familiar with. Define the following:

- EMC
- EPM
- I/O
- LED
- MOP
- NEMA
- OEM
- PE
- PID
- SMV
- SPST
- SPDT
- TB
- v/Hz
- VAC

☐ 3. Study the information in sections 2.2 and 2.3 of the SMVector Manual to interpret the meaning of the model number of the Vector Drive and answer the following questions.

- What is the drive model number ___________
- What is the power rating for this drive, in HP and KW? ___________
- What are the input power requirements for this drive? ___________
- What are the installed i/o modules ___________
- What is the continuous output current of the drive? ___________
- What is the maximum output current of the drive? ___________

- Is the maximum output current adjustable? ___________

☐ 4. The drive protects the motor against eight different kinds of faults. The letters listed below are hints. Read the Technical Data and Fault Messages in the manual and identify the protective functions and list the associated fault name and error code.

- (sc)
- (ef)
- (pl)
- (ov)
- (uv)
- (ms)
- (ot)
- (mo)

☐ 5. Reset the VFD to the factory default settings

1. Press the Mode/Enter (**Mode**) button.
2. If PASS appears, use the arrow keys to enter the controller password *225* and press **Mode**
3. Use the up or down arrow to set the display to **P199**, then press **Mode.** Use the up or down arrow to select **3**, then press **Mode** again.

What is the purpose of this command? (See manual.)

☐ 6. Experiment with the drive.

- Start and stop the motor.
- Start it and adjust its speed.
- Stop it and restart it. What speed does the motor operate at after a restart?
- Try to reverse it. Can you run the motor in reverse by default?
- Open the disconnect switch to de-energize the VFD and watch what happens. Did the VFD immediately shut off? Did the motor restart upon restoration of power.

☐ 7. Check the manual to determine the purpose of the following parameters, then try them out.

- P112
- P104 and P105 - set to 1 second.
- P103 - Read warning and don't exceed 120 Hz!
- P111 - compare the various settings

☐ 8. What are the meanings of the red, yellow and green LEDs on the right side of the display?

☐ 9. Note that *drive mode* setting **P300** is set to **0** by default. With this setting the controller adjusts the output voltage to maintain a constant ratio of voltage to frequency up to a maximum frequency. This mode is is called "constant V/Hz" mode, and is most suitable for loads which have a constant torque requirement, such as winches, elevators, and conveyer belts.

In this step you will observe this by varying the drive frequency and observing the output voltage. Use diagnostic parameter **P506** to measure the drive voltage.

Adjust the drive frequency in 10 Hz steps from 0 to 100 Hz. For each step graph the results on the grid provided in Figure 6.7.

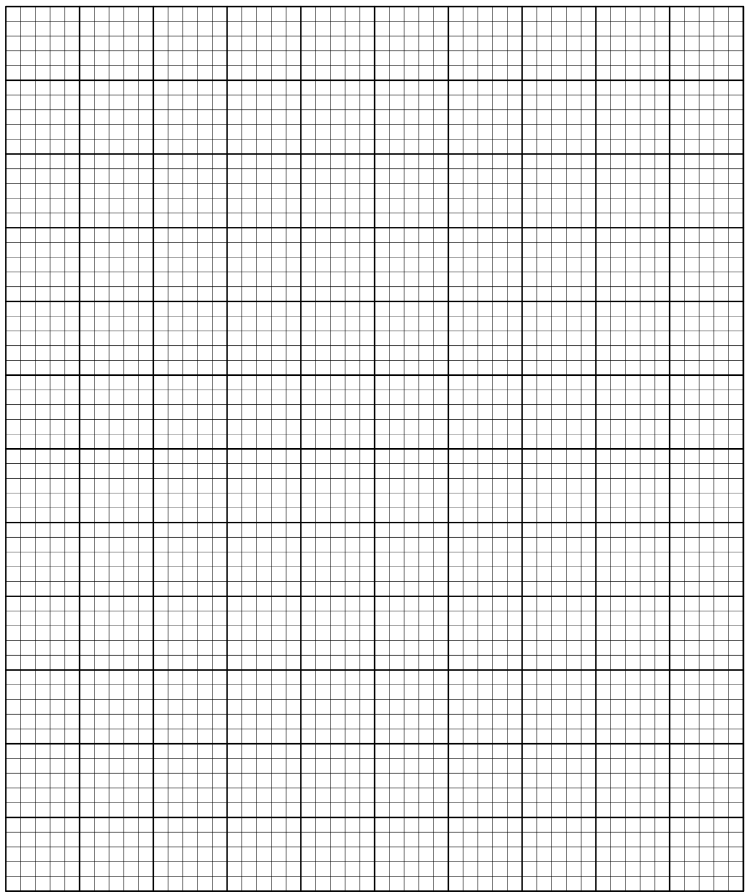


Figure 6.7: Voltage vs. Frequency

☐ 10. Set drive parameter P300 *Drive Mode* to **1** which is "Variable v/Hz" mode. This mode is more suitable than "constant V/Hz" mode for centrifugal pumps and fans. Note: stop the motor before changing the drive mode, or the change may not take effect.

☐ 11. Adjust the drive frequency in 10 Hz steps from 0 to 100 Hz. For each step record the drive voltage, and graph the results on the grid provided in Figure 6.7.

☐ 12. Use your ohmmeter to determine the connections between the switches, potentiometer, and the lamp on the Bud Box and the 18 terminals of the upper terminal strip, and label the diagram in Figure 6.8. For each pair of terminals on the toggle switches, indicate which position (up or down) closes the contacts.

You are provided with the following useful (?) hints.

- The wire colors are not completely arbitrary.

Table 6.2: VFD Speed/Voltage Data

Frequency (Hz)	Constant V/Hz (Volt)	Variable V/Hz (Volt)
0		
10		
20		
30		
40		
50		
60		
70		
80		
90		
100		

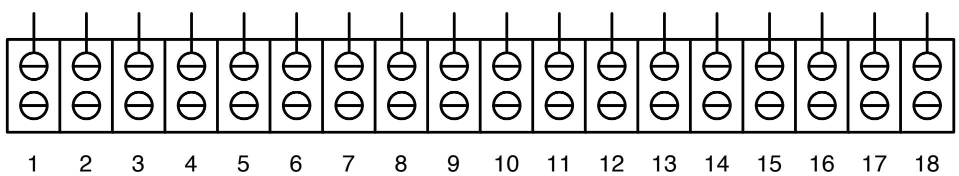


Figure 6.8: Terminal Blocks

- One of the toggle switches is not like the others.
- The potentiometer has three terminals.

☐ 13. Answer the following questions, then continue.

Questions

1. Describe the difference between "Constant V/Hz" and "Variable V/Hz" modes.
2. What are the main components of a Variable Frequency Drive?
3. How can the VFD produce a higher output voltage than its supply voltage?
4. If a VFD installed in the engineroom or a factory failed, what would be required to set up a replacement?
5. What would be the motor's synchronous speed if it was operating at the maximum frequency of the drive? Would you expect the motor to turn at (exactly/more/less) than this speed? Use

$$n_s = \frac{120f}{P}$$

Two Wire Control

Objective

Two-wire control consists of a maintaining contact Single-pole, single-throw (SPST) switch connected between terminals 1 and 4. In this section you will implement two variations of two-wire control.

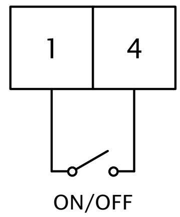


Figure 6.9: Two-wire Control

Procedure

- ☐ 1. Set parameter P100 to 1 = *Terminal Strip*
- ☐ 2. Wire one of the 2-wire SPST switches between terminals 1 and 4, as shown in Figure 6.9.
- ☐ 3. Demonstrate the operation of the motor using the toggle switch.
- ☐ 4. While the motor is running open the knife switch to simulate the loss of voltage, then re-energize the VFD.
- ☐ 5. Set parameter P110 to 3 = *Auto Restart*
- ☐ 6. Repeat steps 3 and 4 to see the operation of *Auto Restart* mode. **Keep hands clear of the shaft when re-energizing.**
- ☐ 7. One method to implement a reversing motor is shown in Figure 6.10. Enable reverse rotation by setting parameter P112 *Rotation* to 1 = *Forward and Reverse*, and enable input 13a by setting P121 to *Reverse Rotation*, then wire a SPST Reverse switch between TB–13a and TB 4. Test for correct functioning.

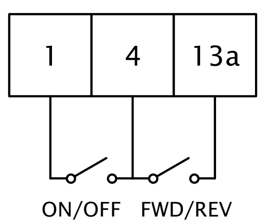


Figure 6.10: Reversing Method 1

Questions

1. What condition is required between terminals 1 and 4 in order to start the motor.
2. What error code is displayed after the disconnect switch is opened? What does it mean?
3. Describe the difference between *normal mode* and *auto restart mode*.
4. For each setting of Parameter P110, categorize the control as either *low voltage release* or *low voltage protection*.
5. How is it possible for the VFD to continue to operate after the power has been lost?

Three Wire Control

Objective

Three-wire control uses a Normally Open, Momentary Contact START pushbutton, and a Normally Closed, Momentary Contact STOP Button. In this section you will implement a three-wire control system.

Procedure

- ☐ 1. Wire the RED and GREEN momentary pushbuttons as shown in Figure 6.11.
- ☐ 2. Set P100 *Start Control Source* to *Terminal Strip*.
- ☐ 3. Set P121 *TB–13A Input Function* to *Start Forward*.
- ☐ 4. Demonstrate the operation of the motor using the GREEN and RED pushbuttons.
- ☐ 5. Change parameter P121 to *Run Forward* and observe the operation of the motor.

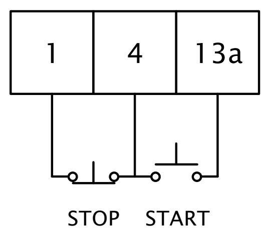


Figure 6.11: Three-wire control

Design Challenge 1

Build and demonstrate a circuit that uses three-wire control and permits the motor to be operated in either direction.

Questions

1. Which control method, two-wire or three-wire, do you consider "better?" Why?
2. If the motor turns the wrong direction when using a three-wire unidirectional control, how could you correct the problem?
3. Consider parameter P121 *TB–13A input*. What is the difference between parameter setting 11 *Start Forward* and setting 13 *Run Forward*?
4. Draw the control wiring diagram and list the four parameters that you used to solve the design challenge.

Speed Control

Objective

Often it is desirable for motors to operate at more than one speed. In this section you will program the VFD for various methods of speed control.

Procedure

2 Speed Controller

In this circuit, you will build a two-wire start/stop control, and use a SPST switch to select either a preset speed, or the speed selected with the keypad.

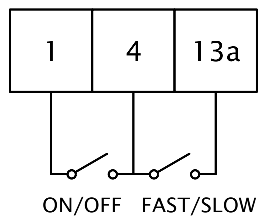


Figure 6.12: Two Speed Control

- ☐ 1. Wire two SPST switches as shown in Figure 6.12.
- ☐ 2. Set P100 *Start Control Source* to *Terminal Strip*.
- ☐ 3. Set P121 *TB–13A Input Function* to *AUTO Reference: Preset*.
- ☐ 4. Set Preset Speed #1 to 30 Hz
- ☐ 5. Demonstrate the operation of the motor. Note that only one speed is actually preset; the other is set by operator using on the local keypad.

Design Challenge 2

Redesign your previous circuit to have two *preset* speeds: 30 Hz and 60 Hz, and no ability for the operator to adjust the motor speed. This can be done without rewiring anything if you add the appropriate instruction to the VFD.

Jog Function

A motor *Jog* function enables a motor to turn slowly under operator control. Jog is used to help position something; for example the Kennedy has a jog function on the jacking gear motor to permit the gears and turbine to be placed in any desired position for inspection.

Jog is typically implemented using a Normally Open (NO) pushbutton. The motor starts and turns slowly when pushed, stops immediately when released. The motor should be stopped before beginning the Jog.

- ☐ 6. Add the green pushbutton serve as the forward jog switch.
- ☐ 7. Set up the necessary parameters such that the motor will turn at 10 Hz when the jog button is pressed.
- ☐ 8. Demonstrate satisfactory operation of the motor.
    - What happens when jog is pressed while the motor is running?
    - What would you need to add a JOG/REVERSE function? Why would that be useful?

8 Preset Speeds

- [ ] 9. Build the control circuit shown in Figure 6.13.
- [ ] 10. Set P199 to 3 to restore the VFD to its default settings.
- [ ] 11. Set P100 *Start Control Source* to *Terminal Strip*.
- [ ] 12. Program terminals 13A, 13B, and 13C as *AUTO Reference: Preset*.
- [ ] 13. Set Preset Speeds 1 through 7 to give 10 to 70 Hz in 10 Hz rpm increments.
- [ ] 14. Operate the motor and verify that that switches control the motor as designed.
    - Is there any pattern to the switch positions/speed settings?
    - Is there any switch pattern that is not associated with a preset speed? Explain?
- [ ] 15. Reprogram the switches to use binary counting to make a sensible pattern of switch positions/speed settings. Use 000 = stop, 001 = 10 Hz, 010 = 20 Hz, 011=30 Hz, etc up to 111 = 70 Hz.

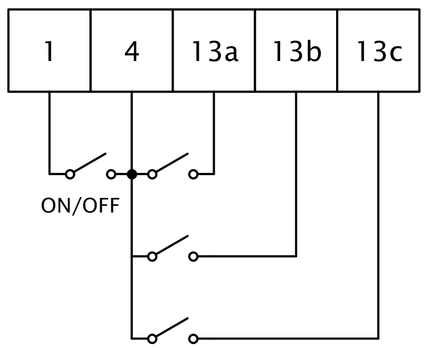


Figure 6.13: Eight Speed Motor

Speed Potentiometer

It is often desirable to have the motor speed command come from an external source rather than a preset speeds or by the operator making speed changes from the keypad. These speed commands could be based on the needs of the process, for example to adjust vent fan speed based on outside temperature in order to save energy.

In this example, you will use a manually operated potentiometer to provide the speed reference, however this circuit could easily be modified to use any 0–10 V DC signal to control the speed according to the needs of the process. Note that this is using *open-loop control*, i.e., there is no feedback used to eliminate speed errors. The VFD has the capability to use *closed-loop* PID control to do this, however you will not be using that method today. See Parameters P200 to P242 for information.

- [ ] 16. Build the control circuit shown in Figure 6.14 so that turning the potentiometer clockwise will increase the motor's speed. Important: You must determine which wires of the potentiometer connect to terminals 2, 5, and 6. Note that the VFD provides +10 Volts DC between terminal 2 and 6, and that the potentiometer acts as a voltage divider to supply an adjustable 0–10 volts between terminals 2 and 5.
- [ ] 17. Set P199 to 3 to restore the VFD to its default settings.
- [ ] 18. Set *Standard Reference Source* to *0–10 VDC* .
- [ ] 19. The diagram on page 18 of the manual suggest the use of a 2 - 10 kΩ resistor. What is the resistance range of out potentiometer? __________
- [ ] 20. Measure and verify that 10 VDC is available from this drive. Voltage __________

☐ 21. Measure the analog input voltage when the pot is

- Fully CCW ___________
- Centered ___________
- Fully CW ___________

☐ 22. Start the motor and verify that the potentiometer adjusts the motor speed as desired.

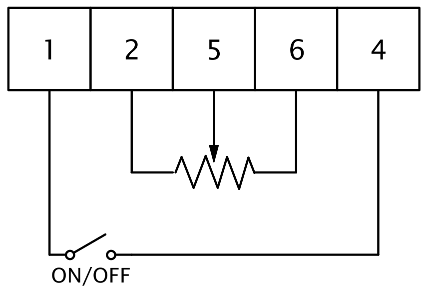


Figure 6.14: Analog Speed Control

Design Challenge 3

Make the necessary changes to add:

- A toggle switch controls the motor's direction (Forward, or Reverse)
- The potentiometer controls the speed between 55 and 65 Hz.

Motor Operated Potentiometer

A *Motor operated Potentiometer* or MOP, increases or decreases speed by input switch or relay. The MOP operates exactly as the pushbuttons on the faceplate of the drive. This is sometimes referred to as *Floating Point Control*. MOP is typically used where speed needs to be set from more than one source or point, or where a relay will trigger small changes in speed. MOP is a basic set point control application.

MOP switches are normally open (NO). Closing them activates the increase or decrease speed. Momentary switches, relays, or throw switches can all be used. A spring-centered double throw switch would be appropriate for manual control.

In this exercise you will build a three wire control with MOP.

☐ 23. Reset the drive to factory parameters by setting P199 to 3.

☐ 24. Build and program 2-wire control circuit.

☐ 25. Add two switches to TB–13a and TB–13b for MOP up and MOP down.

☐ 26. Program the VFD for MOP up and MOP down.

> Note: When you set P122 for MOP up, you will receive an error message on the VFD screen as "F.IL". This error (see error codes in the appendix) means that there is only one MOP function set. The issue is that you just set the TB–13B Input as a MOP Up switch, and if you have a MOP up, you need a MOP down. You just need to configure another one of the inputs as a MOP Down switch to avoid the fault.

☐ 27. Demonstrate MOP operation.

- If you use MOP up and MOP down at the same time, what happens?
- Can you set a minimum and maximum speed for the MOP switches?

Questions

1. Explain how three switches can provide eight speeds.
2. What is meant by Binary Counting?
3. What is the minimum and maximum speeds that the motor can have if the frequency can be programmed from 0 - 500 hertz?
4. What is the real limiting factor for the motor speed?
5. How did you determine the purpose of the potentiometer leads?
6. Discuss the construction of the potentiometer. What other applications can you think of for a potentiometer.
7. Is the potentiometer the same device used as a field rheostat on a generator?
8. List some situations where a Jog Function would be useful.
9. What is dynamic braking, and how can you program it into this system?
10. Why would a spring-centered DPST switch work better for MOP than two separate switches?

I/O Functions and Fault Conditions

Objective

The VFD provides a number of input and output capabilities which will be explored in this exercise.

Procedure

External Signals

External signals such as pressure, level, or limit switches, etc. can be used to trip the motor. In this exercise you will use the normally closed stop switch to simulate an external fault signal.

- ☐ 1. Continue with your previous setup
- ☐ 2. Add the red stop button to TB–13c to simulate an external fault.
- ☐ 3. Verify the operation of the system
    - What does the operator panel display when a fault occurs? ___________
    - What do you have to do to clear the fault?

Indicating Lights

VFD terminal 14 supplies a 24 VDC 50 mA supply which is suitable for driving low current digital devices such as transistors and light emitting diodes. We have one green LED on the Bud box which can be used to demonstrate this functionality.

- ☐ 4. Install the indicating light between terminals 14 and 4.
- ☐ 5. Program TB–14 to turn the light on when the motor is running. Note that the LED will only work when installed with the correct polarity.
- ☐ 6. Reprogram TB–14 to light up when the motor is running in the forward direction only.
- ☐ 7. Reprogram TB–14 to indicate when a fault has occurred, and test by pressing the red button to simulate a fault.

Output Relay

If you need to control the operation of an AC device, or a device that draws more than 50 mA DC, terminal 14 can not be used; however, the VFD provides contacts between terminals 16 and 17 which supports loads up to 3 A. The relay output 16–17 can be set to a large number of functions, and can be set as a normally open (NO) or normally closed (NC) switch. The relay can be set to trigger an alarm or other device, or provide simple indicating status.

☐ 8. Set P140 *Relay Output* to trigger when a fault occurs.

☐ 9. Measure both the resistance and voltage across terminals 16 and 17 while the motor is running and stopped due to a fault.

- Is this a simple contact, or does it supply voltage?

Design Challenge 4

Working with the other group at your bench, wire and program the two motors so that the second motor will start in the event of a fault occurring on the first motor.

Questions

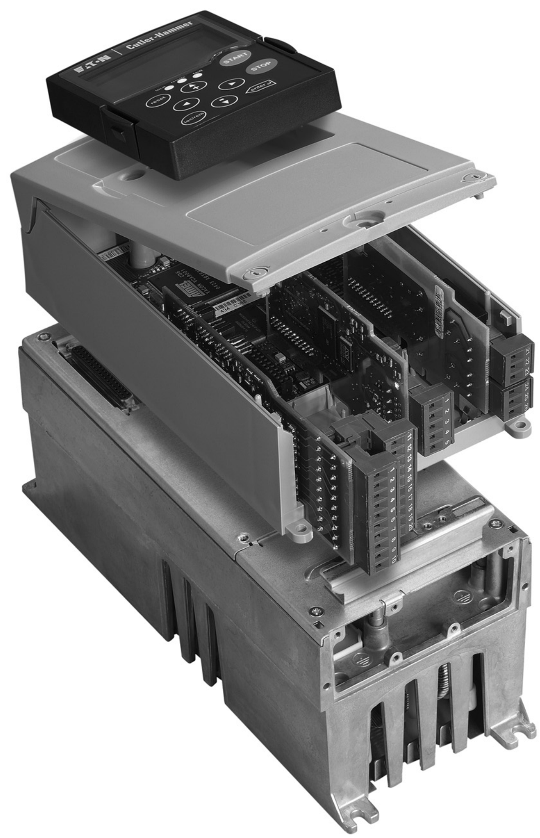
1. Review the parameters and options for Terminals 16 and17. Discuss how those contacts (relay) could be used to operate alarms or other motors. What functions can you envision for this relay?
2. When wiring the LED, does the polarity of the supply voltage matter? Why?

EATON | Cutler-Hammer

AC Drive Theory and Application

Application Guide AP04014005E

Effective May 2008



Introduction

Adjustable Frequency AC Drive System Description

An adjustable frequency AC drive system consists of an ordinary three-phase induction motor, an adjustable frequency drive to control the speed of the motor and an operator's control station.

The most common motor used with an AF drive system is a standard NEMA® design B squirrel cage induction motor, rated for 230 or 460 volt, 3-phase, 60 Hz operation.

The adjustable frequency controller is a solid-state power conversion unit. It receives 240 or 480 volt, 3-phase, 60 Hz power and converts it to a variable frequency supply which can be steplessly adjusted between 0 and 60 Hz. The controller also adjusts the output voltage in proportion to the frequency to provide a nominally constant ratio of voltage to frequency as required by the characteristics of the motor.

The operator's station provides the operator with the necessary controls for starting and stopping the motor and varying the motor speed. These functions can also be performed by a wide variety of automatic control systems.

Benefits of Using AC Drives

AC drives have become very popular in recent years as it is recognized that they provide a very efficient and direct method of controlling the speed of the most rugged and reliable of prime movers, the squirrel cage motor. Eaton's Cutler-Hammer® AC drives provide many economic and performance advantages in a wide variety of adjustable speed drive applications.

The following are some of the benefits provided:

- High efficiency and low operating cost
- Minimal motor maintenance
- Controlled linear acceleration and deceleration provide soft starting and stopping and smooth speed changes
- Multiple motor operation is easily accomplished
- Current limit provides for quick and accurate torque control
- Adjustable speed operation can be accomplished with existing AC motors
- Improved speed regulation can be accomplished by slip compensation
- AC motors are available in a wide variety of mechanical configurations
- Flexibility of machine design due to the light weight and compact size of AC motors
- IR compensation provides high starting torque easily and economically
- AC motors are available in enclosures suitable for hazardous or corrosive environments
- Fewer spare motors are required since the same motor can be used for both adjustable speed and constant speed operations.
- Cutler-Hammer rugged and reliable designs ensure minimum downtime expense
- High speed operation can be economically accomplished using extended frequency operation
- Reverse operation is accomplished electronically without the need for a reversing starter

Basic Principles of AC Drive Operation

There are several classifications of adjustable frequency AC drives. Some common types of drives are Variable Voltage Input (VVI) sometimes called Six Step drives, current source input (CSI), pulse width modulated (PWM) drives, Sensorless Vector drives, Field Oriented drives and Closed Loop Vector drives. The more common AC drives are PWM, Sensorless Vector and Closed Loop Vector drives.

Figure 1 is a block diagram of a typical VVI drive. The AC/DC converter is an SCR bridge, which receives ac power from the input line and provides adjustable voltage dc power to the dc bus. A voltage regulator is required to preset the dc bus voltage to the level needed to provide the required output voltage amplitude to the motor.

Exercise 7 Programmable Logic Controllers

In this exercise[1] you will explore Programmable Logic Controllers using the Click PLC Trainer. You will learn about the basic purpose and capabilities of PLCs, starting with digital and analog input and output, followed by more advanced functions: Math Functions, Timers, and Counters. You will become familiar with ladder logic and the programming software used to write programs and upload them to the PLC, and you will write some ladder logic programs yourself.

At the conclusion of this exercise, the student should be able to:

- Describe the purpose and typical uses of a programmable logic controller
- Describe the basic input and output and logic capabilities of a PLC
- Use Ladder Logic Programming to implement simple PLC functions.

Introduction

A PLC or *programmable logic controller* is a special purpose microcomputer used for automation and control of industrial equipment, such as machinery in power plants, industrial processes, or generally for any purpose. PLCs permit sequencing events and enforcing safety conditions. PLCs are used in many machines, in many industries.

PLCs are rugged and flexible devices which provide for multiple combinations of digital and analog inputs and outputs. They are designed to operated reliably in hostile environments over extreme temperature ranges, with immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored on the PLC in battery-backed-up or non-volatile memory. A PLC is an example of a real-time system since output results must be produced in response to input conditions without delay, otherwise unintended operation will result.

Before the PLC, control, sequencing, and safety interlock logic was mainly provided by relays, cam timers, drum sequencers, and dedicated closed-loop controllers. Since these could number in the hundreds or even thousands, updating them to meet new requirements was time consuming and expensive, as electricians needed to individually rewire the relays to change their operational behavior.

Digital computers, being general-purpose programmable devices, were soon applied to control of industrial processes. Early computers required specialist programmers, and stringent operating environmental control of temperature, cleanliness, and power quality. PLCs have evolved to meet these requirements in a small, rugged, reliable, and inexpensive package.

The main components of PLC systems are:

- **Power supply** The DC Power Supply provides a constant dc voltage to the PLC and other DC components of the system.
- **Input/output section** Input ports receive data signals from external devices, including push buttons, limit switches, and electronic sensors. Output ports take the commands from the processor use them to control external devices connected to them. Input and output ports can be discrete or analog.
- **Processor section** This is the "brain" of the PLC system, comprising the microprocessor and the memory. The processor continuously reads the input data, executes the stored software program, and sends commands to output modules in a fast loop.
- **Communications section** PLCs have at least one communication port used for programming, troubleshooting, sharing data, attaching a visual display, attaching a modem, or connecting to a network. PLCs are often connected to the plant's communication network which enables the PLC to be part of a larger control system and to be remotely accessed.

[1] Portions of this exercise were adapted from *Wikipedia* and *LabVolt Industrial Training Systems - Programmable Logic Controllers*

Click PLC

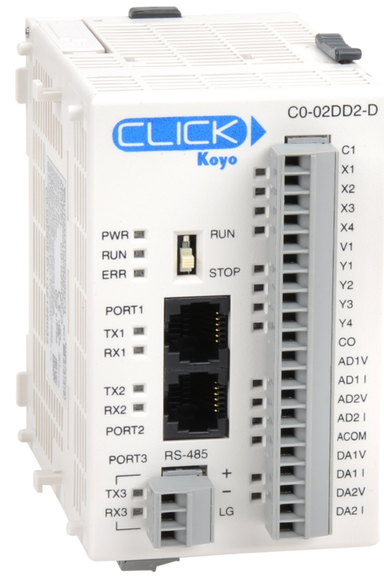


Figure 7.1: Click PLC

In this lab you will be using a *CLICK* PLC Model C0–02DD2-D manufactured by Koyo Electronics Industries Co., LTD., a company which supplies components to automotive manufacturers such as Toyota.

This particular model has four discrete digital inputs, four digital outputs, two analog inputs and two analog outputs. The digital IO operates at 24 VDC while the analog IO uses either a 4 - 20 mA current, or 0 - 5 V DC voltage. In addition the unit has 8 KB user memory for program and data storage, a real time clock/ calendar, battery backup, RS–232 Modbus and ASCII In/Out communications for use with other devices such as graphical display panels. This PLC costs about $129 in 2015. Up to eight expansion modules with different combinations of input and output ports can be added to the main processor.

For this exercise the PLC is interfaced with the PLC trainer shown in Figure 7.2, which connects the PLC inputs and outputs to physical devices. The four digital inputs connect to two single-pole, single-throw toggle switches, a normally open pushbutton (green), and a normally closed push button (red); the four digital outputs control blue, yellow, green, and red LED indicator lamps; the analog input is connected to a potentiometer and the analog output drives a 0 - 5 VDC voltmeter. In addition, the trainer is provided with a 24 VDC power supply and a main power switch.

The Click PLC comes with software used to develop Ladder Logic programs and upload them to the PLC using a USB to Serial cable. Programs are developed graphically by dragging contact and coils to the ladder rungs and assigning them memory addresses. The program includes a comprehensive help system which describes the available capabilities.

Ladder Logic

Ladder Logic is a programming language used to develop software for programmable logic controllers. It is used in industrial control applications where sequential control of a process or manufacturing operation is required.

Ladder Logic programs were originally a graphical representation of the electric circuit diagrams of relay logic hardware. The name is based on the observation that programs in this language resemble ladders, with two

Figure 7.2: PLC Trainer

vertical rails and a series of horizontal rungs between them. The motivation for representing sequential control logic in a ladder diagram was to allow factory engineers and technicians to write logic control software without requiring them to learn a general purpose programming language such as FORTRAN. Development and maintenance were simplified because of the resemblance to familiar relay hardware systems. Today, this argument is less important given that most ladder logic programmers have a software background in more conventional programming languages, however ladder diagrams remain relatively easy for technicians to interpret and understand.

Ladder logic can be thought of as a rule-based language rather than a procedural language. A "rung" in the ladder represents a rule. When implemented with relays and other electromechanical devices, the various rules "execute" simultaneously and immediately. When implemented in a programmable logic controller, the rules are typically executed sequentially by software in a continuous loop called the scan. With sufficient processor speed the loop may be executed in a few milliseconds, so immediate execution is essentially achieved. However proper control of processes with ladder logic programs requires understanding scan time limitations, the execution order of rungs, and the system requirement in order to provide reliable and safe operation.

Ladder logic diagrams represent "contacts" (inputs) that make or break circuits to control "coils" (outputs). Each coil or contact corresponds to the status of a single bit in the programmable controller's memory. If a path can be traced from the left side of the rung to the output through closed contacts, the rung is true (1) and the output is activated. If the path is open, then the output is false (0) and the coil is deactivated. Unlike electromechanical relays, a ladder program can refer any number of times to the status of a single bit, equivalent to a relay with an indefinitely large number of contacts.

Each rung of ladder program typically has one output at the far right which is controlled by one or more inputs to its left on the same ladder rung. The rungs are executed sequentially from left to right and from top to bottom during each scan cycle.

The so-called "contacts" may refer to physical inputs to the programmable controller from real devices such as pushbuttons and limit switches, or they may represent the status of internal storage bits which are generated elsewhere in the program. The "coils" may represent physical outputs which control real devices connected to the programmable controller, such as lamps or relays, or they may represent the status of internal storage bits for use elsewhere in the program.

Some basic symbols used in a Ladder Logic program include:

- —( )— A coil, energized whenever its rung is closed.
- —[ ]— A regular or Normally Open contact, closed whenever its corresponding coil or the input which controls it is TRUE or energized.
- —[/]— A "not" or Normally Closed contact, closed whenever its corresponding coil or the input which controls it is FALSE or de-energized.

Each input or output instruction in the program is assigned an address indicating the location in the PLC memory where the state of that instruction is stored. These memory addresses are referred and accessed by codes. The prefix of the code indicates the type of data stored, and the following digits create a unique identifier. If the bit memory address corresponds to a physical input or output, the code also identifies the location of the wiring connections; the first digit indicates the module, and the rest indicate terminal.

Some of the code prefixes used by the Ladder Logic Software you will be using in this lab are shown in Table 7.1 below.

Table 7.1: PLC Data Types

Prefix	Data Type	Range
X	Input	X001 - X816
Y	Output	Y001 - Y816
C	Control Relay	C1 - C2000
T	Timer	T1 - T500
CT	Counter	CT1 - CT250
DS	Single Byte Integer	DS1 - DS4500
DD	Double Byte Integer	DD1 - DD1000
DH	Hex Integer	DH1 - DH500
DF	Floating Point Number	DF1 - DF500
TD	Timer Value	TD1 - TD500
CTD	Counter Value	CTD1 - CTD250
SC	System Control Bits	SC1 - SC1000

Ladder logic can by used to produce any combination of logical sequences. The following common design patterns should be studied and understood.

Logical AND

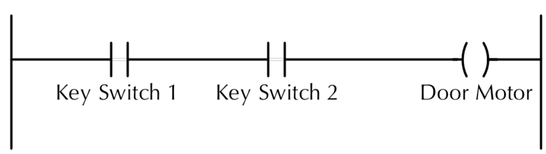


Figure 7.3: Logical AND

The ladder diagram shown in Figure 7.3 realizes the function:

Door Motor = Key Switch 1 AND Key Switch 2

This circuit shows two key switches that security guards might use to activate an electric motor on a bank vault door. When the normally open contacts of both switches close, electricity is able to flow to the motor which opens the door.

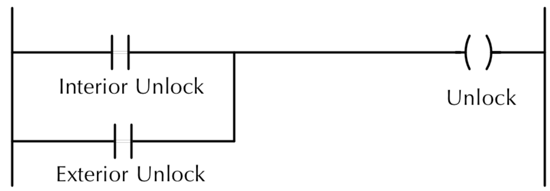


Figure 7.4: Logical OR

Logical OR

The diagram shown in Figure 7.4 realizes the function:

Unlock = Interior Unlock OR Exterior Unlock

This circuit shows the two things that can trigger a car's power door locks. The unlock solenoid gets power when either contact is closed.

Logical AND with NOT

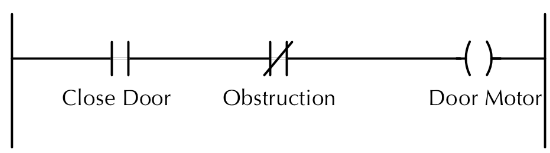


Figure 7.5: AND with NOT

The diagram shown in Figure 7.5 realizes the function:

Door Motor = Close door AND NOT(Obstruction).

This circuit shows a pushbutton that closes a door, and an obstruction detector that senses if something is in the way of the closing door. When the normally open pushbutton contact closes and the normally closed obstruction detector is closed (no obstruction detected), electricity is able to flow to the motor which closes the door.

Industrial STOP/START

In common industrial motor control logic there is a "start" button which energizes the operating coil of a motor contactor, and a "stop" button which de-energizes it to turn off the motor. This design pattern is often referred to as a "Latch."

When the "start" button is pushed the input goes true, via the "stop" button N.C. contact. When the "run" input becomes true the seal-in "run" N.O. contact in parallel with the "start" N.O. contact will close maintaining the input logic true (latched or sealed-in). After the circuit is latched the "stop" button may be pushed causing its N.C. contact to open and consequently the input to go false. The "run" N.O. contact then opens and the circuit logic returns to its inactive state.

The diagram shown in Figure 7.6 realizes the function:

Run = (NOT ES) AND (NOT Stop) AND (Start OR Latch)

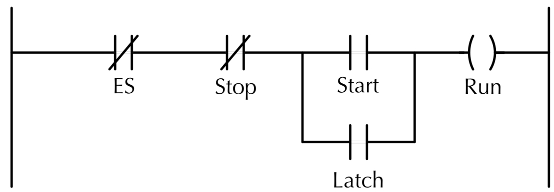


Figure 7.6: Industrial Latch

Note the use of parenthesis to group the logical OR function before evaluating the logical AND function (which has a higher order of operation priority). Also note the use of NOT to represent the "stop" N.C. contact logic.

This latch configuration is a common idiom in ladder logic. In ladder logic it is referred to as seal-in logic. The key to understanding the latch is in recognizing that the "start" switch is a momentary switch (once the user releases the button, the switch is open again). As soon as the "run" solenoid engages, it closes the "Latch" N.O. contact, which latches the solenoid on. The "start" switch opening up then has no effect.

PLC Familiarization

In this section you will explore some of the capabilities of the Click PLC, starting with digital and analog input and output, followed by more advanced functions: Math Functions, Timers, and Counters.

Digital Input

The simplest function of the PLC is responding to Digital inputs and output (I/O). Digital devices, also known as discrete devices, have two states, called variously 0 or 1, False or True, Open or Closed, Off or On, De-energized or Energized, or Inactive or Active depending on context.

The PLC trainer has four digital inputs marked Input 1 through Input 4, and four digital outputs marked Output 1 through Output 4. When programming the PLC the digital inputs are referred to with labels beginning with "X". The four inputs are called: X001, X002, X003, and X004. The four digital outputs are referred to with labels beginning with Y, so the lamps are, from left to right, Y001, Y002, Y003 and Y004. If additional I/O modules are added, additional numbers are used.

N.O. and N.C. Contacts

The most common type of digital inputs are Normally Open (N.O.) and Normally Closed (N.C.) contacts.

- Normally open contacts in the program follow the state of the switch – an open switch means an open input contact and a closed switch means a closed contact. The Normally Open Contact is ON when the related bit is ON.
- Normally closed contacts are the reverse – an open switch means that the corresponding contact is closed and vice-versa. The Normally Closed Contact is ON when the related bit is OFF.

It is important to understand that the input contacts shown in the ladder diagram don't have to correspond to the physical switches attached to the PLC. The action of a Normally Closed physical switch attached to the PLC may control the status of a Normally Open contact in the Ladder Logic Program.

Timing diagrams show the relation between inputs and outputs. The timing diagram for a Normally Open contact is shown in Figure 7.7 and is particularly simple; the output follows the input exactly. With a Normally Closed contact the output is the the exactly the opposite of the input.

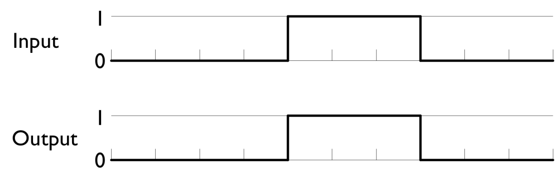


Figure 7.7: Normally Open Contact

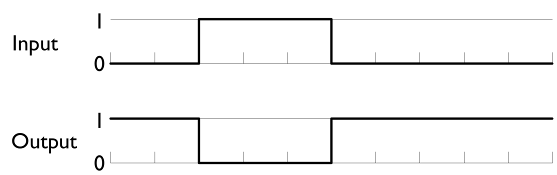


Figure 7.8: Normally Closed Contact

Rising and Falling Edge Contacts

The Edge Contacts close for one scan of the PLC when the associated input value transitions from OFF to ON or vice-versa.

- **Rising Edge** contacts turn ON for one scan when the related bit transitions from OFF to ON. The timing diagram for a Rising Edge contact is shown in Figure 7.9.

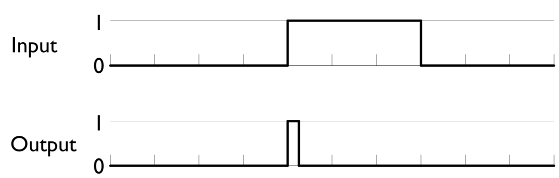


Figure 7.9: Rising Edge Contact

- **Falling Edge** contacts turn ON for one scan when the related bit transitions from ON to OFF. Draw the timing diagram for a Falling Edge contact in Figure 7.10

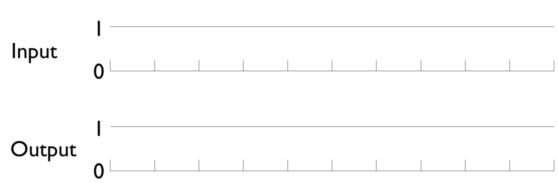


Figure 7.10: Falling Edge Contact

Compare Contacts

The Compare contacts are set to ON or OFF on the basis of a comparison between two values, A and B. When the Data A value satisfies the selected mathematical relationship with Data B, the associated Bit Memory Address is turned ON.

The available comparison operations include

Symbol	Meaning
$=$	A Equals A
$\neq$	A does Not Equal B
$<$	A is Less Than B
$>$	A is Greater Than B
$\leq$	A is Less Than or Equal to B
$\geq$	A is Greater Than or Equal to B

Procedure

☐ 1. Insure that the laptop is running, the trainer 24 VDC power supply is plugged in, and that the USB serial cable is connects the laptop to port 1 of the PLC.

☐ 2. Launch the CLICK programming software by opening the program file *Ladder–1.ckp* found in the *PLC Lab Exercises* folder on the desktop. This file contains the program shown in Figure 7.11

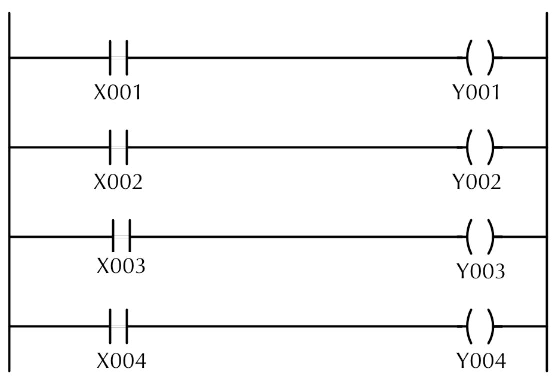


Figure 7.11: Digital Input and Output

☐ 3. Programs need to be uploaded to the PLC before you can run them. Upload this program to the PLC by choosing *Write project into PLC…"* from the *PLC* menu.

Did the program load without error? ☐ Yes ☐ No

What Error Message is displayed in the error window below the ladder diagram?

____

☐ 4. Every program must end with an "Unconditional END" statement. To correct this error, select on the (NOP) statement[2] on Rung 5 and and double click the END statement found under *Program Control* in the Instruction List on the right side of the window. This should change the NOP statement to END.

☐ 5. Save your edited project under a new name using *File>Save Project As…*

[2] NOP stands for "**NO O**peration."

☐ 6. Load the program again using *Write project into PLC…* You will need to click "OK" or "Yes" several times to complete the load.

Does it load successfully this time? ☐ Yes ☐ No

☐ 7. Are any of the lights on? ☐ Yes ☐ No

Exercise the four switches until you understand the operation of the switches and lights.

What is the difference between the red and green buttons?

Which position of inputs 1 and 2 (up or down) correspond to a closed contact?

How does the PLC software indicate a closed contact in the ladder diagram?

☐ 8. Change the function of inputs X002 and X004 from N.O. to N.C. by selecting the Normally Open Contact and then selecting X002, clicking the N.C. —[/]— icon at the bottom of the window, and confirming the address. Do the same for X004.

☐ 9. Reload the project. How is the behavior of the lamps different now?

☐ 10. Change the functions of inputs X001 to a rising edge contact, and X002 to a falling edge contact by selecting the contact clicking Shift-F2 or Shift-F3.

☐ 11. Reload the project. Do the lights only come on for one scan after detecting a change in input from off to on for X001 and from on to off for X002? ☐ Yes ☐ No

Digital Output

Digital output instructions control real-world control elements such as lamps, solenoids, valves, and motors. Output instructions are like the coil and contacts of a motor or an ice cube relay, though with an unlimited number of associated contacts. When the coil is activated, the associated N.O. contacts are closed, and the N.C. contacts are opened. Any real-world devices attached to the PLC then respond.

The Click PLC has two different types of output instructions: Out Coil instructions, and Set/Reset (or Latch instructions).

Out Coil Instructions

Out Coil instructions provide an output which mirrors the state of the rung. Internally, an Out instruction turns ON its associated Bit Memory when the status of the rung is TRUE, and turns OFF its associated Bit Memory when the status of the rung is FALSE.

Set/Reset Instructions

"Set" and "Reset" instructions, also called "Latch" instructions are another way to control the state of an Out Coil. With a standard Out Coil, the value the coil follows the input conditions: ON when the Rung is TRUE, and OFF when the Rung is FALSE. With Set and Reset coils, activating and de-activating the coil are separated into different instructions. Set (Latch) turns the coil ON; Reset (Unlatch) turns the coil OFF.

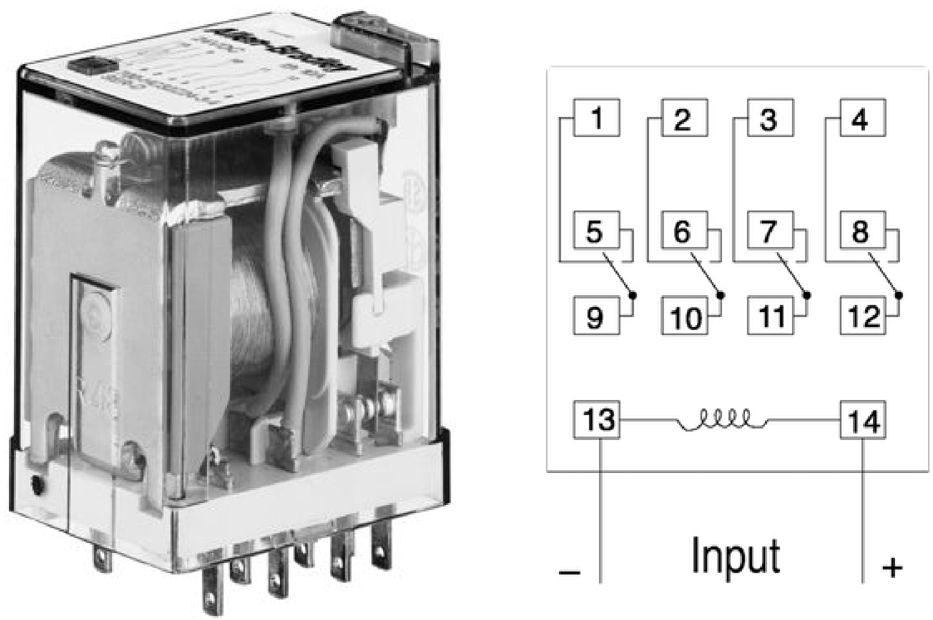


Figure 7.12: Ice Cube Relay

Set/Reset coils permit the PLC to "remember" a condition until another condition occurs. For example, consider a manufacturing operation where a robot places a part into a device, a series of machining operations occur, and then another robot removes the part. If a coil is set when the first robot places the part and reset when the second robot removes it, the coil effectively "remembers" that a part is in the machine.

Internally, the Set instruction turns ON the associated Bit Memory when the status of the rung is TRUE, and the Reset instruction turns the associated Bit Memory OFF when the status of the rung is TRUE.

Procedure

In this section, you will use a coil instruction to implement a latch circuit similar to a Low Voltage Protection Motor controller as shown in Figure 7.13. This circuit uses the green, normally open switch as a start switch, and the red, normally-closed button as the off switch to control the condition of coil C1. Then you will create a similar circuit using a Set/Reset coil.

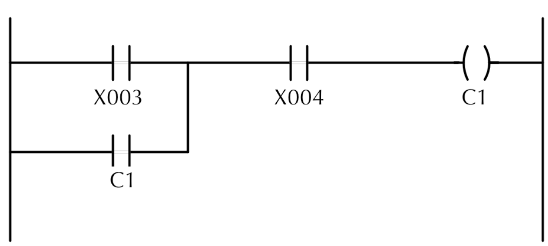


Figure 7.13: Latch Circuit

☐ 12. Modify your project to build the program shown in Figure 7.13. Give the coil the Bit Memory Address C1.

You can delete unneeded rungs by right-clicking the row, and the unneeded components can be removed with the delete key.

To create the latch circuit you need to create a parallel path around the start button. To make it, select the X004 contact, hold the Control Key down, then use the arrow keys to draw the parallel path around X003. If you make a mistake, hold the Control and Shift keys down and use the arrow keys to erase the paths.

Once the parallel path is created, add a normally open contact with bit memory address C1 to associate this contact with the C1 coil you created. Don't forget to add an END statement at the end of the program.

☐ 13. Since coil C1 can have unlimited contacts, use two more contacts to control indicator lights. Add the following to the ladder diagram.

- In branch 2, add a normally open contact C1 controlling an Out Coil with address Y002.
- In branch 4, add a normally closed contact C1 controlling an Out Coil with address Y004.

☐ 14. Load the program into the PLC and test it out by observing the contact and coil statuses on the ladder diagram.

Is contact X004 closed when its button is unpressed? ☐ Yes ☐ No

Why?

Does pressing the start button energize C1 and light the green light? ☐ Yes ☐ No

Does pressing the stop button de-energize C1 and light the red light? ☐ Yes ☐ No

Does the circuit work as expected? ☐ Yes ☐ No

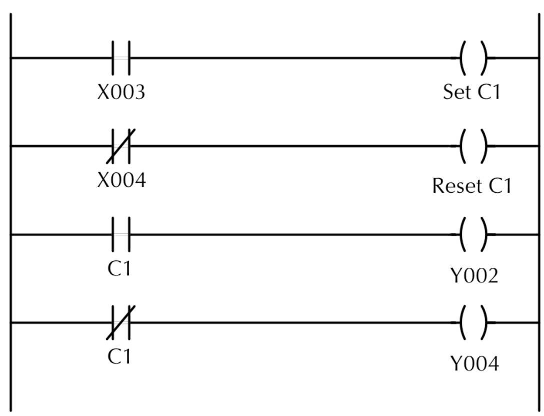


Figure 7.14: Set and Reset Coils

☐ 15. To make your program easier to understand it's possible to assign meaningful "Nicknames" to coils and relays. Select *Program>Address Picker*, and assign the nicknames listed in Table 7.2.

While assigning nicknames, you may find it easier if you only display the addresses that you are currently using by selecting the *Display only used* button at the bottom of the Address Picker.

☐ 16. Show your working circuit to your instructor and describe in your own words how this circuit works.

Table 7.2: Nicknames

Address	Nickname
X003	Start
X004	Stop
Y002	On
Y004	Off
C1	Relay

Now, you will modify your circuit to make a similar control using Set/Reset logic.

☐ 17. Build the ladder circuit shown in Figure 7.14 and test it out.

Does this circuit function the same as the latch circuit you previously built?

☐ Yes ☐ No

☐ 18. What happens if the run button is pushed while the stop button is held down, or vice-versa?

____

How does this behavior relate to the PLCs scanning sequence?

____

☐ 19. Redesign the logic so that the start and stop buttons do nothing at all while the opposite button is held down.

Analog I/O

Although digital input and output are sufficient to solve many interesting problems using PLCs, in other cases we need to deal with continuously variable values, rather than just an ON or an OFF state. For example, consider a steam heater: the position of a steam throttling valve may need to be set at positions between fully closed and fully open based on the temperature of the fluid leaving the heater. Both the valve position and the fluid temperature are analog values.

For cases like this, PLCs can also manage analog input and output. These analog values can be represented by integers or by floating point numbers. Analog values are typically limited to a certain range based on the method of storage used to hold the value in the PLCs memory. For example in the Click PLC, single word integer values are limited to the range –32768 to 32767, and floating point numbers, which can have fractional values are limited to the range $-3.4028235 \times 10^{38}$ to $+3.4028235 \times 10^{38}$.

The Click PLC trainer we are using has two Analog Inputs: AD1, which is wired to the potentiometer knob, and AD2 which is unused. The AD indicates that this is an analog to digital connection, hence an input. It also has two Analog Outputs: DA1, which is connected to the voltmeter, and DA2 which is unused.

The Analog Inputs and Outputs are scaled and possibly range limited as needed before they are stored in the PLC memory. The scaling and memory storage setup is done using the menu command *Setup > CPU built-in I/O Setup…* .

Procedure

☐ 20. Open the *Setup > CPU Built-in I/O Setup* menu click on the Input tab.

What is the scaling factor and storage location for input AD1?

What storage location holds the scaled input value? __________

Is this an integer or a floating point value, and how do you know?

Table 7.3: Scaling Factor for AD1

	Input Range	Scaled Range
Max		
Min		

☐ 21. Now click on the Output tab.

What is the scaling factor and storage location for output DA1?

Table 7.4: Scaling Factor for DA1

	Input Range	Scaled Range
Max		
Min		

What storage location holds the unscaled output value? ____________

☐ 22. As a simple example of the Analog I/O capabilities set up the PLC so that the analog input is displayed on the meter. To do this, the PLC must be given a command to copy the value stored in the input register DF1 to the output register DF3.

Add a new rung to your program and choose the "Copy: command from the Instructions List. The Copy Type should be "Single Copy." Enter the input storage location as the Source, and the output storage location as the Destination.

☐ 23. Load and test the program. Each time the PLC scans the program it will copy the current value from the input knob to the output meter.

Is the analog I/O working as expected? ☐ Yes ☐ No

☐ 24. Try to modify the program so that the meter display is reversed, that is, the meter should read 5 VDC when the knob is fully counter-clockwise and zero when the knob is fully clockwise.

Is this possible by changing the input or output scaling ☐ Yes ☐ No

Math Functions

The Math instruction serves as a powerful calculator to perform mathematical operations during the execution of the Ladder Program. The formula pad of the Math instruction dialog is used to develop the mathematical expression that will be solved during the CPU scan.

The mathematical expression can be developed using the onscreen keypad, the keyboard, and Address Picker, combining constants and stored variable values, as necessary for the application.

When working with decimal data values, the available operators include: standard arithmetic and algebraic operators, parentheses for grouping terms, transcendental functions and operators.

When using Hexadecimal data values a different set of operators is available. The logical operators AND, OR, and XOR are available only for Hex math. The bit operations Shift Left and Shift Right (LSH and RSH) and Roll Left and Roll Right (LRO and RRO) are also available only for Hex math.

Parenthetical expressions can be nested up to eight levels deep. If the Floating Point Data Type is employed in any operation, then all operations will be based on Floating Point math. The Result will be stored in the data format selected for the Result.

Procedure

As an example you will now use a math function to reverse the analog meter.

☐ 25. Click on the next available rung of the Ladder and double click on Math in the instruction list. Set the Result storage location to DF5, which is an unused floating point register.

☐ 26. Set up a formula which will make DF5 = 0 when DF1 = 100 and make DF5 = 100 when DF1 is zero.

Write your formula here.

☐ 27. Change the Copy command to copy DF5 to the meter instead of DF1.

☐ 28. Load and test your program.

Does it work as expected? ☐ Yes ☐ No

Challenge

For this challenge exercise use math functions or compare contacts to light up one, two, three, or all four lights in response to the analog input.

Specifications:

- The analog meter should indicate the position of the knob.
- The range of input values is 0.0 to 5.0
- The number of lamps turned on should be equal to the integer portion of the value displayed on the meter, for example:
  - If the meter reads 0.6, no lamps should be on.
  - If the meter reads 3.4, three lamps should be on.

Timers

PLC timers are output instructions that perform the same function as traditional mechanical or electronic time delay relays. They provide an instruction which waits before doing something. On the Click PLC, the waiting period is adjustable to any value between 1 ms and 32767 days (which is about 90 years).

There are two varieties of timer function available:

- **On-Delay** This type of timer "delays turning on". After triggering the timer, there will be an adjustable delay before the output of the timer is activated. The timer turns off when the input turns off. This is the most common timer and is sometimes called TON. See the timing diagram shown in Figure 7.15.

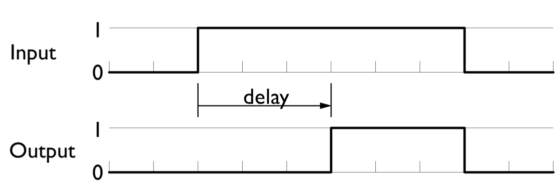


Figure 7.15: Off Delay Timer

- **Off-Delay** This type of timer is the opposite; it "delays turning off". When the timer is triggered, the output is turned ON. When the trigger signal goes away, the output is held ON for an adjustable period before it is turned OFF. This timer is sometimes called TOF. See the timing diagram shown in Figure 7.16

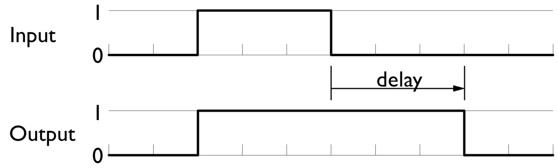


Figure 7.16: Off Delay Timer

Procedure

☐ 29. Start by building a two line program where:

- input switch X001 triggers Timer T1, an On Delay timer with a 1 sec set point and
- input switch X002 triggers Timer T2, an Off Delay timer with a 1 sec set point.

☐ 30. Add two more rungs to the program: Rung 3 where N.O. contact T1 controls Lamp Y001, and Rung 4 where N.O. contact T2 controls Lamp Y002.

☐ 31. Load and run your program. Try turning on and off both switches at the same time.

Do the lamps follow the timing diagrams shown in Figure 7.15 and Figure 7.16?

☐ Yes ☐ No

☐ 32. Add a N.C. contact T1 in Rung 1 Column B, and a N.C. contact T2 in Rung 2 Column B. Your program should look as shown in Figure 7.17

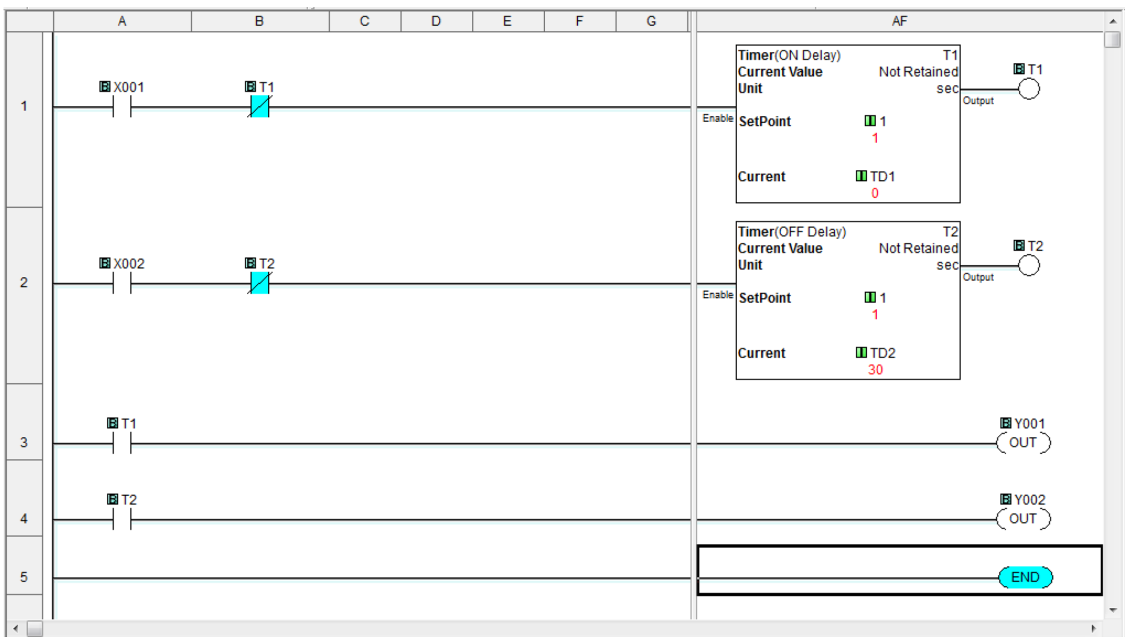


Figure 7.17: On and Off Delay Timers

What do you predict will be the behavior of the lights when the PLC is running?

☐ 33. Load and run the program. Was your prediction correct? ☐ Yes ☐ No

Explain the observed behavior of the lights.

____

____

☐ 34. A simple way to implement a blinker is to use one of the system clocks available using addresses SC3 to SC9. Each of these clocks has a different frequency; see the system help file under *Help>Help Topics* menu, then see *Reference > System Control Relays*.

Use a system control relay to make lamp Y003 flash every 500 ms.

Challenge

Build a blinking light program, where the duration of the on and off periods are the same, and the blink duration is adjustable between 10 ms and 3 sec using the knob.

When you have finished, show your working program to the instructor, and draw the ladder logic you used below.

Counters

Unsurprisingly, PLC Counters count things. Counters have three inputs: Up, Down, and Reset, where Up increments the count, Down decrements the count, and Reset sets the count back to zero. The counter also has a Set Point, and when the count reaches the set point the output of the counter is turned ON.

In the Click PLC counters are designated by addresses beginning with CT, so for example you might call your first counter CT1. The accumulated count value is held in the corresponding address CTD1. When the count in CTD1 reaches the set point, CT1 is set to true.

To use a counter, you must know 3 things:

- Where the pulses that we want to count are coming from? Typically this is from one of the inputs, or a clock.
- How many pulses before we react? This is the set point. It can be a constant defined when you make the counter, or it can be an integer value stored in the PLC memory.
- When we will reset the counter to start over? After we count 5 widgets lets reset the counter, for example.

Procedure

☐ 35. Start a new program and on the first rung add a Up/Down counter. Call the counter CT1 and make the Set Point 10.

☐ 36. Connect X001 to the Up input, X002 to the Down Input, and X003 to the Reset input. You will need to add lines using Ctrl-Arrow for the Down and Reset inputs.

☐ 37. Load, run, and test your program.

Does Input one increment CTD1 each time it is switched on? ☐ Yes ☐ No

Does Input two decrement CTD1 each time it is switched on? ☐ Yes ☐ No

Does Input three reset CTD1 back to zero? ☐ Yes ☐ No

Does coil CT1 go on when the Set Point is reached? ☐ Yes ☐ No

Can the count in CTD1 go above the Set Point? ☐ Yes ☐ No

Can the count in CTD1 go below zero? ☐ Yes ☐ No

☐ 38. Replace N.O. contact X003 with CT1. What does this do?

____

☐ 39. Modify your program to prevent the count from ever going negative.

Challenge Projects

Now that you have see the basic capabilities of the Click PLC, put your understanding to use by completing the following Challenge Projects.

Garage Door

A garage door for your machine shop has a reversible motor, upper and lower limit switches, and a door obstructed switch.

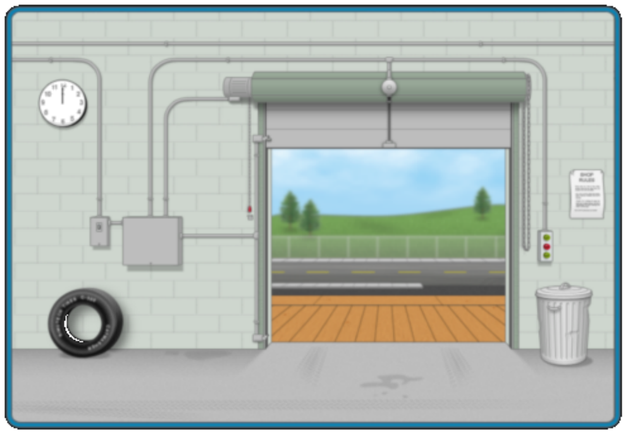


Figure 7.18: Garage Door

Specifications

Input/Output

Input	Meaning	Output	Meaning
Input 1	Up/Down	**Blue Light**	Door Open
Input 2	Obstruction	**Yellow Light**	Door Closed
Input 3	Open/Close/Revers Button	**Green Light**	Door Moving
Input 4	Stop	**Red Light**	Door Stopped
		Analog Output	Door Position

Basic Operation

- Use Red and Green buttons for Start/Stop Control.
- Use Input 1 to set the motor direction Up/Down.
- Use Red and Green lights to indicate Motor Running/Stopped.
- Use Blue and Yellow Lights to indicate door fully open or closed.
- Use the analog indicator to represent the door's position.
  Down = 0, Up = 5.
- When the door reaches its limit, the motor stops and the appropriate light turns on.
- The door should take 10 seconds to go from closed to open, or vice-versa.

Single Button Control

Change the functionality of the red and green buttons such that:

- If the door is fully closed, pushing the Green button makes it start opening.

- If the door is fully opened, pushing the Green button makes it start closing.
- If the door is partially open, pushing the Green button makes start opening.
- If the door is moving, pressing the Red button makes it reverse direction.

Obstruction Switch

Add obstruction switch functionality:

- If the door is closing and the Obstruction switch is triggered, the door reverses and opens.
- If the motor is stopped, or raising, triggering the Obstruction switch does nothing.

When you have a working program, draw the ladder diagram here.

Parking Lot Gate System

A parking lot can accommodate up to 6 cars. Your job is to design and program the PLC control of the entrance and exit gates. The lot is equipped with vehicle sensors on the entrance and the exits, and 4 indicator lights

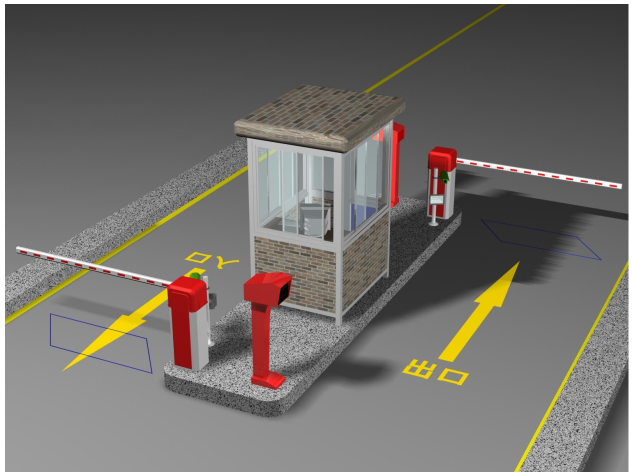


Figure 7.19: Parking Lot Gates

Specifications

Design and build a PLC program to meet the following specifications:

Input/Output

Input	Meaning	Output	Meaning
Input 1	Entrance Sensor	**Blue Light**	Entrance Gate Open
Input 2	Exit Sensor	**Yellow Light**	Exit Gate Open
Input 3	Payment Button	**Red Light**	Lot Full
Input 4	Reset Button	**Green Light**	Space available

Lot Full Lights

- Use a counter to keep track of the number of cars in the lot.
- Use a data register to store the lot capacity, C_{max}.
- Provide a reset switch to initialize the lot count to zero.
- The counter should never register vehicle counts above C_{max} or below zero.
- Increment the lot count when a car drives off the entrance sensor.
- Decrement the lot count when a car drives off the exit sensor.
- When the lot is full, the green light should be off and the red light on.
- When the lot has room for another car, the green light should be on and the red light off.

Gate Control

- If the lot is full when a car triggers the input sensor, flash the red light until the car backs up off the input sensor. Don't add this car to the lot count.
- When a car triggers the input sensor, if there is room in the lot, enable the payment button.
- When the payment button is enabled, flash the green light.

- When the payment button is pressed, open the entrance gate.
- When a car triggers the exit sensor, open the exit gate, indicated by the blue lamp.
- Close the exit gate 5 seconds after the vehicle clears the exit sensor sensor.

When you have a working program, draw the ladder diagram here.