HVACR Troubleshooting Fundamentals

Electricity and Wiring Diagrams

Jim Johnson

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HVACR Troubleshooting Fundamentals:
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Foreword

A Note From The Author…

During my tenure as a trade school instructor, one of the modules I had the opportunity to facilitate was Electrical Fundamentals, in which the students were brand new. Our daily schedule was from 7:30 AM to 4 PM, and during morning classroom sessions we followed the 50-minute military format, taking a ten-minute break every hour.

As we began our break time on the first day of class, I said:

"During the time we've been here in class this morning, someone in our city has bought an electrical part that they don't need, either due to technician error, dishonesty, or a combination of those two things."

It was a bold statement. And the reaction from my students was always surprise. However, as any experienced instructor knows, at that point in a student's study of HVACR, with that deer-in-the-headlights look still fresh, and the aspect of the-authority-at-the-front-of-the-room brand new, it wasn't likely that I would experience any blow-back from anything I said, even if somebody thought it was outrageous.

However, after a few days of working together with the group eight hours a day in our 50/50 classroom and lab session schedule, someone would inevitably work up the courage to ask about what I had said when we took our first classroom break. And, discussing some of the situations I had experienced in the field carried some weight on the subject. But, when one of our graduates, some of whom had only been working for a few months, came back for a visit and offered their input, it was much more convincing.

When asked about the idea of electrical troubleshooting mistakes being made between 7:30 and 8:20 in the morning, some said that they too had doubts about what they heard on their first day in class. However, they discovered that due to a lack of understanding of electrical concepts and the inability to correctly interpret wiring diagrams on the part of some of those who showed up to service equipment, their customers would indeed often wind up paying for parts they didn't need.

Some of them also expressed doubt that it took that much time into the day for mistakes to occur.

Jim Johnson

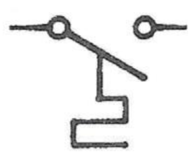
Preface

The philosophy of this book is that a firm understanding of the fundamentals of electricity and the ability to translate the 'language' of wiring diagrams that employ symbols, are the foundation for developing the skills necessary to accomplish a proper diagnosis when troubleshooting electrical failures in HVACR equipment.

The HVACR service industry doesn't need parts changers. What the craft needs are technical professionals who are confident in their ability to use wiring diagrams and test instruments to isolate the source of an electrical problem, then replace what needs to be replaced…..and only what needs to be replaced…..in order to get a customer's equipment back on line in a timely manner and at a fair price.

Interpreting and understanding wiring diagrams is a process of learning a second language. Someone who is fluent in both English and Spanish can immediately recognize that the term "perro" in Spanish translates directly to "dog" in English. And they also understand that the translation can be more specific, such as "la perra" translating to "female dog". The reason a bilingual person can make this distinction is that they pursued the study of language beyond the very basic elements of the process, investing the time and effort necessary to understand it at a higher level. In the case of the above example, it involves learning about the refined methods of presenting the differences between masculine and feminine in language.

And so it goes with wiring diagrams. A schematic symbol such as this….



….could be referred to simply as a switch because that is fundamentally what it is.

However, a more specific definition of this symbol would be a close-on-temperature-rise switch, a thermostat; a thermostat that, when closed due to its sensing a rise in temperature, initiates the cooling cycle of HVACR equipment.

A competent and confident HVACR electrical troubleshooter has a complete understanding of wiring diagrams. And they are dedicated to putting that knowledge to use in an ever-changing craft in which the learning continues throughout their career.

ACKNOWLEDGEMENTS

When I wrote my first textbook, there were many people to thank, and one segment of the dedication read "…to my wife Peggy Lee, who has been with me through all the ups and downs and twists and turns of my personal and professional life for 25 years…" and, here is the dedication for this book….

Dedication:

To my wife Peggy Lee, who has been with me through all of the ups and downs and twists and turns of my personal and professional life for 50 years.

Thanks To:

Renee Tomlinson and Marlena Stavropoulos for their help in developing this updated version of the original text; Simpson Electric, Fluke Corporation, and Fieldpiece instruments for images from their user manuals; RSES Journal, Indoor Comfort News and ACHR News readers who have helped in contributing to the development of troubleshooting problems; and to the students in my trade school classes and technicians who have attended my workshops and were not afraid to ask questions.

HVACR Troubleshooting Fundamentals
Electricity and Wiring Diagrams

LIST OF ILLUSTRATIONS

UNIT 1

Generating Electricity & Electron Flow

Figure 1-1 Coal is chemical energy, which when burned becomes heat energy, which generates steam energy, which becomes mechanical shaft energy to turn the generator, which results in electrical energy.

Figure 1-2 High pressure steam contacting the blade of a turbine results in mechanical energy that spins the shaft connected to the generator.

Figure 1-3 A permanent magnet showing the lines of force and the north and south poles of a magnetic field.

Figure 1-4 An electromagnetic section of a generator. When magnetic lines of force are cut by a conductor, a current is induced in the conductor.

Figure 1-5 A conductor is positioned so that it cuts the lines of force in the magnetic field when the rotor of the generator spins.

Figure 1-6 This illustration shows an elementary atom. The neutron and proton combine to form the nucleus of the atom, around which the electron is in orbit. As with the principles of magnetism, a negative/positive concept applies in atomic theory, which is also referred to as electron theory.

Figure 1-7 This illustration shows a silver atom. Because of its atomic structure, five orbits of shells and a single outer shell electron, silver is an excellent conductor of the electrical energy.

Figure 1-8 In the case of a good conductor of electricity, the single valence electron of a material is easily knocked out of its orbit by the effect of a source of energy, such as magnetism.

Figure 1-9 A copper atom. Copper is a good conductor of electricity but not as efficient as silver. Because of its atomic structure, containing only four orbits of atoms, it has less energy than silver.

Figure 1-10 The atomic structure of an insulating material differs from that of a conductive material. While conductor atoms have only one valence electron that is easily knocked out of orbit, the atom of an insulator has up to 8 valence electrons.

Figure 1-11 Conductors, semiconductors, and insulators differ in their atomic structure. A conductor atom (a) has only one valence electron, a semiconductor atom, (b) will have up to 4 valence electrons, and an insulator atom, (c) contains up to 8 valence electrons.

Figure 1-12 The atomic structure of a material dictates whether it will be a good conductor of electrical energy, or if it will be an effective insulator.

UNIT
2

Alternating Current, Direct Current And Electrical Power

Figure 2-1 As illustrated by the AC sine wave in this illustration, alternating current is generated at 60 cycles per second in the United States. In Canada, in Europe, and in other countries, the energy in alternating current will reach a positive and negative peak value 50 times per second, which means electricity is generated at 50 cycles.

Figure 2-2 A DC circuit showing a voltage, also known as potential difference, of 12 volts. The light bulb has a resistance of 6 Ohms. Using the proper Ohm's Law formula allows the calculation of the current draw (amperage) in the circuit.

Figure 2-3 When using an Ohm's Law memory wheel such as the one shown here, cover what you want to know, and the formula you need to use for the calculation will be explained.

Figure 2-4 The electric furnace heating element in this example has a resistance of 12 ohms, and the applied voltage is 240 VAC. Using Ohm's Law to calculate the current draw of the element is the first step in determining what the cost of operating the element will be.

Figure 2-5 One way to consider voltage as pressure in an electrical circuit is to compare two water tanks that, although they have the same diameter flow pipe, the difference in elevation causes one tank to be able to deliver flow at a higher pressure.

UNIT 3

Electrical Distribution Systems

Single-Phase & Three-Phase Power

Figure 3-1 Electrical energy is generated at a high voltage level. This voltage is then stepped up higher in order to transport it along high voltage transmission lines, which are conductors that are not insulated. The voltage is then stepped down by a substation for distribution to buildings.

Figure 3-2 An example of electromagnetism in which the conductor remains stationary and the magnets are connected to the spinning shaft assembly.

Figure 3-3 Current flowing through a conductor results in an electromagnetic field around the conductor.

Figure 3-4 In a step-up transformer, voltage is applied to the primary windings. The electromagnetic field from the primary travels around the iron core, and when the larger secondary windings pick up the electromagnetic field, the result is a higher output of voltage.

Figure 3-5 In a step-down transformer, when voltage is applied to the primary windings that have more turns than the secondary windings, the result is a lower voltage output.

Figure 3-6 The step-down transformer, in addition to being a segment of an electrical generating system, is an integral component within HVACR equipment. Note the sine wave, the symbol for alternating current generation, indicating voltage applied to the primary windings. The symbol on the secondary windings indicates voltage output.

Figure 3-7 This illustration shows the typical layout of the components within a distribution panel in a single-phase residential application. Since there are two power (HOT) wires, it is referred to as a single-phase power supply.

Figure 3-8 Note the horizontal assemblies shown fastened to the buss bars in the open space below the breakers. These attachments to the main buss bars in a distribution panel allow breakers to be clipped into place. The two types of breakers found in residential distribution panels are referred to as single-pole and double-pole breakers.

Figure 3-9 Single-pole breakers are wired to a 120 VAC (Volts Alternating Current) circuit and two-pole breakers are wired to a 240 VAC circuit. The "hot" legs of the wiring are designated as L1 (L= Line) and L2. The designation "N" refers to the neutral wiring in the panel.

Figure 3-10 A 120-volt receptacle that may be found in a gas furnace installation.

Figure 3-11 In a situation in which a gas furnace is connected to the circuit via a standard power cord and the system uses a duplex receptacle, a load test can be conducted by operating the furnace and simultaneously checking with a voltmeter.

Figure 3-12 To check for voltage drop in a single receptacle, a temporary adapter that allows the furnace power cord to be connected to the circuit and also allows for checking with a voltmeter can be employed to accomplish the test.

Figure 3-13 When checking with a voltmeter between the hot and the ground terminals of a receptacle that is wired for proper polarity and ground, the reading will be 120 VAC.

Figure 3-14 When checking with a voltmeter between the neutral and the ground terminals of a properly wired receptacle, your voltmeter should read 0 volts.

Figure 3-15 In the case of a 240-volt, single-phase condensing unit of a split system, a two-pole breaker in the distribution panel is wired to an outdoor fused disconnect.

Figure 3-16 One style of fused disconnect used in HVACR installations is designed with a pull-out fuse holder.

Figure 3-17 Testing for excessive voltage drop in a 240-volt circuit involves more than the procedure for 120-volt circuits, beginning with checking at the L1 and L2 (Line 1 and Line 2) connections as the wiring enters the fused disconnect, and on to the T1 and T2 (Terminal 1 and Terminal 2) connections on a component within the HVACR equipment known as a contactor.

Figure 3-18 With the main breaker in the on position and the HVACR equipment operating, checking for proper voltage begins with establishing a baseline voltage at the wiring connections where the power is delivered into the distribution panel.

Figure 3-19 This illustration shows the two-pole breaker that is wired to the HVACR equipment. Checking with a voltmeter at these test points will show the output voltage from the panel.

Figure 3-20 When checking for voltage drop across the closed contacts of a contactor, place one lead of the voltmeter on an L terminal and the other lead on a T terminal. The meter will show a difference in potential across the terminals, which will be the amount of voltage drop.

Figure 3-21 In the fundamental construction of a single-phase generator, a single winding and a magnetic field are employed.

Figure 3-22 In the fundamental construction of a three-phase generator, three windings and a magnetic field are employed.

Figure 3-23 The schematic symbol diagram for a Delta transformer system is shown at the left and the pictorial diagram is at the right.

Figure 3-24 A schematic symbol diagram and a pictorial illustration of a Wye transformer system.

Figure 3-25 A typical electrical distribution panel that can accommodate a three-pole breaker for three phase HVACR equipment.

UNIT
4

Electrical Supply Circuit Protection

Fuses & Circuit Breakers

Figure 4-1 Our magnifying glass shows that the alloy element of the fuse is unaffected by the normal operation of the room air conditioning unit. Note that the fuse is shown in the hot leg of the power supply to the receptacle. It is common to refer to the element in a fuse as a fuse link or fusible link.

Figure 4-2 A short circuit in the power cord is causing a circuit overload and the fuse link senses the over-temperature situation.

Figure 4-3 A broken fuse link shuts the equipment down.

Figure 4-4 The types of fuses shown here are (a) Edison Base (also referred to as a screw type or plug type fuse), (b) Type S Plug fuse, (c) Type S Adapter, (d) Dual-element Plug fuse, (e) Ferrule Type Cartridge fuse, and (f) Knife-Blade Cartridge fuse.

Figure 4-5 Circuit protection requirements are clearly marked on manufacturer equipment tags.

Figure 4-6 In some installations a circuit breaker inside the building is the only protection in the equipment circuit.

Figure 4-7 A fusible link may be positioned within the fuse, so an air barrier allows it to fail safely. In some fuses, an arc-quenching material, such as silica sand, may surround the link to prevent arcing when the fuse blows.

Figure 4-8 A three-phase fused disconnect switch. In order to ensure proper equipment operation, all wiring connections must be tight and the clips that hold the fuses must be in good condition. When removing fuses from a disconnect box the proper method is to use a fuse puller rather than using a screwdriver to pry them loose.

Figure 4-9 A 240-volt, single-phase, disconnect with a pullout assembly that contains two fuses. The fuse assembly is removed by gripping the handle in the center and pulling straight out. The safety shield in the lower segment of the assembly can be removed while leaving the fuse pull-out in place.

Figure 4-10 In a typical 240-volt, single-phase fused disconnect assembly, the wiring from the circuit breaker in the distribution panel is identified as Line 1 and Line 2 and the wiring connections to the equipment are identified as Load 1 and Load 2. Note that in addition to the hot wires in the box, there is a connection for ground.

Figure 4-11 Checking at the Line 1 and Line 2 connections in a disconnect assembly to confirm 240-volts from the circuit breaker in the distribution panel.

Figure 4-12 Checking at the Load 1 and Load 2 connections in a pull-out, fused disconnect assembly to confirm that the fuses are OK.

Figure 4-13 In a pull-out fused disconnect, the fuses are held in brass spring assemblies that allow a connection between Line 1/Load1 and Line2/Load2 when the fuse holder is in place.

Figure 4-14 Testing from one leg of the load side of the power supply to ground in a fused disconnect box with the fuses in place will show 120-volts if the fuse is OK. If a load to ground test shows 0-volts, the fuse is blown.

Figure 4-15 In a pull-out switch disconnect assembly, the handle is removed to kill the power to the equipment.

Figure 4-16 The knife blade assemblies that bridge between the Line and Load segments of the pull-out switch disconnect may be made of brass, or they may be copper coated aluminum.

Figure 4-17 This illustration shows the openings for the knife blade switch and a segment of the safety shield, which can be removed by pulling out on the plastic tab once the switch assembly is pulled out.

Figure 4-18 In a pull-out switch type of disconnect, removing the switch allows for a quick check to find out if power is applied to the assembly.

Figure 4-19 With the safety shield removed from a 240-volt, single-phase pull-out switch disconnect box, the wiring connections are exposed. The Line connections are located in the upper segment of the box, connected directly to one segment of the spring clips that hold the pull-out switch. The Load connections are in the lower segment, connected to fuse spring clips.

Figure 4-20 Fuses installed in a pull-out switch disconnect.

Figure 4-21 With the fuses in place, the safety shield removed, and the pull-out switch inserted, testing to check if the fuses are responsible for equipment sitting dead can be accomplished.

Figure 4-22 Testing from the left Load terminal in a pull-out switch disconnect assembly to the ground terminal will prove whether the fuse is blown, or if it is OK.

Figure 4-23 Testing from the right Load terminal in a pull-out switch disconnect assembly to the ground terminal will prove whether the fuse is blown, or if it is OK.

Figure 4-24 Installing an improper fuse can create a dangerous situation.

Figure 4-25 Due to improper fusing an overcurrent situation caused overheating and damage to this pull-out switch disconnect box.

Figure 4-26 In this pull-out switch assembly, the Line connections are shown in the center of the connector and Load connections are at the left and right. Note also the ground connecting plug.

Figure 4-27 A two-pole breaker is used to provide a 240-volt, single phase power supply to HVACR equipment. The switch in this example is shown in the ON position and the distribution panel cover has been removed to show the wiring connections.

UNIT 5

Proper Use of Test Instruments

Figure 5-1 An analog meter operates on the principle of a pointer (often referred to as a needle) moving and indicating a specific measurement. *Image courtesy of Simpson Electric.*

Figure 5-2 An analog meter set to the R x 1 scale and ready to measure resistance on a low scale. Connecting the meter leads to the COM and V/Ω ports shown at the bottom right of the meter case will allow a component test for resistance. The top row of numbers represents the ohms scale. Also note the ohms adjustment knob (ΩADJ) shown at the left of the meter control section.

Figure 5-3 With the black lead connected to the COM port and the red lead connected to the VΩ port, the pointer on the ohms scale is showing that the component under test has a resistance of approximately 1 ohm.

Figure 5-4 When testing a switch for continuity (fundamentally no resistance) an analog meter can be set for a more sensitive scale. The finest scale of measurement is commonly the R x 10K scale. This scale is also an effective test of battery life. If the pointer won't adjust to 0 when the meter is set to a resistance scale, it's likely that the battery needs to be replaced.

Figure 5-5 The ohms adjustment knob has been used to set the pointer to 0 ohms. The meter is now ready to test between the terminals of a closed switch to determine whether the switch assembly has continuity.

Figure 5-6 A digital multi-meter set to measure resistance and continuity.

Figure 5-7 When the ohms setting is selected on this meter, other functions are available at the same dial setting when the SELECT button of the meter on the meter is used to toggle.

Figure 5-8 While experienced technicians have an overall understanding of the proper use of test instruments, there is always a learning curve when using a particular model of meter for the first time. This particular model of meter, in addition to accomplishing electrical and temperature measurements, is capable of wireless communication to allow data transfer to other specific devices.

Figure 5-9 Manufacturer's instruction manuals provide written instructions and illustrations to explain the specific operation of a particular model of test device. This image shows that one way to consider resistance and continuity tests of a load is that setting the dial at a setting that will allow accurate measurement of a load that has relatively high resistance. Choosing the continuity test setting will also determine whether the load has failed open. *Image courtesy of Fieldpiece Instruments*

Figure 5-10 This illustration from a downloaded manual for a Fluke 16 multi-meter shows resistance and continuity testing procedures.

Figure 5-11 The fundamental difference between potential voltage and applied voltage must be understood when troubleshooting electrical problems in a circuit. Potential voltage is available at the power source to equipment. Applied voltage refers to work being done because energy is applied to a component that is doing the work.

Figure 5-12 With the selector knob set to the correct position and using the SELECT button to toggle between the specific voltage settings available on this particular model of test instrument, tests can be accomplished on hot circuits. Note the screen on the left showing the sine wave, the symbol for alternating current. On the right screen, the solid line with the dashed line below is the symbol for direct current.

Figure 5-13 When a meter employs a selection of range settings for voltage, the technician needs to understand how to properly set the device in order to get accurate information. *Image courtesy of Fieldpiece Instruments.*

Figure 5-14 In this example, the selector is set to a DC voltage setting and the chosen range is 50 volts. *Image courtesy of Fieldpiece Instruments.*

Figure 5-15 When a digital meter reads AC voltage in what is commonly referred to as a 120-volt circuit, the accuracy of the device goes beyond the standard and measures the voltage precisely.

Figure 5-16 A digital meter reading micro-amps to determine if an ignition system is operating properly. Note the solid and dashed line in the upper right-hand corner of the meter display, indicating direct current.

Figure 5-17 This meter is set to a micro-amp selection in order to measure the current draw in the circuit. *Image courtesy of Fieldpiece Instruments*

Figure 5-18 In some troubleshooting situations, manufacturers may require testing of a segment of a control circuit that involves checking the amperage in alternating current. As this illustration shows, the device is set to the 200-milliamp scale in order to accomplish a current draw check. *Image courtesy of Fieldpiece Instruments*

Figure 5-19 A spring loaded clamp that is positioned around the wire in a standard 240 or 120-volt AC circuit allows a technician to read the amperage draw of the circuit, or isolate and check the amperage draw of a component within the equipment. *Image courtesy of Fieldpiece Instruments*

Figure 5-20 When an amp clamp is placed properly, the wire is in the center of the clamp, allowing the device to provide an accurate reading of the current draw through the wire.

Figure 5-21 Some digital test instruments allow a measurement of amperage with the connection of an amp clamp as an accessory. Always consult the manufacturer's user manual for specific instructions on how to attach accessories and choose the proper meter settings in order to obtain accurate information.

Figure 5-22 When some devices are set specifically to check a capacitor, the display screen will show the identifier μF for the procedure.

Figure 5-23 A meter set to check capacitance. Note that the selector knob is set to 20 MFD and the red lead has been removed from the VΩ port in order to be inserted into the MFD port.

Figure 5-24 A meter set to check a diode. The correct setting on the ohms scale of the device has been selected and the probes are used to check the diode. Note the electrical symbol for the diode on both the face of the meter and the instruction from the manufacturer's user manual. *Image courtesy of Fieldpiece Instruments*

Figure 5-25 Some models of digital multi-meters can also be used to check temperature. In this illustration a Type K thermocouple is attached to the meter, and the device is showing 82.9° F.

Figure 5-26 When using a clamp type accessory and a digital meter to measure tubing temperature, the surface of the tube should be clean to allow for an accurate measurement.

Figure 5-27 Alligator clips can be used to ensure good connections during electrical testing.

Figure 5-28 This illustration shows the difference in size between standard lead tips and extended lead tips that allow for testing wire harness connectors (often referred to as Molex connectors) without disconnecting the wiring. Extended leads are often coated with carbon or other materials up to their sensing tip in order to prevent damage to electronic control systems during certain diagnostic testing procedures.

Figure 5-29 This illustration shows one manufacturer's method of accessing the battery compartment located on the back side of a digital meter.

Figure 5-30 The chemical make-up of a battery will cause it to corrode over time. When the test device containing this battery was inspected after a long storage time frame exposed to extreme elements, there was significant damage to the electronic components of the meter.

Figure 5-31 Disassembly of the case of a digital meter exposes the operating components of the device. Always handle carefully and avoid touching the printed circuit board components of the meter. Note the location of two fuses in this particular example shown on the two sides of the case near the bottom.

UNIT
6

Wiring Diagrams
&
HVACR
System Components

Figure 6-1 A schematic symbol for a step-down transformer used in HVACR electrical systems. The two voltage systems that exist in equipment are operating voltage and control voltage. The control voltage is 24 VAC and the operating voltage can be 120 VAC, 240 VAC or 480 VAC.

Figure 6-2 The fundamental dual voltage schematic diagram is built on the symbol of the transformer. With lines added to the symbol from both windings, other symbols representing loads and switches can be shown in the appropriate location on the diagram with the connecting lines drawn from these component symbols to the extended lines on the transformer symbol.

Figure 6-3 A step-down transformer with a 120 VAC primary (indicated by the black and white wire color code) and a 24 VAC secondary. In this example the manufacturer is using red and green to show the output wiring connections. The color green in this case is not an indication of a ground connection. Manufacturers use a variety of colors to indicate the 24-volt connections of a transformer.

Figure 6-4 In this example, the voltage input is identified as L1 and L2 (Line 1 and Line 2) and connected to PR1 and PR2 (Primary). The output voltage of 24 VAC is delivered from the SEC1 and SEC2 (Secondary) connections of the transformer.

Figure 6-5 In this example, a temporary wiring connection has been accomplished to the primary winding of a transformer. This particular transformer is designed for use in a situation in which the equipment voltage is 120 VAC, and the meter shows the proper voltage is being applied to the primary connections.

Figure 6-6 In order to either confirm or eliminate the transformer as the possible source for a “sitting dead” complaint, once a voltage test proves that the proper voltage is applied to the primary winding, a test of the secondary winding connections is accomplished to measure the output voltage.

Figure 6-7 With a meter set to the proper scale relative to Ohms, testing the primary winding of a transformer will provide an accurate measurement of resistance.

Figure 6-8 The resistance of the secondary winding of this transformer is 3.3 Ω.

Figure 6-9 The secondary winding of this transformer has failed. The meter display is showing "OL" which is an indicator of "Open Line".

Figure 6-10 A pictorial illustration of a transformer that shows the relationship between the primary and secondary winding of the transformer as being related only to the concept of an electromagnetic field set up by current flow through a winding.

Figure 6-11 An example of a schematic diagram that is built on the symbol of the transformer, and showing switches, loads, and the circuits of the equipment. Loads are identified by the letter "L". Switches are identified by the letter "S". Two other components shown here are capacitors, identified as "CAP". In our example, they are not strictly considered to be a load or a switch.

Figure 6-12 One example of a schematic diagram that uses abbreviations to identify the loads and switches in the equipment. An abbreviation that one manufacturer may use for a particular component will often not be the identical one used by a different manufacturer for the same component.

Figure 6-13 A contactor is a device used to control the operation of a compressor. The switching segment of the device is wired in series with the compressor motor. The coil is operated on control voltage.

Figure 6-14 One common method of controlling the operation of a compressor is to allow the equipment voltage to pass through the equipment voltage switching assembly when 24 volts is applied to the operating coil of the contactor, causing the switch contacts to close.

Figure 6-15 "L" on contactor connections stands for "Line". "T" on contactor connections stands for "Terminal". When a contactor is wired correctly, power input is at the Line connections. Power output is at the Terminal connections when the contactor coil is energized, closing the contact and spring assembly.

Figure 6-16 The resistance of this coil is approximately 12 Ohms, which is typical of this type of component. If the meter showed "OL" with this test, the coil would be open and the contactor would have to be replaced.

Figure 6-17 One example of diagram showing only one set of contacts while the component may actually have more than one switch, is a fan relay. In this example, the coil and one set of contacts in the relay are being used to control the indoor fan motor.

Figure 6-18 A typical relay that has been used for decades in the HVACR industry to control the operation of an indoor air handler motor, as well as other applications in equipment operation.

Figure 6-19 This relay has eight terminal connections. Two of the connections are for the operation of the coil while the other connecting terminals provide a connection to the switching circuits of the device. “COM” is an identifier for what is known as a common terminal on the device.

Figure 6-20 Upon closer inspection of a relay such as this found in HVACR equipment, technicians can find information about the coil operating voltage and manufacturer’s identifying numbers.

Figure 6-21 With the wiring disconnected from the terminals of the relay coil, the leads of an ohmmeter are attached as shown here to measure the resistance of the coil.

Figure 6-22 The result of our coil test in this case is 15.8 Ω resistance, which is typical for this type of relay coil if it is OK.

Figure 6-23 Checking N.O. terminals of a relay to determine that they are, in fact, open without voltage applied to the coil.

Figure 6-24 Testing at the N.O. terminals on a relay should show “Open Line” without control voltage applied to the relay coil.

Figure 6-25 If the N.O. relay contacts are in good condition, the meter will display a very low resistance when voltage is applied to the relay coil. In the event that the meter showed 1 Ohm resistance or more, it would indicate that the contacts are corroded, and would cause excessive voltage drop in the circuit.

Figure 6-26 Testing the N.C. contacts of a relay without control voltage applied to the coil should show a very low resistance on the meter display.

Figure 6-27 Tracing a circuit from source to source. Beginning at L1 on the diagram, then tracing through the load, and all the way through the circuit to L2, simplifies the concept of current flow in a circuit through a load.

Figure 6-28 Tracing both the equipment and control voltage circuits to understand the operation of a component that is only energized with equipment voltage when control voltage is applied to the coil of the device, causing the equipment segment of the device to close and allow a complete circuit to the operating component.

Figure 6-29 When this equipment is operating, all of the equipment voltage components are operating due to a call for cooling by the thermostat.

Figure 6-30 In this illustration, the crankcase heater and the transformer primary show applied voltage. All the other circuits involved in the sequence of operation of the equipment show potential voltage.

Figure 6-31 From a schematic standpoint, potential voltage can be read at SEC1 and SEC2, as well as at the power-in switch of thermostat assembly and at the direct wiring connections from SEC2 on both the indoor fan relay coil and contactor coil. However, from a practical standpoint, checking for potential voltage at the operating coils would be accomplished by checking at SEC1 and at the direct wire connections on the coils.

Figure 6-32 With the thermostat system switch, temperature switch, and fan switch in closed positions, the potential voltage is now applied to the indoor fan relay coil and contactor coil.

Figure 6-33 With no call for cooling from the thermostat, the two circuits on our schematic that would show applied voltage at test points A and B are the crankcase heater and primary of the transformer.

Figure 6-34 When there is a call for cooling from the thermostat and the indoor fan relay and contactor coils are energized, the contacts of the contactor and the switching contacts in the indoor fan relay are designed to close. This process allows voltage to be applied to the compressor, condenser fan motor and indoor fan motor.

Figure 6-35 A run capacitor is wired in a motor circuit in series with the start winding. Understanding this fact helps in identifying the windings of the motor in this example. This illustration shows the path of current flow from L1, through the start winding of the motor, and back to L2. When a motor of this type is fully operational, there will be current flow through both windings.

Figure 6-36 A pictorial diagram provides some insight on where some components in the equipment are located and how wiring connections are accomplished. Pictorial diagrams often show wiring harness color code. This example also shows that the manufacturer is using a number/letter method of identifying the components, information that would also appear on a legend accompanying the diagram.

Figure 6-37 A segment of a pictorial diagram that illustrates the operation of an electronic time delay relay. The transformer secondary is shown schematically, while the other components and the wiring harness are shown from a pictorial perspective.

Figure 6-38 This electronic time delay relay is one example of a Delay-On-Break device that may be used in a gas furnace system to delay the shut-down of the indoor air handler motor.

UNIT
7

HVACR Motors

Figure 7-1 A simplified illustration of an AC (Alternating Current) electric motor operating through one complete rotation. Note the S and N designations for South and North poles of the magnets. The permanent magnet known as the rotor is mounted in a bearing assembly at each end of the motor and rotates due to the push/pull of the magnetic fields.

Figure 7-2 The run windings of this motor are identified as the A windings and the start windings are the B windings. Also shown here is a fundamental fact regarding the difference between start and run windings in a motor; that the start winding will have more turns than the run winding.

Figure 7-3 An example of a PSC motor circuit. Understanding how to troubleshoot this these components begins with understanding what are, and are not, connecting points on the diagram.

Figure 7-4 Tracing a circuit from L1, on through the motor run winding to common, and then to L2 shows the flow of current through the run winding when the circuit is energized.

Figure 7-5 Tracing a circuit from L1, on through the run capacitor and motor start winding to common, and then back to L2, shows the flow of current when the start winding is energized.

Figure 7-6 In a motor that does not use a run capacitor to implement a PSC system, when the motor is running after the instant of start, the run winding electromagnetic field only accomplishes the movement of the rotor.

Figure 7-7 In a PSC operation, both the run and start windings provide a “bump” for the rotor, resulting in a more efficient operation of the motor.

Figure 7-8 In this schematic representation of a PSC circuit, the individual circuits for the run and the start winding can be traced from source to source.

Figure 7-9 A motor run capacitor is constructed of foil plates that allow for the storage of electricity up to a given level until it is discharged.

Figure 7-10 This run capacitor has a rating of 10 microfarads and has a voltage rating of 370 to 440 VAC. When repairing equipment with a failed run capacitor, the best rule to follow in the field is to use an exact replacement. In some situations, a manufacturer may indicate a + or – 10% listing on a capacitor label, or the listing may show + 10% and – 5%.

Figure 7-11 An example of a dual run capacitor that may be found in equipment that has been in service for an extended period of time. In these instances, rust and corrosion make it difficult to read the terminal markings on a capacitor manufactured with a metal case.

Figure 7-12 This capacitor label is still legible. We can determine that the capacitor for the compressor is 60 MFD and the capacitor for the outdoor fan motor is 5 MFD. The capacitor in this example is in a metal case. In some situations, you will find run capacitors in a plastic case.

Figure 7-13 This run capacitor label shows a basic diagram for a dual capacitor, identifying the black terminal as common, the white terminal as the compressor connection, and the green terminal as the outdoor fan motor connection.

Figure 7-14 Here, a check with a digital meter shows that the FAN segment of this dual capacitor has failed, specifically that it is open.

Figure 7-15 A check with a digital meter shows that the HERM segment of this dual capacitor is weakening due to age. It has a 60 MFD rating, and the meter display is showing 54.4 MFD.

Figure 7-16 When checking components for proper value, a good practice to follow is to use meter leads with alligator clip extensions in order to ensure an accurate reading.

Figure 7-17 Our meter display shows that the 10 MFD capacitor under test is OK. In the event that a run capacitor is holding a charge and test instrument leads are connected, the display on the screen will be delayed, or in some cases the meter may show “Disc” to indicate it is discharging the capacitor prior to reading the microfarad value.

Figure 7-18 This start capacitor is rated from 189 to 227 microfarads. Its operating voltage range is 250 VAC. Start capacitors are manufactured in plastic cases.

Figure 7-19 Start capacitors, like run capacitors, employ foil plates to temporarily store electrons before discharging them. Unlike run capacitors that are oil-filled, start capacitors contain an electrolytic fluid.

Figure 7-20 A pop-out hole will release gasses that could build up if a start capacitor overheats due to being in a circuit longer than it is designed to be.

Figure 7-21 This start capacitor which was removed from a small refrigeration system has a microfarad rating in the range of 88-108. Clipping the meter leads to the capacitor terminals and selecting the proper setting will allow a test instrument to measure the capacitor value.

Figure 7-22 With the meter test accomplished, it shows that the actual microfarad capacity of the capacitor is 96.8, a result that would prompt the technician to recommend its replacement.

Figure 7-23 A schematic representation of a motor that employs a centrifugal switch to break the circuit to the start winding once the start mode has been accomplished.

Figure 7-24 In a motor that employs a switch to take the start winding out of the circuit, there is a large difference between the resistance of the run and start windings due to the length and gauge of the wire used.

Figure 7-25 A motor that employs a start capacitor. The centrifugal switch assembly is located at the back of the motor and the rotation of the rotor assembly causes it to open once the motor has reached its running speed.

Figure 7-26 A potential relay is a device that contains a coil and an N.C. switch. When the coil is energized, the switch is opened until the coil is de-energized at the end of the compressor run cycle.

Figure 7-27 On a potential relay, the terminals used for the operation of the device are 1, 2, and 5. Terminals 4 and 6 are used as convenient tie points for wiring harness connections and have no connection to the operation of the relay.

Figure 7-28 The wiring configuration of the connections to a potential relay are standard: #5 is wired to common on the compressor, #2 is wired to the start winding of the compressor, and #1 is wired to the start capacitor.

Figure 7-29 This wiring diagram shows what is known as a CSR (Capacitor-Start-Capacitor-Run) compressor motor circuit.

Figure 7-30 On a call for cooling that closes the contactor, current will be applied to both windings and the start capacitor will be in the circuit until the N.C. switch on the potential relay is opened. There is no current flow through relay coil due to its high resistance.

Figure 7-31 With the motor operating, the start winding generates the back EMF that energizes the relay coil, causing the N.C. switch in the relay to open, taking the start capacitor out of the circuit.

Figure 7-32 This potential relay coil is showing 2,100 ohms resistance with our digital test device set on the proper scale to read the high resistance of the coil.

Figure 7-33 When testing a potential relay coil that has failed, a properly set test instrument will show “OL” indicating that the coil has no resistance.

Figure 7-34 Testing between terminals 1 and 2 on the potential relay to determine if the switch is OK, or if it has failed.

Figure 7-35 When testing the switch segment of a potential relay with an ohmmeter and the display shows a fraction of an ohm, the switch is considered to be in good condition.

Figure 7-36 Testing with an ohmmeter between the C (Common) and R (Run) terminals will check the resistance of the run winding. Testing between the C and S (Start) terminals will check the resistance of the start winding.

Figure 7-37 When testing PSC compressor motor windings, the difference between the resistance of the windings will often be slight.

Figure 7-38 Fractional horsepower refrigeration system compressors often employ a current relay to accomplish compressor motor starting. It is an electromechanical device.

Figure 7-39 An internal overload protector on a small refrigeration system compressor is held in place by a clip, enabling it to sense the compressor dome temperature. In some cases, external overload protectors may also be designed to sense current draw.

Figure 7-40 A schematic representation of a current relay and compressor terminals shows that the coil of the relay is wired in series with the run winding and the switch assembly is wired in series with the start winding.

Figure 7-41 A start capacitor is also sometimes employed in a current relay motor circuit. It is also common for some manufacturers to use the letter “M” (Main) to identify the run winding of the compressor on their diagrams.

Figure 7-42 Confirming that power is applied to the relay and the inlet of the overload protector.

Figure 7-43 After confirming power applied to the inlet of the overload protector, O-volts measured at the outlet of the overload protector proves that it has failed, preventing the motor from attempting a start.

Figure 7-44 A compressor test cord that connects to a 120-volt power supply and allows for connecting directly to the compressor terminals allows a technician to start the compressor and use an ammeter to check its current draw.

Figure 7-45 A solid state device known as a PTC (Positive Temperature Coefficient) relay is used in small refrigeration systems.

Figure 7-46 A schematic representation of a PTC relay, run capacitor, and compressor circuit. The schematic symbol within the PTC relay indicates that it is a resistor that increases in resistance as the temperature increases.

Figure 7-47 In a PTC relay circuit at the instant of start, the path of current flow is through the relay resistor.

Figure 7-48 In the run mode, the PTC device maintains a high resistance and the path of current flow is through the run capacitor, creating the PSC motor circuit.

Figure 7-49 A 3-speed PSC operated motor is one that is typically found in HVACR equipment that employs a gas or electric heating system along with a refrigeration system for the cooling mode.

Figure 7-50 The path of current flow to operate a multiple speed motor on high speed is shown here. In addition to the high-speed winding, the start winding is also energized. If the equipment operation called for the motor to operate on medium or low speed, L1 would be routed through those connections instead of the high-speed winding.

Figure 7-51 When working with 120-volt multiple speed motors, the most common color code used for the start, common, high, and low speed connections are shown.

Figure 7-52 A multiple speed air handler motor is controlled by a relay assembly integrated into a printed circuit board control that switches the circuit in order to operate the motor in the selected mode of equipment operation. The equipment in this example has a gas heat system.

Figure 7-53 A segment from a pictorial diagram showing a 4-speed indoor air handling motor and the control relay assembly on a printed circuit board.

Figure 7-54 An ohmmeter check showing an open motor winding. With the wiring harness disconnected, checking with an ohmmeter should show resistance when testing a motor winding.

Figure 7-55 Using a clamp type ammeter around the appropriate wiring connection, an operating motor can be checked for proper current draw.

Figure 7-56 A standard 3-phase A/C motor has 3 separate windings to propel the rotor.

Figure 7-57 This schematic diagram shows the wiring connections for a Delta three-phase motor designed to operate on a low or high voltage, specifically 240 VAC or 480 VAC.

Figure 7-58 A six-winding, three-phase motor shown in a Wye configuration.

Figure 7-59 This motor is wired for 240 VAC operation. In three-phase motors of this type, while the control device line side connections are identified as L1, L2, and L3 as with single-phase contactors, the terminal side connections of a magnetic starter may be identified as C1, C2, and C3.

Figure 7-60 This motor is wired for 480 VAC operation.

Figure 7-61 In this example L1 is wired to winding A, L2 is wired to winding B, and L3 is wired to winding C, and the motor is rotating clockwise.

Figure 7-62 By reversing the L1 and L2 leads connected to the motor, the rotation of the motor is changed to a counter-clockwise direction.

Figure 7-63 An example of variable speed technology employed in the operation of a refrigeration system compressor. The equipment power supply is 120 VAC. The compressor is three-phase and operates on DC voltage.

Figure 7-64 Specific information from a manufacturer's troubleshooting guide that shows test points and the voltages that should be read if the electronic control system is operating properly.

Figure 7-65 An NTC device designed to sense temperature and send information to a variable speed compressor control board will often employ a quick connect for the wiring harness. The sensor may be positioned to sense air flow, or it may be clipped to a segment of refrigeration system tubing.

Figure 7-66 An NTC thermistor may be designed with a clip that will allow it to sense a segment of refrigerant system tubing and send that information to the compressor control board.

Figure 7-67 An example of a manufacturer's chart that shows what the resistance of a certain NTC thermistor should be at a given temperature.

Figure 7-68 One example of a variable speed motor that has a separate control section attached to the motor case. This motor is used as a drop-in replacement for a standard PSC direct drive motor and can be wired for clockwise or counterclockwise rotation. It also operates on both 115 and 230 VAC. When it is employed in a 115 VAC power supply system, a jumper wire is installed behind the access door shown on the brain segment of the assembly.

Figure 7-69 The wiring connections to an OEM ECM are accomplished with two harnesses connected to the motor assembly. A 5-pin connector is for the operating power supply, and a 16-pin connector allows for the connection of the control assembly wiring harness.

Figure 7-70 When a constant flow ECM is wired to operate on 120 VAC, terminal #3 is Ground (G), terminal #4 is Neutral (N), and terminal #5 is hot (L1). A jumper wire is installed between terminals 1 and 2 to allow the motor to operate on 120 VAC.

Figure 7-71 One example of a manufacturer-specific test device used in troubleshooting an ECM. By disconnecting the control harness from the motor and replacing with the harness of the test device, then connecting the alligator clips of the device to a 24-volt power supply, the test device can be turned on to check the operation of the motor. (Image courtesy of Regal Beloit)

Figure 7-72 Depending on the specific version of an ECM, a test device of a different specific design may be used in the troubleshooting process.

Figure 7-73 When a constant flow ECM is wired to operate on 240 VAC, terminal #3 is Ground, terminal #5 is L1 and terminal #4 is L2. Terminals #1 and #2 are not connected via a jumper wire when the motor is operated on 240-volts.

Figure 7-74 Once the power to the equipment has been off for at least five minutes, it is safe to remove the screws and separate the control from the motor case.

Figure 7-75 This ECM control has two high voltage capacitors that could cause serious injury if a technician doesn't wait at least 5 minutes to allow them to discharge before removing the control segment from the motor assembly. The motor wiring harness disconnect is also shown here.

Figure 7-76 With a test instrument set properly, the windings of an ECM motor can be checked for resistance. Here our meter shows 5.5 Ω.

Figure 7-77 This test from a motor lead to the motor case shows that the motor winding is not shorted to ground. If the motor was grounded, the meter would show continuity.

Figure 7-78 A single speed ECM Outdoor Fan Motor that employs a separate control board.

Figure 7-79 Checking for control voltage at a two-speed outdoor control board is accomplished by testing between common and either of the 24 VAC connections.

Figure 7-80 In the case of a PWM operated outdoor fan motor, AC operating voltage for the motor is checked at L1 and L2, and the DC control voltage measurements are accomplished at PWM1 and PWM2.

UNIT 8

Wiring Diagram Review
Gas & Electric Furnaces

Figure 8-1 The gas furnace represented in this schematic diagram does not have an electronic control system, spark or hot surface ignition system, or induced draft system.

Figure 8-2 Identifying the assemblies related to the operation of a gas furnace helps in interpreting the schematic diagram. Considering the view shown here, it is understood that the Disconnect Switch Assembly and Thermostat Assembly, while they are shown as part of the schematic, they are wall-mounted, remote, relative to the furnace cabinet. The Fan/Limit Switch Assembly and the other components shown are located in the furnace cabinet.

Figure 8-3 The electrical system in this gas furnace is ready to operate, waiting on a call from the thermostat to initiate a cycle of operation. The hot leg of the 120 VAC power supply is shown in red and neutral is blue. The 24- VAC power supply is shown in yellow.

Figure 8-4 When the thermostat closes on a call for heat, there is current flow through the gas valve solenoid, resulting in the opening of the valve, allowing gas flow to the burners to be ignited by the standing pilot.

Figure 8-5 With the gas burners operating, the fan switch reacts to the temperature rise in the heat exchanger and closes. As a result, there is a complete circuit to the indoor fan motor.

Figure 8-6 Until the temperature in the room reaches the thermostat set-point, all the circuits in the furnace are complete.

Figure 8-7 In this schematic, a time delay relay is used to control the operation of the indoor blower motor. In the event that the limit switch opens in an over-temperature situation, it also operates the indoor blower motor.

Figure 8-8 Conducting voltage tests at the points where 24 volts is supposed to be applied, and in the 120-Volt blower motor circuit, will confirm the condition of the time delay relay. The 120-volt switch check is testing from one switch terminal back to the hot leg of power, and through the motor winding back to the neutral side of the circuit.

Figure 8-9 The terminals identified with the letter H are the connections to the heating element in the relay. Terminals 2 and 4 in this example are wired to the relay switch contacts.

Figure 8-10 In electric heating systems a sequencer is used to make and break circuits to heating elements in steps. In addition to the "H" terminals that are wired to the 24-volt heating segment of the device, a sequencer has at least two sets of switching contacts.

Figure 8-11 The switching terminals of this sequencer are identified as "M" connections. The 24-volt heating segment of the device is connected to the un-marked brass terminals shown at the bottom. A device such as this is designed to energize two heating elements in sequence.

Figure 8-12 This illustration shows one example of M terminals that would be wired in series with a heating element, which is a high current draw device, and the A terminals that would be wired in series with another sequencer's control segment, which is a very low current draw device.

Figure 8-13 In some electric furnaces a sequencing timing device may control a heating element along with indoor blower motor operation, and also have an auxiliary contact that will close to energize a second sequencer.

Figure 8-14 This wiring diagram shows the schematic symbols used to illustrate the circuitry in an electric furnace.

Figure 8-15 When the thermostat calls for heat, a 24-volt circuit through the Fan Control and Sequencer #1 is complete and the resistance coils in those components begin the process of providing heat to close contacts on the equipment voltage segment of the circuit that are wired in series with the heating element and indoor blower motor.

Figure 8-16 Upon an initial call for heat, one heating element and the indoor fan motor are operating. This illustration also shows the complete circuit through the primary winding of the transformer that is present whenever power is applied to the equipment.

Figure 8-17 When the resistor coil of SEQ #2 is energized, the M1 M2 contacts will close to complete a circuit to the second heating element. If necessary, the continued call for heat will energize the resistor coil in subsequent sequencers, causing all the heating elements to be energized.

Figure 8-18 Performing a voltage and amp draw check on an individual heating element will determine whether or not it is providing heat.

Figure 8-19 An example of a P.C. board control system for a gas furnace. (Image courtesy of Carrier Corporation)

Figure 8-20 A pictorial diagram provides an alternate view of the printed circuit board control system of a gas furnace. (Image courtesy of Carrier Corporation)

Figure 8-21 A legend explains the component identifiers that are abbreviated on schematic and pictorial diagrams. (Image courtesy of Carrier Corporation)

Figure 8-22 Equipment notes that accompany the schematic and pictorial diagram provide information about the equipment installation and other factors regarding the operation of the electrical system. (Image courtesy of Carrier Corporation)

Figure 8-23 In the case of this printed circuit board control, the manufacturer's troubleshooting information would include written instructions for accomplishing voltage tests at specific points.

Figure 8-24 An example of components such as a fuse, control relays, and dip switches that are shown schematically and are located on the printed circuit board.

Figure 8-25 An example of a fuse that is removed from a printed circuit board for testing with an ohmmeter.

Figure 8-26 A gas furnace limit switch that may be referred to as a thermo-disc type of switch.

Figure 8-27 In this schematic diagram, the limit switch is identified as component # 7H. Switches of this type may react to excessive temperature, open, then re-set when they cool down, or they may be referred to as a one-time limit switch because once they open, they don't re-set. In this specific case, it is a one-time switch. Also shown wired in series with the secondary of the transformer is a fuse (# 11C).

Figure 8-28 The 2F relay on this board is used in the event that the furnace is an air handler in a heat/cool application, operating the fan on high speed for the cooling mode. The 2A relay is used for time delay operation of the blower motor in the heating mode. The protective fuse can be removed to be checked with an ohmmeter.

Figure 8-29 A segment of a pictorial diagram that shows an N.O. pressure switch. When the switch reacts to the positive pressure in the furnace vent system, it closes allowing the sequence of operation to continue.

Figure 8-30 A pressure switch assembly contains an N.O. switch mounted to a bellows assembly. Pressure hose connections from the switch to the vent system allow the device to sense the pressure in the vent to close the switch and allow an ignition system circuit.

Figure 8-31 In this pictorial diagram, the 24 VAC Spark Electrode operates on a call for heat when the N.C. switch in the Pilot allows the circuit for the spark to ignite the pilot flame. An N.O. switch in the pilot assembly allows the gas valve to open once the pilot is proven.

Figure 8-32 When a flame sensing rod is operating properly, it sends a message to the ignition control system that the flame is present, allowing the gas valve to remain open and continue the sequence of operation of the equipment. The ignitor in this example operates on 24 VAC.

Figure 8-33 A control module, gas valve, ignitor and flame sensing rod.

Figure 8-34 In a direct spark ignition system, the spark electrode ignites the main burner directly on a call for heat from the thermostat.

UNIT
9

Wiring Diagram Review
Comfort Cooling & Refrigeration Systems

Figure 9-1 A simplified dual-voltage schematic diagram for a comfort cooling system without legend identifiers.

Figure 9-2 This illustration shows a dual-voltage schematic for a comfort cooling system with legend identifiers. Color coding for the thermostat wiring is also shown: R (Red=Voltage into the thermostat, G (Green=Wiring to Fan Relay Coil) Y (Yellow=Wiring to Contactor Coil…Cooling).

Figure 9-3 In some cases protective switches are wired in series with the contactor coil, but in the equipment voltage circuit. When this method of operation is employed a Control Relay (CR) makes and breaks the circuit to the contactor coil via a set of N.O contacts. Also in the CR are a set of N.C. contacts wired in series with the Crankcase Heater (CH).

Figure 9-4 An external crankcase heater is designed with an adjustable clamp and is fastened near the bottom of the compressor.

Figure 9-5 A crankcase heater that is inserted into a tubing cavity (Heating Element Encasement) in the compressor.

Figure 9-6 This diagram represents a small package unit air conditioner manufactured by York International Corporation. In addition to symbols and the legend, the individual wires are numbered, and the wire harness color code is shown.

Figure 9-7 The simplest form of a control thermostat is a bi-metal strip consisting of two dissimilar metals that, when reacting to temperature change, warp and make or break a set of contacts.

Figure 9-8 In this design of electromechanical thermostat, the bi-metal strip warps to change the position of the mercury bulb. The mercury inside the bulb makes and breaks the 24-volt power source to operate contactor coils and relays.

Figure 9-9 This example of a typical digital thermostat sub-base shows where the field wiring is connected to the screw terminal connections, and the pin connections that allow for connecting the thermostat body to the sub-base.

Figure 9-10 This illustration shows a segment of a digital thermostat and the connecting pins on the thermostat body that allow it to be connect to the sub-base.

Figure 9-11 One example of a digital thermostat that allows for energy saving programming in a cooling/heating application.

Figure 9-12 This illustration shows a low voltage wiring harness connected to a thermostat sub-base (Red=Voltage, Yellow=Cooling, White=Heating, Green=Fan) for one type of heating/cooling application. In the event that this device is used in other applications, such as a heat pump, additional wires in the harness would be connected to other terminals on the sub-base.

Figure 9-13 The terminal wiring connections on the equipment printed circuit board allow for connection of the low voltage control wiring harness. When the wiring harness is removed, jumpers can be installed on the appropriate wiring connections to eliminate the thermostat and the wiring from the equipment to the thermostat and operate the equipment manually.

Figure 9-14 In this partial wiring diagram, the compressor windings are shown along with the potential relay. Also note the optional run capacitor that would allow this compressor motor to operate as PSC.

Figure 9-15 A partial diagram from a comfort cooling system that shows another example of identifying the potential relay in a compressor circuit. The switch of the relay is shown as being wired between terminals 1 and 2, and the coil is shown wired between terminals 2 and 5.

Figure 9-16 This illustration shows the electrical system that employs a hot gas solenoid valve and timer to accomplish defrost in a commercial reach-in refrigerator.

Figure 9-17 One example of a defrost timer that controls the operation of an electric defrost system in a commercial reach-in refrigerator.

UNIT
10

Wiring Diagram Review
Heat Pumps

Figure 10-1 A simplified dual-voltage schematic diagram of a packaged unit heat pump showing symbols and circuits without legend identifiers.

Figure 10-2 A separate diagram that shows a supplemental heat segment in heat pump equipment. Supplemental heat components may be field installed by the technician because manufacturers offer the equipment without supplemental heat capability in mild climates where the refrigeration system is considered capable of providing the heat necessary for comfort in the building.

Figure 10-3 This illustration shows the main segment of a heat pump diagram and an accompanying diagram that contains a supplemental heat strip assembly that is field installed when the refrigeration system is not capable of providing all the heat necessary in a structure, and when there is a need for additional heat to maintain building temperature during the defrost mode of the equipment.

Figure 10-4 When the thermostat system switch is turned to the cooling position, and there is a call for cooling, a 24-volt circuit is complete to the CR and IFR coils. As a result, the three 240-volt motors necessary for a cooling operation are energized.

Figure 10-5 When the thermostat system switch is turned to the heating position, and there is a call for heat, the 24-volt RVR coil is energized and the equipment is operating with one stage of heat.

Figure 10-6 Upon a call for second stage heat from the thermostat, the 24-volt HC1 relay coil is energized providing OTS1 is closed. This results in a complete circuit through SH1 when the HC1 contacts close.

Figure 10-7 With the refrigeration system and two heat strips operating, this heat pump is operating at full capacity.

Figure 10-8 In the defrost mode, the 230-volt DFR coil is energized when the air switch closes due to low air pressure through the outdoor coil. The 230-volt N.C. DFR contacts open, breaking the circuit to the reversing valve solenoid, and the 24-volt DFR contacts close to make a circuit through the HC1 coil.

Figure 10-9 When a time/temperature device is employed to accomplish defrost of a heat pump outdoor coil, the defrost cycle is initiated by time as long as the sensed temperature is low enough.

Figure 10-10 A Delta T system employs two sensing devices. When the temperature differential between the two sensors reaches a selected point, the control initiates the defrost mode. Termination of defrost occurs when the temperature rises.

Figure 10-11 A bi-metal switch may be used in conjunction with a timing device to control the operation of the defrost mode.

Figure 10-12 A partial wiring diagram from a Trane/American Standard Inc. heat pump that shows a segment of the control board and the method of shutting down the outdoor fan motor in the defrost mode.

Figure 10-13 An electronic control board in a heat pump is commonly powered by the 24 VAC secondary from the equipment transformer. In addition to controlling components and interpreting information from thermistor sensors, the manufacturer's information may show DC voltage test points. This type of control is commonly referred to as an electronic demand type device since it does not operate on a timing process, but rather by monitoring the temperature differential between the two thermistors and initiating a defrost mode when necessary.

Figure 10-14 An example of a logic board that allows the technician to force a defrost and select timing of total compressor run time for defrost cycles.

Figure 10-15 One example of an information table provided by manufacturers that shows what the resistance of a thermistor should be at a certain corresponding temperature. The type of thermistor shown here is an NTC (Negative Temperature Coefficient) device.

Figure 10-16 This schematic diagram is for a single-phase 208/230 VAC, 60 HZ package unit heat pump with an indoor X-Motor control remote and outdoor remote control ECM, model year 2018.

APPENDIX A

Troubleshooting Problems

Figure A-1 A partial wiring diagram that shows the compressor and outdoor fan motor circuits of a split system heat pump. The customer's complaint is that the equipment has not been keeping the building comfortable since the weather turned warmer in the summer season.

Figure A-2 This wiring diagram shows a comfort cooling system that employs a dual capacitor, potential relay and start capacitor.

Figure A-3 A partial diagram showing the test points on a printed circuit board control system in a gas furnace.

Figure A-4 A manufacturer's schematic diagram that shows the components of a forced air electric furnace.

Figure A-5 Checking with a meter for proper AC voltage applied to an ECM motor and the correct DC voltage applied to the control segment of the motor control.

Figure A-6 A three-phase roof-top gas heat system wiring diagram.

Figure A-7 A segment of a manufacturer's wiring diagram for a split system.

Figure A-8 A segment of a manufacturer's wiring diagram for a condensing gas furnace.

Figure A-9 A manufacturer's diagram for a package unit air conditioner.

Figure A-10 Wiring instructions for connecting a general replacement fan motor so that it will operate in the correct direction.

Figure A-11 A heat pump wiring diagram.

Figure A-12 An electric furnace that employs five sequencers to control the operation of five heating elements.

Figure A-13 A manufacturer's diagram for a heat pump that employs a logic board for defrost.

Figure A-14 The schematic diagram for a comfort cooling system prior to the equipment modification in which a potential relay and start capacitor was added.

Figure A-15 Legend for the schematic diagram shown in Figure A-14.

Figure A-16 A wiring diagram for an ice machine that employs a series of relays that make and break circuits to various components during the freeze and harvest cycles of the machine.

Figure A-17 An electronic expansion valve that regulates refrigerant flow.

Figure A-18 Thermistors that sense temperature to control refrigerant flow.

Figure A-19: This example of a troubleshooting chart for the remote condensing unit of a split system employs dot indicators to identify possible causes and solutions.

Figure A-20: This flow chart is the first one in a series of three that this manufacturer employs to document test procedures for a hot surface ignition system that's not firing. As this chart shows, the first question to consider is whether or not the ignitor is glowing.

Figure A-21: When the technician is directed to the second flow chart in a series, it outlines specific test procedures as well as direction to a subsequent chart if necessary.

Figure A-22: This final flow chart shows a diagnosis and specifies which component needs to be replaced in order to restore the normal operation of the equipment.

Figure A-23: A manufacturer's flow chart that shows specific test procedures for the indoor blower motor.

Figure A-24: A troubleshooting flow chart for a supplemental heating system in a heat pump. In addition to outlining troubleshooting steps, a flow chart may show a reminder about time delay operation of components.

HVACR TROUBLESHOOTING FUNDAMENTALS

Electricity & Wiring Diagrams

SECTION
1

FUNDAMENTAL ELECTRICAL CONCEPTS

In order to effectively troubleshoot HVACR equipment, you must be familiar with the basic principles of electricity. And, once you have a firm understanding of these fundamental concepts, you can apply that knowledge to test and evaluate the electro-mechanical and electronic components used in HVACR systems, and the wiring that connects them together, to pinpoint the source of a problem.

UNIT
1

Generating Electricity and Electron Flow

Learning Objectives

After studying this unit, you will be able to:

1. Describe the process through which a generating plant converts raw material into electrical energy.
2. Relate the process of generating electricity to magnetism.
3. Understand why some materials allow electricity to flow easily and why other materials are fair or poor conductors of electricity.

If you were to ask the average person to explain electricity, you may get a brief description of a generating plant located near a city, and a network of wires leading to homes, offices, stores, schools, and factories. For those not employed as an HVACR technician, a general explanation such as that would be sufficient because the average person doesn't need an understanding of electricity beyond making use of it in their home or at work, and staying away from downed power lines. When troubleshooting and servicing HVACR equipment, however, you'll need a complete understanding of how electrical energy is generated, how it is transported to the desired location to operate equipment, and how it is made to perform useful work.

This information is the foundation for learning how to troubleshoot electrical systems, allowing the technician to develop a firm understanding of electro-mechanical and electronic components, and the circuitry that connects the components together, accomplishing the intended sequence of operation of equipment.

QUICK NOTE:

While most people view the residential and light commercial HVACR field as a situation in which most of the tasks performed are related to working with refrigerants, the reality is that the majority of troubleshooting problems involve electrical systems.

As an HVACR technician, you must be able to use equipment wiring diagrams that not only illustrate electrical circuits, but also show and explain the position and function of components that control the operation of the motors, electrically operated valves, heating elements, and other components in refrigeration and air conditioning equipment. The simple way to look at this is that you will need to understand what “right” is in the first place, so you will be able to recognize “wrong” when you see it.

One way to approach developing this skill and learning to troubleshoot is to consider two questions:

1. "How is electricity really produced?"

2 "Why does copper conduct electricity while rubber does not allow electrical energy to flow?"

Once you have answered questions like these and have eliminated any doubts about electricity, its fundamentals, and its relationship to the operation of HVACR electrical systems, it is an element of your ability to perform confidently as a service technician. This is not to say that you will need to review all the principles discussed in this section every time you're called to solve an electrical problem. But, after studying and understanding the material that follows and filing it away mentally, you will eliminate any mysteries about electricity that would otherwise muddle the thought processes required for logical, step-by-step analysis of a malfunctioning piece of equipment.

PRODUCING ELECTRICITY

Electrical energy begins at a generating station and, in simple terms, is defined as a form of energy that performs useful work when converted to light, heat, or mechanical energy. This definition should be easy for us to accept because we see it in action every time we turn on a light, use a toaster when making breakfast, or turn on the HVACR equipment in our home or workplace.

To answer our first question and go beyond the common knowledge that the electricity we use comes from a power plant, and that a generator is used to produce the energy, it will help if you view the electrical generating station from a simple perspective. It is a factory that takes a raw material, such as coal or oil, or employs a hydroelectric or nuclear process, and changes chemical energy into another form of energy: electricity.

Figure 1-1 illustrates, in its simplest form, the process of converting chemical energy into electrical energy. You'll note that, as you trace the process we are showing in this example from its beginning (a mine supplying coal) to its end, the energy takes five different forms.

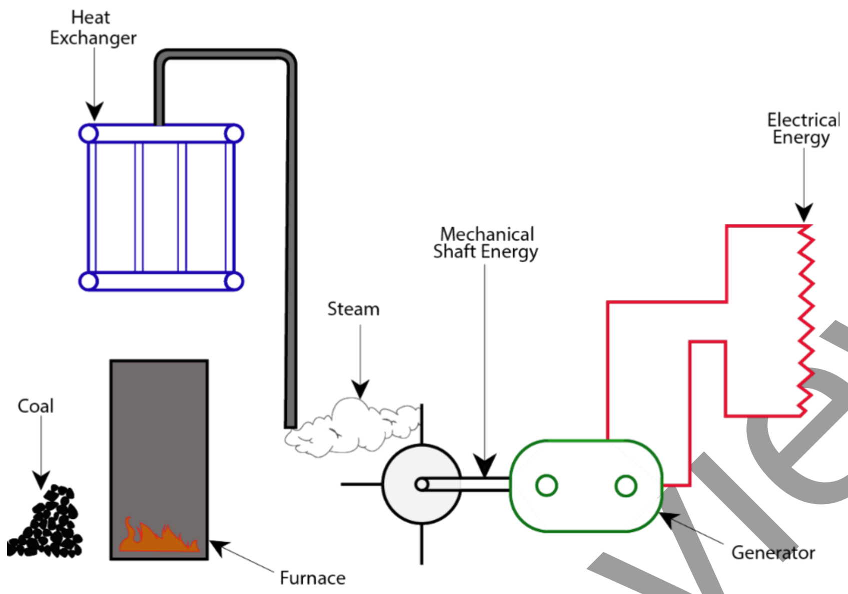


Figure 1-1 Coal is chemical energy, which when burned becomes heat energy, which generates steam energy, which becomes mechanical shaft energy to turn the generator, which results in electrical energy.

In our example, this power plant uses coal as its raw material. Machinery is used to grind the coal into a fine powder, the consistency of which is comparable to face powder. The fine powder is then transported by introducing air pressure into a piping system that leads to furnaces. The pulverized coal is ignited and burned. At this point, the chemical energy is transformed into heat energy.

The heat energy is then used to raise the temperature of water in a closed-loop piping system that is routed through the furnace. The temperature of the water is raised until it boils, changing into steam. The steam is then heated further until its temperature reaches 1,000° Fahrenheit.

Some electrical generating stations may differ from the illustration in Figure 1-1 in that they use a different source of heat, such as nuclear fission, or they may use water power to achieve mechanical energy. However, the final objective is the same: to spin the generator that produces electrical energy.

Allowing this high-pressure steam to expand and be released in a controlled manner, and contact the blades of a turbine, such as the type shown in Figure 1-2, results in a mechanical energy. The mechanical energy is then transferred to the shaft of the turbine, which is connected to the generator rotor.

Atomic Theory/Conductors and Insulators

Referring to the chart in Figure 1-11:

Mica is an effective ________________________________ material.

Silicon is a ____.

Copper is an effective ____ of electricity.

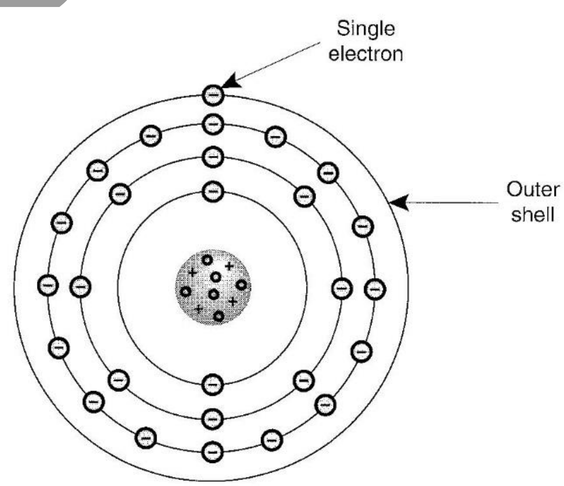
The single electron that is furthest from the nucleus of the atom and can be easily knocked out of orbit is referred to as a:

____ electron.

An insulator can have up to _______ valence electrons.

A silver atom contains ________ orbits which are known as shells of electrons.

The illustration below illustrates the atomic structure of a __________________________ atom.



UNIT
2

Alternating Current, Direct Current And Electrical Power

Learning Objectives:

After studying this unit, you will be able to:

1. Describe the difference between alternating current and direct current.
2. Understand the relationship between voltage, amperage and resistance in regard to Ohm's Law.
3. Explain how the electric company charges customers for electricity.

The power supplied to HVACR equipment is alternating current (AC). As described in Unit 1, alternating current is generated through the process of cutting the lines of force of a magnetic field with a conductor. From a practical standpoint, this means that alternating current reverses its direction from negative to positive every time the conductor cuts the lines of force of both poles of the magnet.

When considering direct current (DC) in HVACR equipment, it is used to power printed circuit board control systems and related solid state components. This unit will discuss both AC and DC current, Ohm's Law, and electrical power.

COMPARING DIRECT CURRENT & ALTERNATING CURRENT

Unlike alternating current, direct current does not reverse direction. DC flows in one direction only and is a type of current produced by a battery rather than an alternator. A good example of producing direct current is a dry battery that you would find in a flashlight. An illustration of the difference between alternating current and direct current is shown in Figure 2-1.

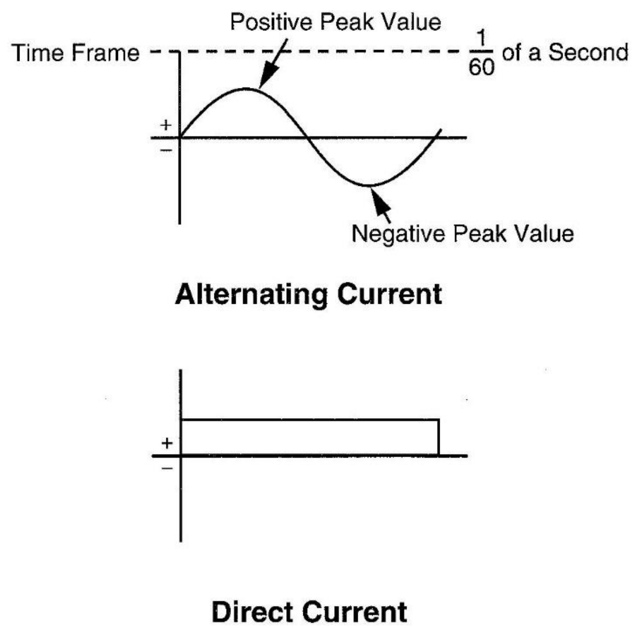


Figure 2-1 As illustrated by the AC sine wave in this illustration, alternating current is generated at 60 cycles per second in the United States. In Canada, in European, and in other countries, the energy in alternating current will reach a positive and negative peak value 50 times per second, which means electricity is generated at 50 cycles.

As you can see, the waveform (commonly referred to as a sine wave) for alternating current shows that during the time frame of 1/60th of a second, the energy reaches both a positive and negative peak value. The time form of a 1/60th of a second relates to a two-pole generator that is spinning at 3,600 RPM (Revolutions per Minute) to achieve what is referred to as a frequency of 60 cycles per second. The term "Hertz", commonly abbreviated as "HZ" is used to identify cycles per second. A frequency of 60 cycles per second would be identified on equipment tags as "60 HZ".

QUICK NOTE:

Terms that identify units of electrical measurement are derived from the names scientists who made discoveries in electrical principles. In the case of the cycles of alternating current, "Hertz" is derived from the name of a German scientist, Heinrich Rudolph Hertz.

UNIT
3

Electrical Distribution Systems

Single-Phase & Three-Phase Power

Learning Objectives:

After studying this unit, you will be able to:

1. Identify the various types of voltage, phase and current systems used in supplying power to residential, commercial, and industrial buildings.
2. Explain the process of checking for proper supply voltage in a building distribution panel.
3. Make fundamental voltage checks under no-load and load conditions.

Almost all the electrical power we use is produced by large generating stations that use either a fossil fuel such as coal or oil to generate heat and create the steam necessary to turn a generator turbine. Some generating stations are referred to as nuclear power plants. The source of the heat in a nuclear system is known as a reactor that relies on uranium as the fuel, creating a chain reaction that generates heat from the process of controlled nuclear fission. The heat from this process is used to raise steam. The central part of a nuclear system is the reactor that is temperature controlled by coolant that is pumped through the system.

Alternate sources of electrical energy are wind power systems and hydroelectric power plants that employ water flow from a dam or natural resource, and solar systems that generate electricity from the sun. One type of device that accomplishes this is a photovoltaic panel that absorbs and converts sunlight into electricity. Another type of solar system employs what is known as a parabolic mirror system. In this type of system a tube containing synthetic oil is positioned near a mirror that concentrates the sun onto the tube, heating the oil. The heated oil is then used to heat water and generate steam.

Photovoltaic panels are one segment of a PV system, which also employs a solar inverter to change the electric current generated by the panels from DC to AC. Large arrays of PV systems are often owned by utility companies. PV systems are also becoming popular in smaller commercial and residential applications, allowing building owners to generate their own electricity. These systems are grid connected, meaning they are connected to the wiring network that transfers power over large areas. This allows the building owners to sell the electrical energy their system generates to the utility company and receive credit toward their utility bill.

STEP-UP AND STEP-DOWN TRANSFORMERS IN ELECTRICAL DISTRIBUTION SYSTEMS

Once electrical energy has been generated, the task of electrical distribution must be accomplished. The generating plant delivers the electrical energy from its generators at a very high voltage level, which is stepped up further by a transformer system at the beginning of the electrical grid. Other transformers step the voltage down near the end of the wiring system.

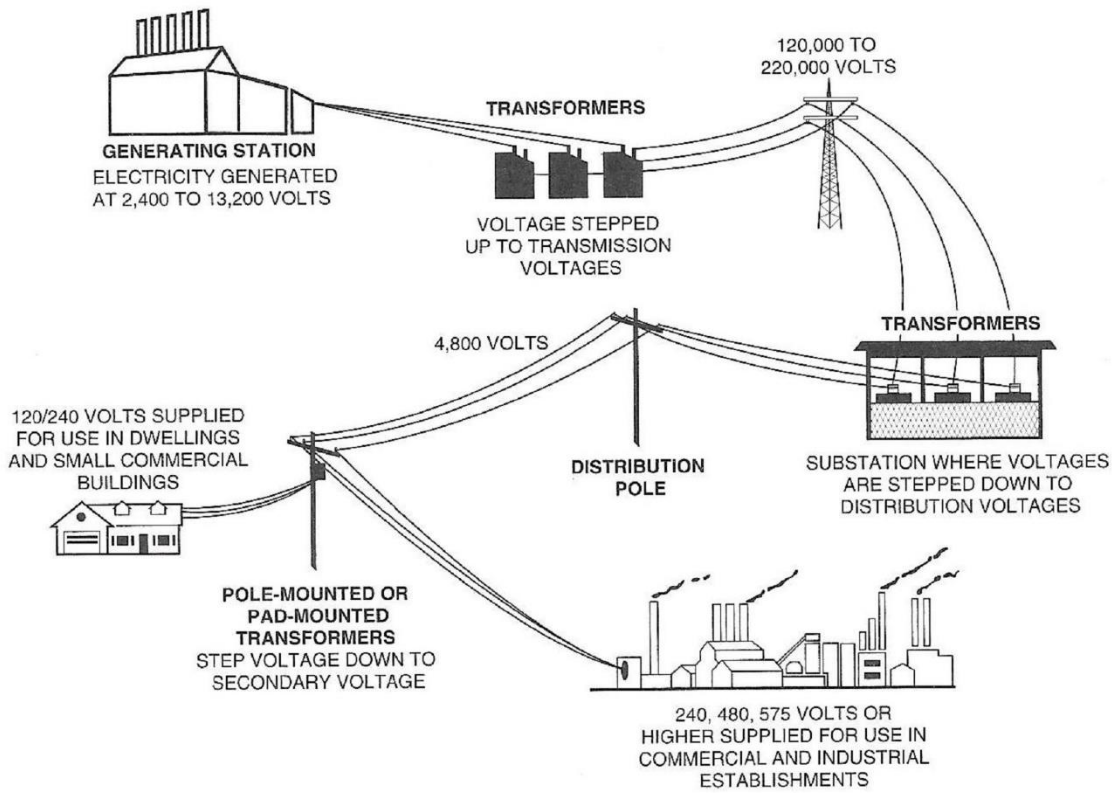


Figure 3-1 Electrical energy is generated at a high voltage level. This voltage is then stepped up higher in order to transport it along high voltage transmission lines, which are conductors that are not insulated. The voltage is then stepped down by a substation for distribution to buildings.

As Figure 3-1 shows, a typical utility company generates electricity at a voltage level ranging from 2,400 to 13,200 volts. Located in close proximity to the generating station are transformers that step the voltage to an even higher level, ranging from 100,000 to 200,000 volts. The reason the energy needs to be at a high level is due to the resistance that exists in all conductors. Stepping the voltage up to this high level allows it to be transported over long distances. Near the end of the distribution grid, other transformers step the voltage down to allow it to enter the final segment of the wiring system.

With the voltage stepped down to approximately 4,800 volts, the energy is then transported to surrounding buildings which have their own transformers that step the voltage down again to the level that is applied through the meter to the electrical distribution panel.

Understanding how a transformer works to either step voltage up or down begins with understanding how alternating current is generated. As we said in Unit 2, alternating current is generated when a conductor cuts the lines of force of a magnet. (See Figure 3-2)

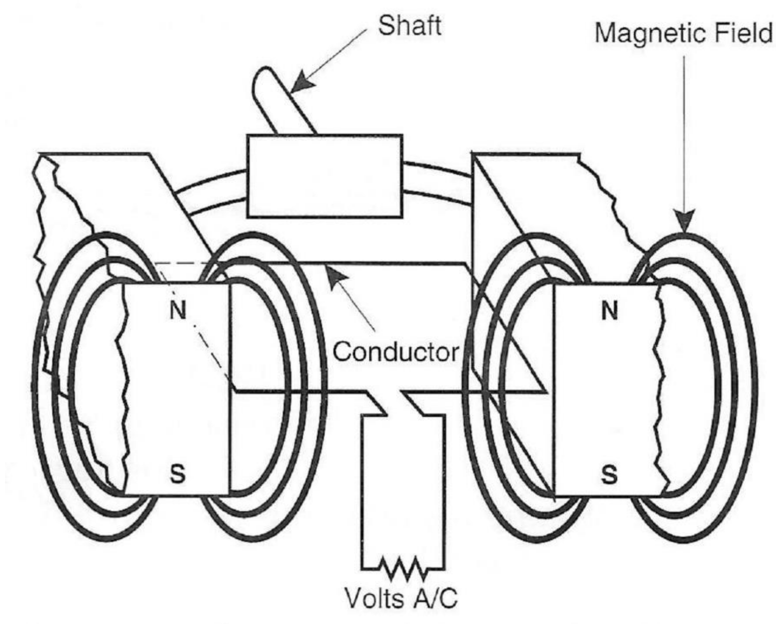


Figure 3-2 An example of electromagnetism in which the conductor remains stationary and the magnets are connected to the spinning shaft assembly.

With the concept of setting up an energy within a conductor through the process of electromagnetism understood, what follows is the understanding that when current flows through a conductor, there will be an electromagnetic field around the conductor as shown in Figure 3-3.

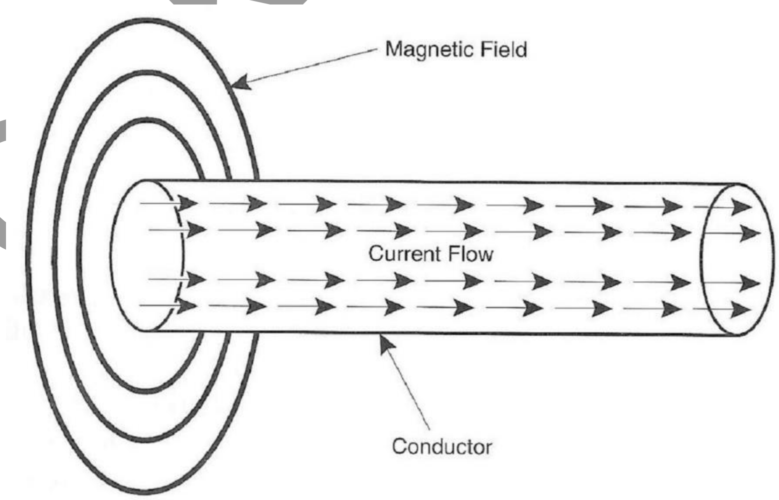


Figure 3-3 Current flowing through a conductor results in an electromagnetic field around the conductor.

UNIT
4

Electrical Supply Circuit Protection

Fuses & Circuit Breakers

Learning Objectives:

After studying this unit, you will be able to:

1. Explain how a fuse acts as a protective device in an electrical circuit.
2. Identify the different types of fuses used in HVACR equipment circuits.
3. Explain the process of testing to determine if a fuse in a disconnect box has blown.
4. Describe the method of operation of an electrical system circuit breaker.

HVACR electrical systems, as with any electrical circuit, must be protected. Protection is necessary to prevent excessive temperature situations that could damage the power source or cause wiring and components to fail in the event of an overload condition. A severe overload condition can create a fire hazard.

The most common method of circuit protection begins with circuit breakers located in the building distribution panel, and in the case of HVACR equipment, often also employs fuses at the point of the wiring service to the equipment. In older buildings, if the electrical distribution panel has not been upgraded, it is possible that fuses, rather than circuit breakers, will still be in use.

It is the technician's responsibility to be absolutely certain that the fuses being used in the protection of HVACR equipment are the proper type of fuse for the application, and that that they are correctly rated for the specific circuit in which they are employed.

FUSE PROTECTION IN A POWER SUPPLY CIRCUIT

Because the potential for a short or an overload exists in all circuits, protection is required. The fuse is the simplest of all circuit protection devices, containing an alloy element that, in the event of an overcurrent situation, will melt and break. The three fundamental characteristics of a fuse are:

1. Has no effect on the circuit during normal operation.
2. Sensing when a current overload exists.
3. Opens the circuit before any damage is done to the circuit components.

To illustrate the factors above, we'll use a series of images that show the function of a fuse. In Figure 4-1, a room air conditioning unit is operating normally and the fuse is not affecting the operation of the equipment.

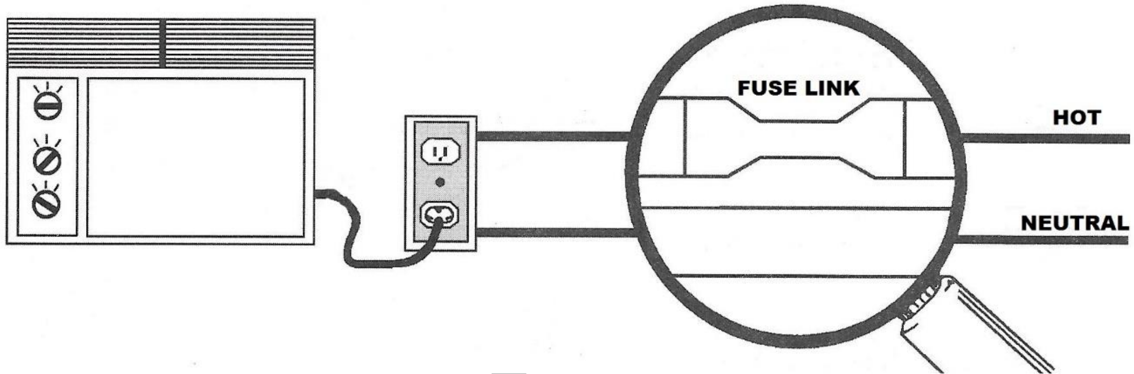


Figure 4-1 Our magnifying glass shows that the alloy element of the fuse is unaffected by the normal operation of the room air conditioning unit. Note that the fuse is shown in the hot leg of the power supply to the receptacle. It is common to refer to the element in a fuse as a fuse link or fusible link.

In Figure 4-2, a problem is developing with the power cord of the equipment.

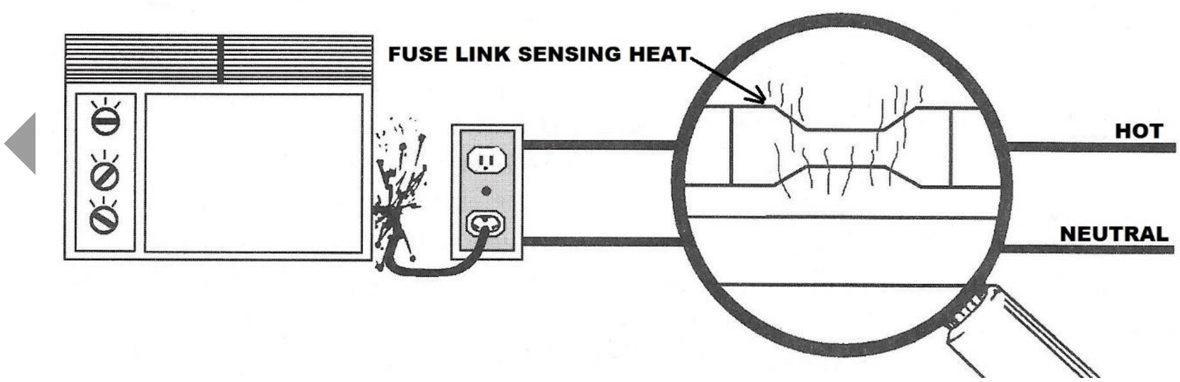


Figure 4-2 A short circuit in the power cord is causing a circuit overload and the fuse link senses the over-temperature situation.

From a simple perspective, consider the element within a fuse, which may be made of zinc, copper, aluminum, or other alloys, to be a good conductor of electricity when a power supply circuit and the equipment it is connected to are operating normally. When an overcurrent situation occurs, fuses are designed to fail safely, which means that any arc inside the fuse when it blows must be quenched. In some cases, the element may be surrounded by air, or arc quenching materials may be employed. (See Figure 4-7)

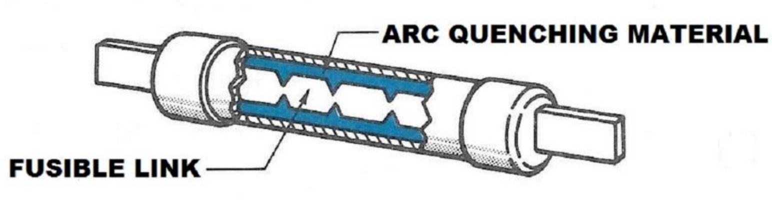


Figure 4-7 A fusible link may be positioned within the fuse so an air barrier allows it to fail safely. In some fuses, an arc-quenching material, such as silica sand, may surround the link to prevent arcing when the fuse blows.

In our example we're showing a knife-blade type fuse, which is typically manufactured with an arc quenching material since this style of fuse is commonly found in commercial equipment applications; equipment with a significant level of current draw. Figure 4-8 shows a three-phase disconnect assembly.

Figure 4-8 A three-phase fused disconnect switch. In order to ensure proper equipment operation, all wiring connections must be tight and the clips that hold the fuses must be in good condition. When removing fuses from a disconnect box the proper method is to use a fuse puller rather than a screwdriver to pry them loose.

UNIT FOUR SUMMARY

HVACR electrical systems, as with any electrical circuit, must be protected to prevent a severe overload condition that can create a fire hazard.

In the case of HVACR equipment, the breaker in the distribution panel and a fused disconnect box are typically used to protect the electrical circuit. In older buildings, if the electrical distribution panel has not be upgraded, it is possible that fuses, rather than circuit breakers, will still be in use.

It is the technician's responsibility to be <u>absolutely certain</u> that proper fuses are being used in the protection of HVACR equipment.

The three fundamental characteristics of a fuse are:

1. Has no effect on the circuit during normal operation.
2. Sensing when a current overload exists.
3. Opens the circuit before any damage is done to the circuit components.

In addition to understanding the method of operation of a fuse, technicians need to be aware that different styles of fuses are employed depending on the specific type of circuit and equipment the fuse is protecting.

Time delay fuses, also known as dual element fuses, must be able to withstand an excessive level of current draw for a short period of time.

Not all equipment is protected by both a circuit breaker and a fused disconnect. In some cases, a disconnect switch may not be fused, and the only protection in the equipment circuit is a circuit breaker inside the building.

When an overcurrent situation occurs, fuses are designed to fail safely, which means that any arc inside the fuse when it blows must be quenched. In some cases, the element may be surrounded by air, or arc quenching materials may be employed.

Working from the perspective that troubleshooting is the systematic elimination of the possibilities, it makes sense to begin the process within the disconnect box because it is fundamentally in the "middle" of the electrical circuit. It also allows for an illustration of the "If/Then" approach to troubleshooting

When checking for power in this particular style of fused disconnect, removing the safety shield will show the Line wiring connections from the breaker in the distribution panel that brings power into the disconnect assembly and the Load wiring connections that take the power out of the box to the equipment.

<u>Always use extreme caution when removing safety shields to expose wiring connections! When the circuit breaker in the main distribution panel is turned on, wiring inside the disconnect box will be hot!</u>

UNIT
5

Proper Use of Test Instruments

Learning Objectives:

After studying this unit, you will be able to:

1. Explain the safety aspects regarding the proper use of analog and digital meters.
2. Describe how to accomplish continuity, resistance, voltage, current, capacitance, and temperature measurements with multi-meters.
3. Explain the process of checking circuits and electrical components relative to troubleshooting and repairing HVACR equipment.

HVACR service managers face a variety of challenges in the day-to-day operation of their department. And surveys show that one of the issues they deal with on a regular basis in their in-house training sessions is ensuring that technicians are able to understand and properly use test instruments.

Using test devices involves more than safely checking hot circuits with a voltmeter to ensure that power is applied to equipment as we discussed in Unit Four. Technicians must also understand the subtle difference between testing for continuity and resistance of components, and properly interpreting that information. And they must also know how to apply the information a meter shows in regard to current draw of a given component and/or the overall operation of the equipment, and the importance of temperature measurements where necessary in order to evaluate the operation of an electrical system.

This unit will discuss the fundamental principles of the operation of analog meters because, as with any technical skill, complete mastery of a craft requires a firm foundation of understanding all aspects of a subject.

An overview of how to use digital test equipment to obtain good information about a given component or an electrical system being tested, and how to relate that information to troubleshooting and repairing equipment, is also discussed in this unit.

FUUNDAMENTALS OF ANALOG METERS

With the invention of mechanically operated clocks, people learned to tell time.

Generations of individuals learned that when the big hand is on the 12, and the little hand is on the 3, that the time is 3 O'clock, and by applying the fundamental knowledge about the difference between night and day, they recognized the concept of AM and PM to determine if it was 3 O'clock in the morning or 3 O'clock in the afternoon.

After a significant number of years into the digital age, elementary school teachers identified a pattern with some of their students. Their intellectual grasp of telling time related only to the concept of numbers displayed on a screen, limiting their overall understanding of how watches and clocks functioned.

And, so it goes with technicians developing their HVACR troubleshooting skills and using test instruments to track down the source of a problem in an electrical system. Mastering the use of the variety of digital meters used in the service industry requires a fundamental understanding of how all meters, including analog meters, function.

In Figure 5-1, we are showing a typical analog meter that accomplishes a variety of electrical measurements.

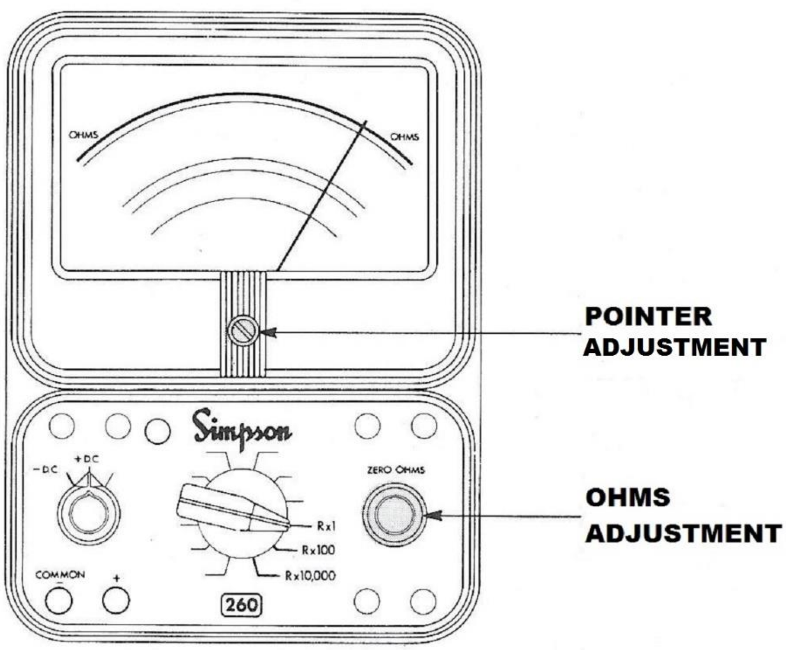


Figure 5-1 An analog meter operates on the principle of a pointer (often referred to as a needle) moving and indicating a specific measurement. *Image courtesy of Simpson Electric.*

An important point to keep in mind regarding test equipment is that the reference mentioned in regard to using the SELECT button applies to the particular make and model of the meter shown in figures 5-6 and 5-7. When working with a different model of meter, such as the one shown in Figure 5-8, different specific procedures apply when using this test instrument to test and troubleshoot.

Figure 5-8 While experienced technicians have an overall understanding of the proper use of test instruments, there is always a learning curve when using a particular model of meter for the first time. This particular model of meter, in addition to accomplishing electrical and temperature measurements, is capable of wireless communication to allow data transfer to other specific devices.

An effective way to approach the process of learning about test instruments is to consider that there are always some similarities that exist due to industry standards, and when switching from one make and model of meter to another there will always be some differences.

For example, consider that when it comes to connecting meter leads to an instrument, the standard code for the connection to the COM port is black and the connection for second lead is red. It's also a common practice for this port to be labeled as the VΩ connection to the meter. And, certain symbols used to identify meter functions are also standardized. However, when considering the dial settings on either analog or digital meters, the method of operation will always vary from one manufacturer to another. Procedures may even change in regard to different models available from the same manufacturer.

A fundamental aspect of troubleshooting HVACR electrical systems is determining whether or not there is a problem in the power supply in the equipment causing voltage drop. With a digital meter, precise measurements can be accomplished in order to determine if the voltage drop in a circuit exceeds the maximum allowed under NEC (National Electric Code) guidelines.

MEASURING CURRENT WITH A DIGITAL MULTIMETER

The process of measuring current (amperage draw) with a digital meter can be easily understood by breaking the process down into to two fundamental categories:

1. Direct Current Circuit
2. Alternating Current Circuit

A common application of measuring direct current in HVACR troubleshooting involves fossil fuel heating systems that employ an electronic ignition system. Figure 5-16 shows one example of the main components of this type of electrical system and how a meter is used to check its operation.

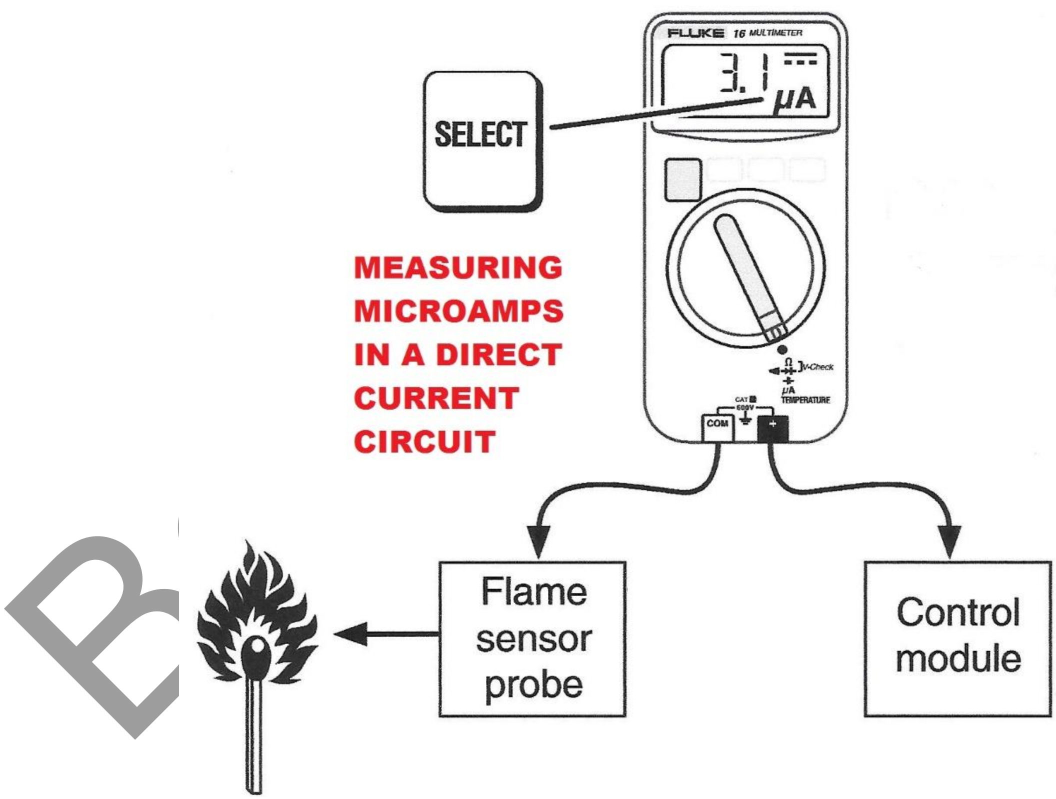


Figure 5-16 A digital meter reading micro-amps to determine if an ignition system is operating properly. Note the solid and dashed line in the upper right hand corner of the meter display, indicating direct current.

HVACR TROUBLESHOOTING FUNDAMENTALS

Electricity & Wiring Diagrams

SECTION
2

WIRING DIAGRAMS AND HVACR SYSTEM COMPONENTS

In order to effectively troubleshoot HVACR equipment, you must be familiar with the basic principles of electricity. And, once you have a firm understanding of these fundamental concepts, you can apply that knowledge to test and evaluate the electro-mechanical and electronic components used in HVACR systems, and the wiring that connects them together, to pinpoint the source of a problem.

UNIT
6

Wiring Diagram Structure & Symbols

Learning Objectives:

After studying this unit, you will be able to:

1. Identify the three basic circuits employed in HVACR electrical systems.
2. Explain how schematic and pictorial diagrams guide technicians in the troubleshooting process.

When very young children begin learning basic language skills, the most common situation is that they are learning in a one language only environment. In some cases, the environment is bilingual, which means that someone learning to communicate in this situation considers it natural to translate between one language and another.

Learning a second language later in life after learning everything about communication in one language only for an extended period of time is more difficult. It requires far more concentration on the aspect of translating from one language to another, committing not only new language rules to memory, but also the memorization of terms for many things that are spelled and sound completely different from our primary language.

And the reality of HVACR electrical troubleshooting is that no one begins learning the second language of wiring diagrams at a very young age.

Yes, learning how to use wiring diagrams is basically the same as learning to speak a second language. Symbols, along with abbreviated lettering are used to represent components and identify connection points. Perfectly straight lines that make perfect 90-degree turns are drawn in a schematic diagram to represent a wire that isn't in fact perfectly straight or makes a perfect 90-degree turn.

The bottom line for technicians and electrical troubleshooting is this:

Developing the skill to read a wiring diagram, interpreting what it means, and then translating the information that appears on paper to apply it to the actual equipment being serviced.

This unit will provide the fundamental information necessary to accomplish that objective.

WIRING DIAGRAM STRUCTURE

There are two categories of wiring diagrams that technicians work with when troubleshooting HVACR electrical systems; the schematic and the pictorial.

We'll begin our discussion on schematic diagrams with the symbol for a transformer. In Figure 6-1 we're showing the fundamental symbol on which the schematic diagram is built, regardless of the specific type of equipment.

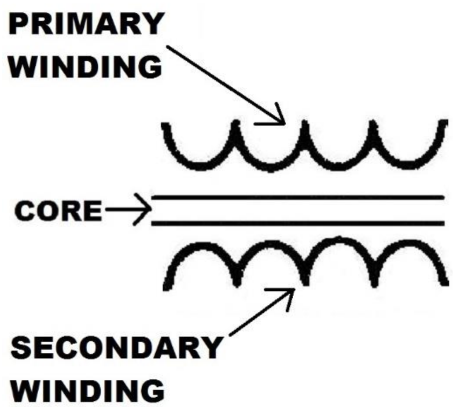


Figure 6-1 A schematic symbol for a step-down transformer used in HVACR electrical systems. The two voltage systems that exist in equipment are operating voltage and control voltage. The control voltage is 24 VAC and the operating voltage can be 120 VAC, 240 VAC or 480 VAC.

As we're showing here, the fundamental symbol for a transformer can be designed with two lines representing the laminated steel or iron core of the device. The insulated wire windings shown will be wrapped around the core. Figure 6-2 shows what is done with the symbol when using it as a basis for a schematic diagram.

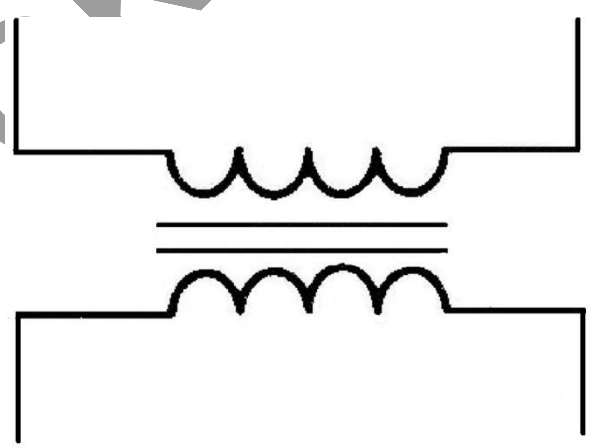


Figure 6-2 The fundamental dual voltage schematic diagram is built on the symbol of the transformer. With lines added to the symbol from both windings, other symbols representing loads and switches can be shown in the appropriate location on the diagram with the connecting lines drawn from these component symbols to the extended lines on the transformer symbol.

In Figure 6-8, with the test instrument set to a low resistance scale, an accurate reading of the secondary winding resistance will be rendered. In this example, as we would expect, the resistance of the secondary winding (3.3 Ohms) is lower than the reading obtained when checking the primary winding because the secondary winding has fewer turns of wire wrapped around the transformer core.

In Figure 6-9 the display screen is showing the reading your test instrument would provide in the event that the secondary winding of the transformer has failed.

Figure 6-9 The secondary winding of this transformer has failed. The meter display is showing "OL" which is an indicator of "Open Line".

In the event that the resistance check shown in Figure 6-21 resulted in an “OL” display on our meter, the diagnosis would be that the coil has failed open, and the relay would need to be replaced.

In addition to checking the coil resistance, an ohmmeter can be used to check the N.O. and N.C. condition of the relay terminal connections. In Figure 6-23 meter leads are attached to terminals #1 and #3.

Figure 6-23 Checking N.O. terminals of a relay to determine that they are, in fact, open without voltage applied to the coil.

And, Figure 6-24 shows the result our meter would display if the contacts inside the switch are in their proper position, ready to be switched to a closed position when 24-volts is applied to the coil of the relay shown in our sample schematic diagram.

Figure 6-24 Testing at the N.O. terminals on a relay should show “Open Line” without control voltage applied to the relay coil.

In the event that control voltage is applied to a relay coil while the N.O. terminals are under test with an ohmmeter, the display should show a fraction of an Ohm resistance, indicating that the contacts inside the switch are closed and will provide almost no resistance to allow current to flow unrestricted through the circuit. (See Figure 6-25)

Figure 6-25 If the N.O. relay contacts are in good condition; the meter will display a very low resistance when voltage is applied to the relay coil. In the event that the meter showed 1 Ohm resistance or more, it would indicate that the contacts are corroded, and would cause excessive voltage drop in the circuit.

Another situation in which a very low resistance would be displayed by the meter is when the N.C. terminals of the relay are tested as shown in Figure 6-26 without any voltage applied to the relay coil.

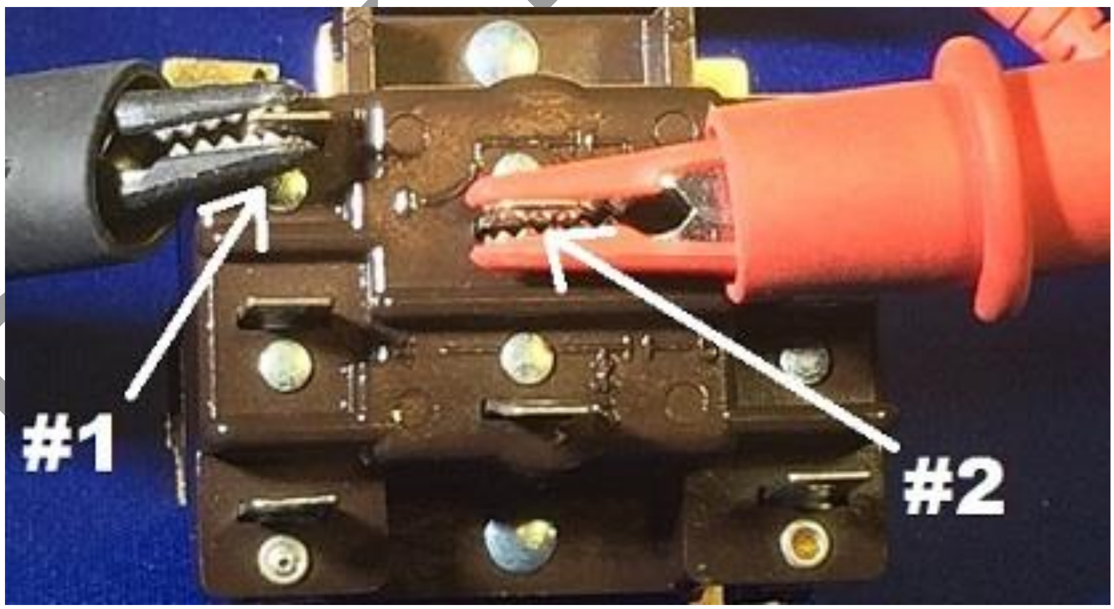


Figure 6-26 Testing the N.C. contacts of a relay without control voltage applied to the coil should show a very low resistance on the meter display.

PICTORIAL WIRING DIAGRAMS

While schematic diagrams provide an accurate map of the electrical circuits, pictorial diagrams, while they also show circuitry, are more valuable to the technician in regard to the process of showing how components and wiring harnesses may be physically arranged. Figure 6-36 shows one example of a pictorial diagram of a gas furnace electrical system.

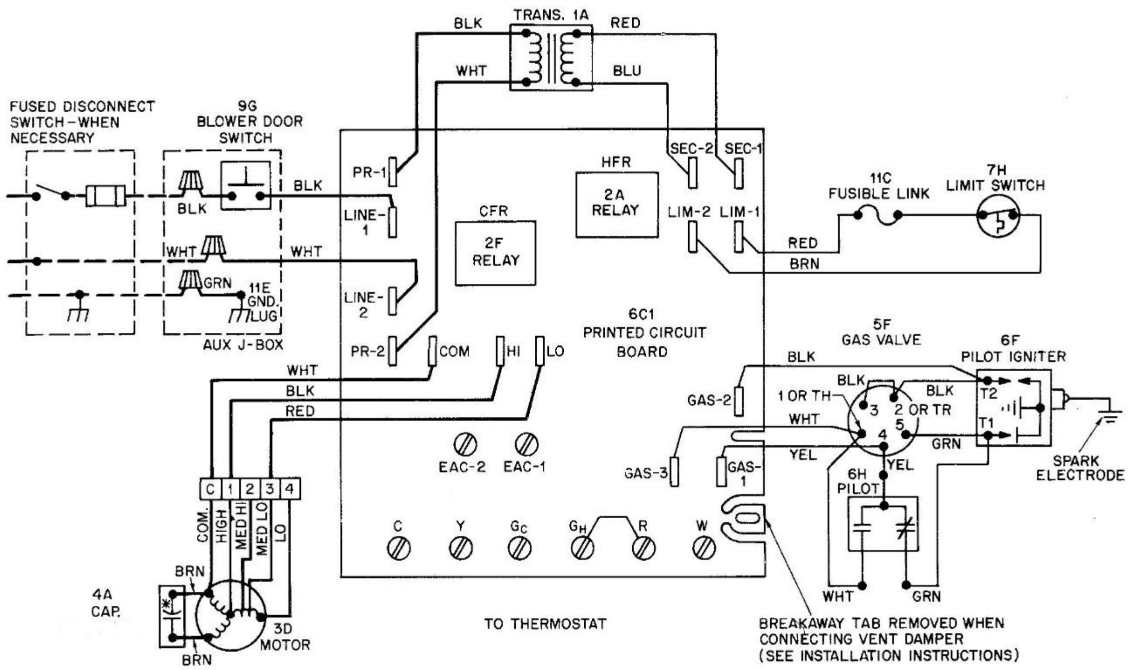


Figure 6-36 A pictorial diagram provides some insight on where some components in the equipment are located and how wiring connections are accomplished. Pictorial diagrams often show wiring harness color code. This example also shows that the manufacturer is using a number/letter method of identifying the components, information that would also appear on a legend accompanying the diagram.

This illustration shows an early version of a printed circuit board control system employed in the operation of a gas furnace. Note that some of the components discussed in this unit; transformer, fan motor, and relay, are shown not strictly in a symbol format, but are drawn more as a picture. You'll also note that in some cases, schematic type symbols are incorporated in showing some components.

One example of this is 3D Motor. Windings are shown in the motor and the schematic symbol for a run capacitor is used, however, the wiring harness and its connection to the printed circuit board are shown more as a picture. This also applies to the 1A Transformer.

Also note that the schematic symbol for a switch that reacts to temperature is used to show the 7H limit switch. And, within the 6H Pilot, the symbols for a normally closed and normally open switch are shown.

UNIT 7

HVACR Motors

Learning Objectives:

After studying this unit, you will be able to:

1. Explain the fundamental operating characteristics of motors used in HVACR equipment.
2. Describe the proper procedures involved in checking motors, relays, capacitors and contactors with test instruments.
3. Explain the operation of three-phase A/C motors and variable speed motors.

With an understanding of the basic electrical principles and the structure of schematic and pictorial diagrams discussed so far in this text, the next step in developing your electrical troubleshooting skills involves performing specific tests relative to motors, relays, and capacitors.

From a fundamental perspective, motors in HVACR equipment are used to handle indoor air in duct systems, outdoor air in air-cooled condensing systems, operate refrigeration compressors, and accomplish forced-air venting in fuel burning equipment. What this means for you as a technician working in the field and responding to a customer's complaint that their system is not performing properly is that you will be using test equipment in several different ways.

In one situation, you may be using an ammeter to check for proper current draw of an operating motor. In another instance you may have to use a voltmeter to determine whether or not a motor is the fault, or if a problem in the electrical system is responsible for the failure of the motor to operate. Or, evaluating a motor may involve testing with an ohmmeter to check for proper resistance of motor windings.

Also, when it comes to replacing a failed motor or other electrical component, you may encounter situations in which an exact replacement part is not available due to the age of the equipment you're servicing. One example of this may be a replacement motor that has different color coded wiring, or may need wiring changes in order to operate in the proper direction.

Another aspect of this is that it’s very likely you will encounter situations in which a previous repair was performed and a component that was not classified as OEM (Original Equipment Manufacturer) was used.

With a firm understanding of motors and how run and start capacitors, and relays and contactors are used to control their operation, you will be able to avoid mistakes and also correct unsafe and improper repairs that you encounter in the field.

This unit will discuss the fundamentals of motor design, and how capacitors are used to help them start and run efficiently. It will also provide an overview of variable speed motors.

MOTOR WINDINGS

Motors, like transformers, employ wire wound around an iron or steel core that creates an electromagnetic field when electrical energy is applied. The difference between the two is that while a transformer electromagnetic field is used to create a lower voltage in its secondary winding due to fewer turns of wire in that winding, a motor converts the electrical energy into mechanical energy.

The operating principle of a fundamental motor is based on the laws of magnetism (like poles will repel each other and unlike poles will attract each other) and the mechanical action is a result of two types of magnets within the motor.

….The electromagnet that is a result of wire wound around the stator of the motor.

….The permanent magnet that is identified as the rotor of the motor.

Figure 7-1 shows an illustration of these two magnets within a motor assembly.

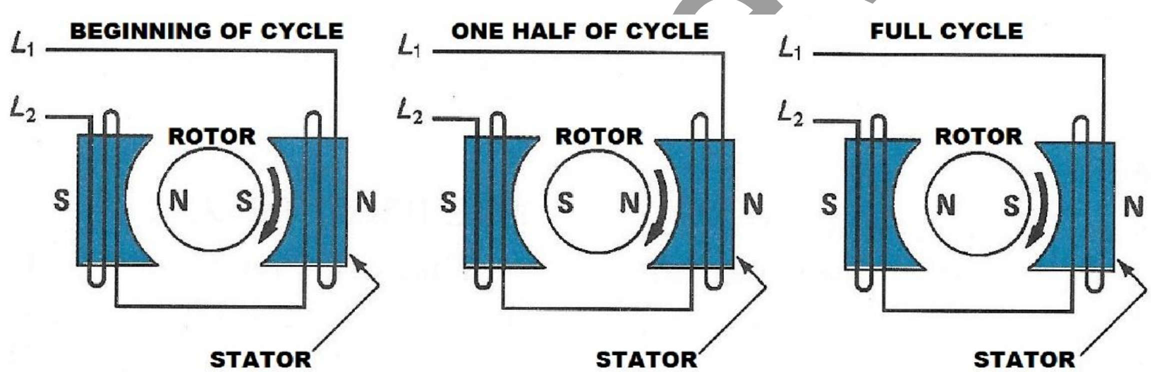


Figure 7-1 A simplified illustration of an AC (Alternating Current) electric motor operating through one complete rotation. Note the S and N designations for South and North poles of the magnets. The permanent magnet known as the rotor is mounted in a bearing assembly at each end of the motor, and rotates due to the push/pull of the magnetic fields.

In addition to understanding the concept of the laws of magnetism relative to motors, a knowledge of how alternating current works is also helpful when considering their method of operation. 60 Hertz is the alternating current in the United States.

This means that every 1/60th of a second, the S pole of the electromagnet becomes an N, and the N becomes an S. This polarity switch causes the permanent magnet to continue moving as long as power is applied to the electromagnet.

A rotor is mounted in close proximity of the electromagnet and has a series of magnetic bars located around its surface to accomplish the continuous rotation created by the attraction and repulsion.

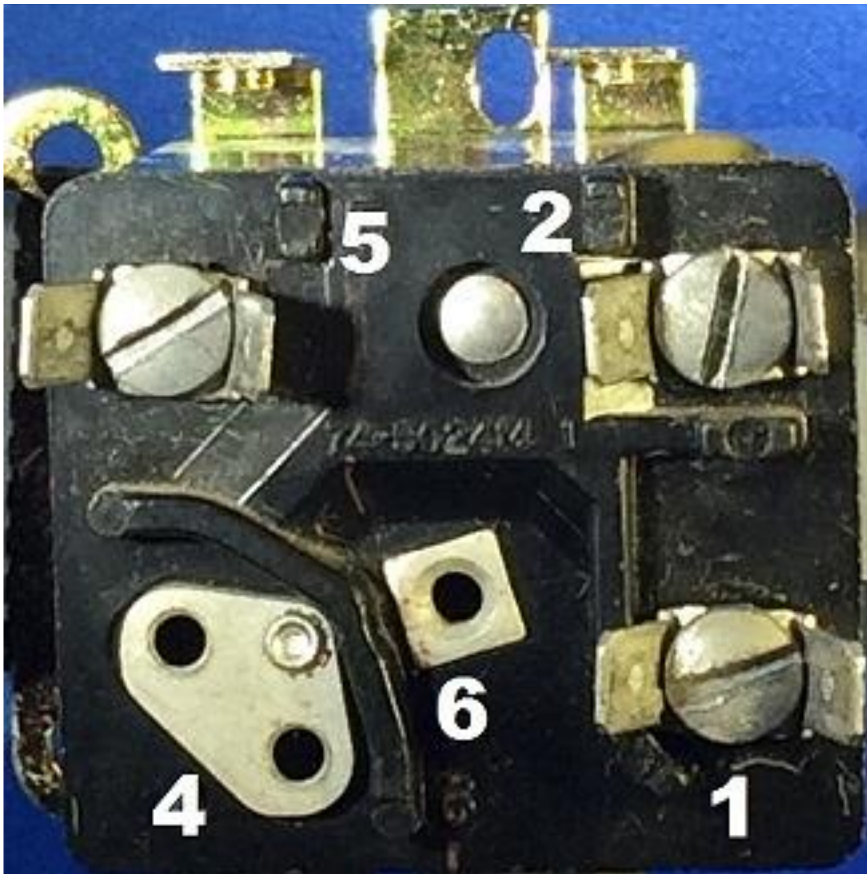


Figure 7-27 On a potential relay, the terminals used for the operation of the device are 1, 2, and 5. Terminals 4 and 6 are used as convenient tie points for wiring harness connections and have no connection to the operation of the relay.

As this illustration shows, when bench testing this device, the terminals 2 and 5 which are wired to the relay coil, are the connections to which an ohmmeter check should show resistance. At terminals 1 and 2, which are wired to the normally closed switch in the relay, an ohmmeter check should show continuity.

Two other terminal connections that are commonly found on potential relays are #4 and #6, which have nothing to do with the inner components of the relay. These two connections, often referred to as “dummy” terminals, are sometimes used as a tie point for wiring harness connections involving components such as an outdoor fan motor or run capacitor.

The #4 and #6 connecting points and the #1, #2, and #5 on the relay may the threaded in order to allow for the addition of a spade terminal connection (as shown above), or the relay may be equipped with permanent spade connectors.

An important point for technicians to understand about potential relays is that an OEM relay is designed specifically to apply to the compressor in the HVACR equipment.

Variable speed motor technology is also applied to refrigeration system compressor operation. One example of varying the speed of a compressor according to the load (the amount of work that needs to be done in regard to transferring heat) is shown in the illustration below in Figure 7-63, an example of a small refrigeration system that would be found in equipment such as an under-counter beverage storage unit.

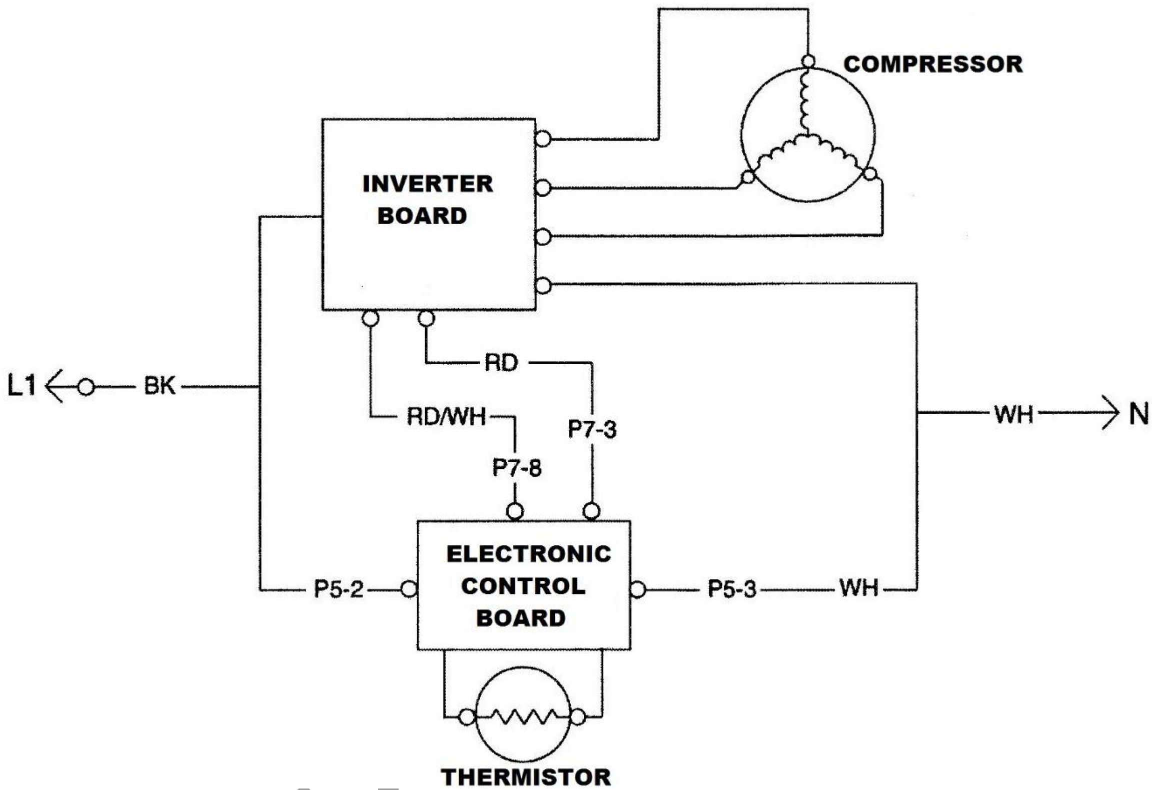


Figure 7-63 An example of variable speed technology employed in the operation of a refrigeration system compressor. The equipment power supply is 120 VAC. The compressor is three-phase, and operates on DC voltage.

When taking a fundamental approach to troubleshooting this type of electronic compressor control system, consider the concept of input and output. The input to the inverter board, for example is 120 VAC, while the output is a DC voltage determined by the manufacturer in a specific situation. The electronic control board in this example also has a 120 VAC input as well as input from a thermistor, an electronic device that senses temperature and sends information to the board.

In regard to output from the inverter, it serves to speed up or slow the compressor down depending on the input information it receives from the printed circuit board. A primary factor to understand about troubleshooting this type of compressor is that in some cases the manufacturer's service manuals will explain that it is not necessary, nor recommended, to test the output of the inverter. However, it may be common in some models of equipment of this type to check the input voltage of the inverter as a troubleshooting step.

Separating the brain section from the back of the motor assembly requires the removal of two screws (Figure 7-74), exposing the control unit high voltage capacitors and motor wiring disconnect harness (Figure 7-75).

Figure 7-74 Once the power to the equipment has been off for at least five minutes, it is safe to remove the screws and separate the control from the motor case.

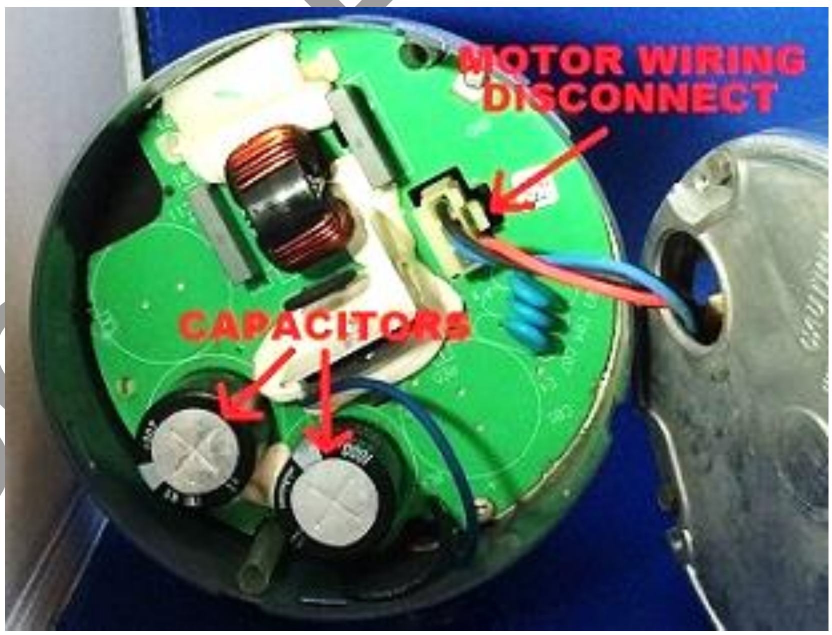


Figure 7-75 This ECM control has two high voltage capacitors that could cause serious injury if a technician doesn't wait at least 5 minutes to allow them to discharge before removing the control segment from the motor assembly. The motor wiring harness disconnect is also shown here.

Disconnecting the motor wiring harness (in our example with blue, red, and black wires) from the control assembly will allow you to accomplish motor winding tests.

Figure 7-76 With a test instrument set properly, the windings of an ECM motor can be checked for resistance. Here our meter shows 5.5 Ω.

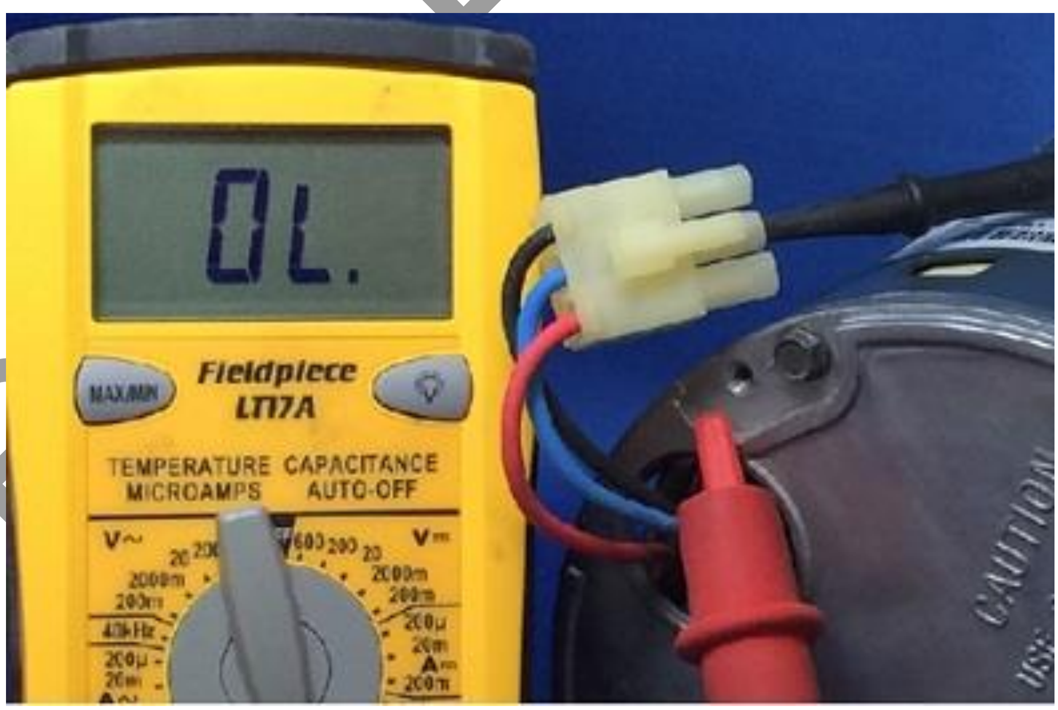


Figure 7-77 This test from a motor lead to the motor case shows that the motor winding is not shorted to ground. If the motor was grounded, the meter would show continuity.

UNIT 8

Wiring Diagram Review: Gas & Electric Heating Systems

Learning Objectives:

After studying this unit, you will be able to:

1. Interpret a schematic diagram to determine the sequence of operation of gas and electric furnaces.
2. Explain how to isolate components for voltage tests in troubleshooting procedures.
3. Describe the process of confirming a failed component via resistance and continuity tests with an ohmmeter.

This unit provides a general overview of gas and electric heating system wiring diagrams. The skill to examine pictorial and schematic diagrams and isolate components and circuits applies to all types of heating systems. It doesn't matter if they show the most fundamental fuel-burning heating equipment such as a standing pilot gas furnace, or a unit that employs an electronic system that controls the operation of a glow coil or spark ignition system, induced draft, and a variable speed air handler motor.

The concept of interpreting symbols and circuitry, and applying that knowledge to understanding the sequence of operation of the equipment in order to determine which component is responsible for a breakdown is what troubleshooting is about.

DEVICES & SEQUENCE OF EQUIPMENT OPERATION

The bottom line for HVACR technicians is that the majority of the time we are only called upon when something stops working. On some occasions we may have the opportunity to perform preventive maintenance checks on a system, and when this occurs, we should consider it a golden opportunity to observe equipment and the sequence of operation when the electrical system is working properly.

As an example, consider an on/off cycle for a gas furnace that employs a hot surface ignition system and induced draft in the furnace vent….

….The thermostat calls for heat.
….The induced draft motor is energized.
….The hot surface ignitor is energized.
….The gas valve is energized, allowing gas flow to the burners.
….The blower motor is energized.
….The thermostat is satisfied when the room temperature rises to the set point.
….The gas valve is de-energized, stopping the flow of gas to the burners.
….The blower motor is de-energized on a time delay system.

And there we have it, an outline of the steps that a gas furnace goes through when it is cycled on and off. Our simplified description of sequence begins with one switch (the thermostat), explains the operation of the loads that do their job while the system is providing heat, and describes what happens when the thermostat de-energizes the heat source to end a cycle.

Other factors to understand about the sequence of operation of a gas furnace are:

….Additional switches in the furnace that make and break circuits to loads, some of which are control or safety devices that react to temperature, and others that are within relays that may be electromechanical or solid state design.

….The equipment can operate as intended because it employs a dual voltage system of a 120-Volt equipment power supply and a 24-Volt control voltage.

In regard to an electric furnace, the simplified sequence of operation can be described:

….The thermostat calls for heat.
….The blower motor is energized to ensure air flow across heating elements.
….The 24-volt control segment of a device is energized to allow an equipment voltage switch within the device to close and energize a heating element.
….If necessary, additional control devices are employed to operate additional elements.
….The thermostat is satisfied, de-energizing the heating element(s).
….The blower motor is de-energized on a time delay system.

An electric furnace also requires additional switches for safety and component control.

The switching segments of a sequencing device may have terminal connections that identify a switch as being either a Main (M) switch or an Auxiliary (A) switch as shown in our example in Figure 8-10. In the timing of the switches in a device identified as M or A, the main switch closes first due to its close proximity to the heating segment of the device, and the auxiliary switch closes on a subsequently longer delay time.

In some cases, the switching terminals are not identified as M or A terminals, but are all identified with the same letter. One example of this type of device is shown in Figure 8-11.

Here, all the switch identifiers are labeled with the letter M. Also in this example, the terminals that are not identified by any letter markers are the connections to the 24-volt heating segment of the sequencer.

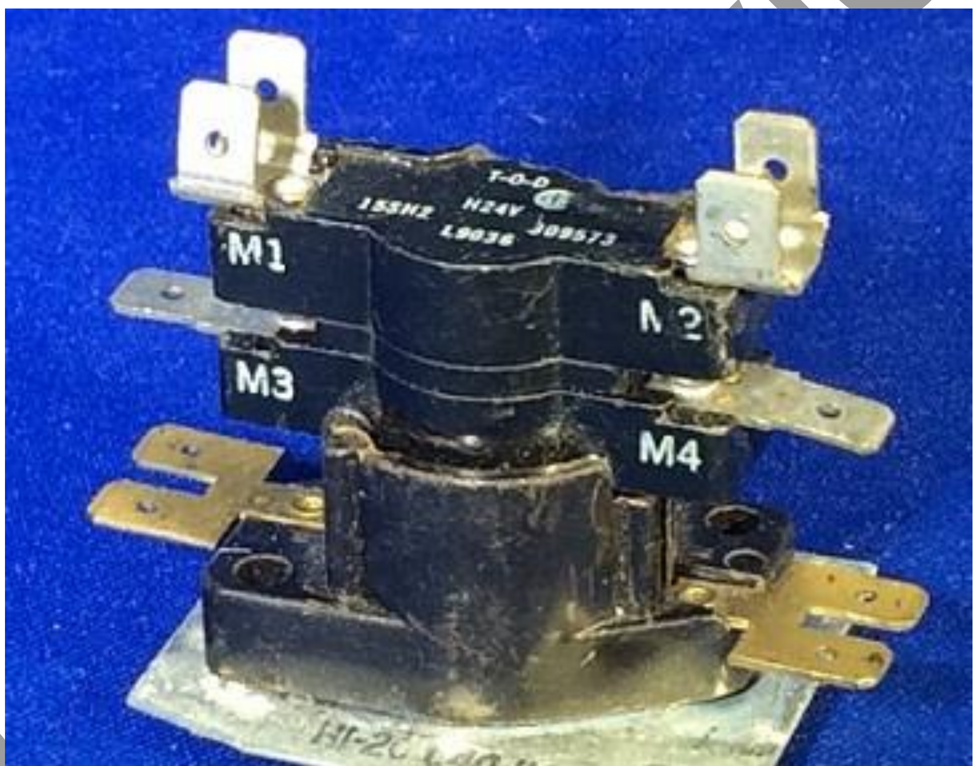


Figure 8-11 The switching terminals of this sequencer are identified as "M" connections. The 24-volt heating segment of the device is connected to the un-marked brass terminals shown at the bottom. A device such as this is designed to energize two heating elements in sequence.

An important factor to keep in mind about letter identifiers on sequencers in electric heating equipment is that a manufacturer may employ an auxiliary switch that isn't intended to be wired to a heating element, but instead to another sequencer control segment. Figure 8-12 illustrates how M and A switching assemblies are commonly wired to control the operation of equipment.

In the schematic diagram, this limit switch is shown as component # 7H.

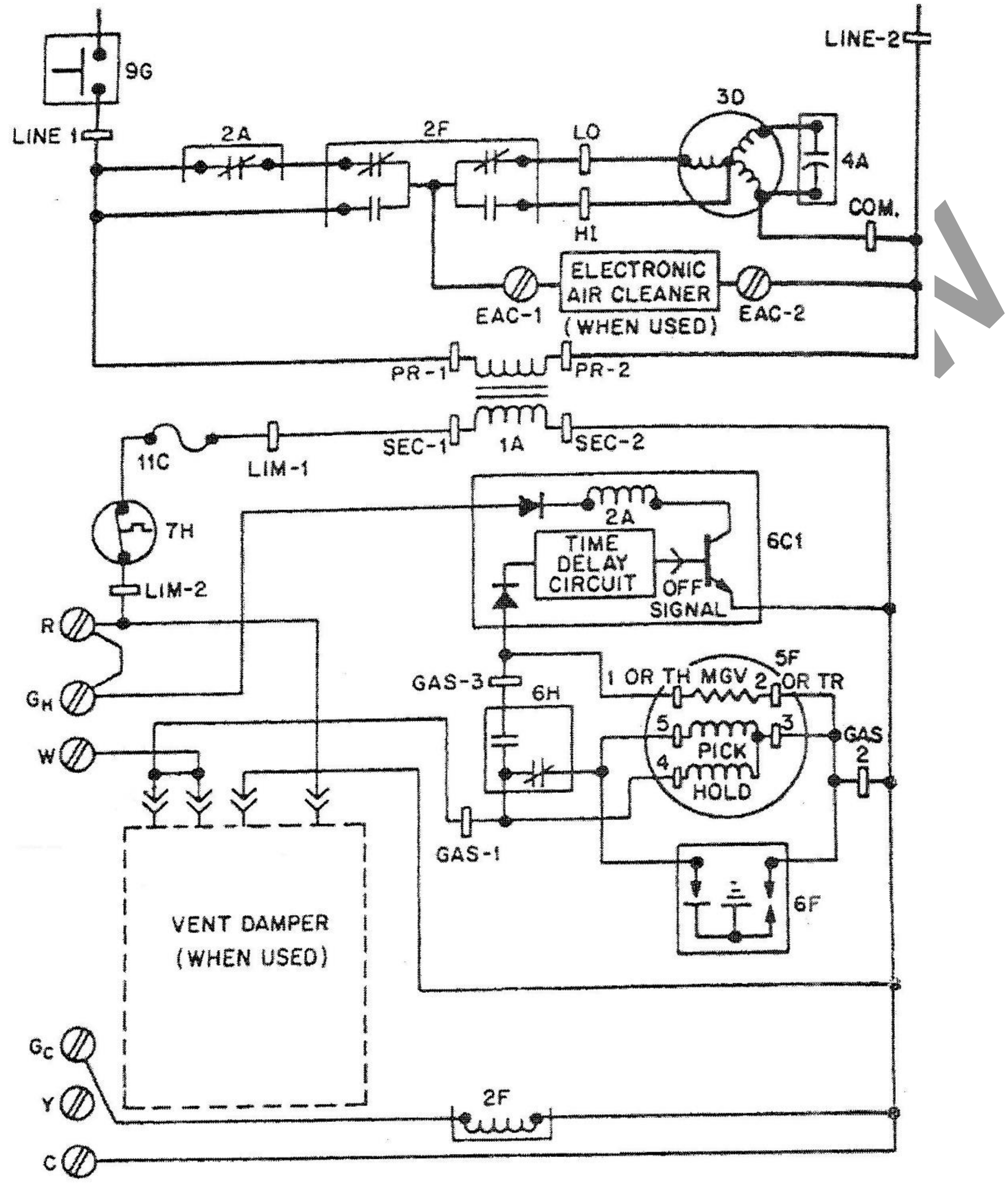


Figure 8-27 In this schematic diagram, the limit switch is identified as component # 7H. Switches of this type may react to excessive temperature, open, then re-set when they cool down, or they may be referred to as a one-time limit switch because once they open, they don't re-set. In this specific case, it is a one-time switch. Also shown wired in series with the secondary of the transformer is a fuse (# 11C).

The schematic above shows another example of the variety of ways that manufacturer's draw their diagrams, depending on the make and model year of the equipment. Some of the factors to understand about the particular model of furnace are:

….Component 5F is a five-wire gas valve that contains two wound coils (Pick and Hold) and a resistive coil (MGV). This is one example of a gas valve that is used in a pilot flame spark ignition system.

….Component 6F is the spark ignitor. On a call for heat, the Pick and Hold coils of the valve allow pilot gas flow and the spark ignites the fuel. Once the pilot is proven, the MGV resistive coil is energized, allowing gas flow to the burners.

….Component 6H is the pilot switch assembly. Note the N.O. switch that closes, allowing a circuit to both the MGV and the 6C1 Time Delay that will allow a circuit to the indoor blower motor through the relay contacts 2A.

Figure 8-28 shows the P.C. board for this equipment, the 2A and 2F relays and the protective fuse.

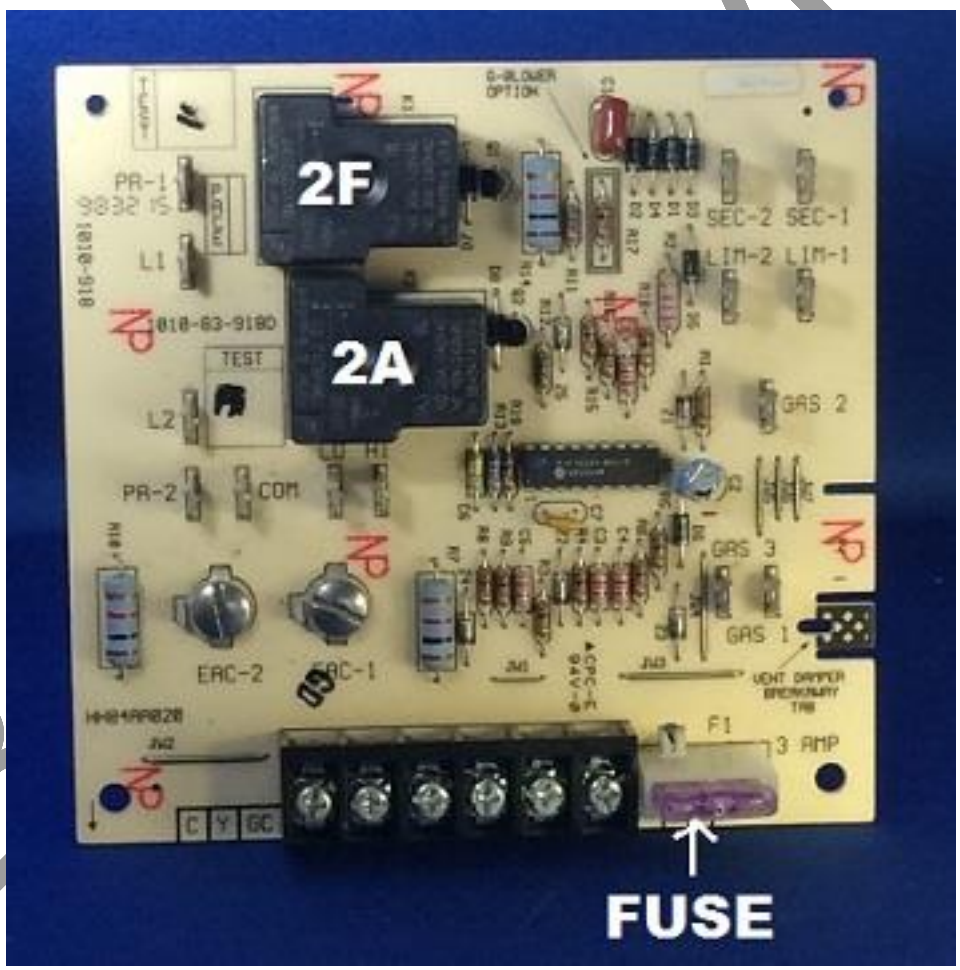


Figure 8-28 The 2F relay on this board is used in the event that the furnace is an air handler in a heat/cool application, operating the fan on high speed for the cooling mode. The 2A relay is used for time delay operation of the blower motor in the heating mode. The protective fuse can be removed to be checked with an ohmmeter.

UNIT
9

Wiring Diagram Review:
Comfort Cooling & Refrigeration Systems

Learning Objectives:

After studying this unit, you will be able to:

1. Read a typical schematic for comfort cooling and refrigeration systems and explain the sequence of operation.
2. Isolate circuits on schematic diagrams to accomplish troubleshooting procedures.
3. Identify hot gas and electric defrost circuits in refrigeration equipment.

This unit provides an overview of dual-voltage schematic diagrams for comfort cooling systems and refrigeration systems such as those found in light commercial applications that do not employ step-down transformers for control purposes.

Typical comfort cooling equipment in residential and light commercial applications are commonly single-phase operation, employing compressor motors that operate with potential relays, run and start capacitors, and indoor and outdoor fan motors that are PSC operation. In some commercial applications, the power supply is three-phase, which means that the motors will not operate in conjunction with capacitors.

Regardless of the equipment supply voltage, comfort cooling electrical systems are represented by dual-voltage schematic diagrams that are designed from the symbol for the schematic, showing the equipment voltage for operating motors, and 24-volt control voltage systems that employ thermostats, coils, and other devices to protect and operate the equipment. ECM technology (variable speed motors) is also common in regard to both indoor and outdoor air handling for comfort cooling equipment.

Electrical systems for refrigeration equipment found in walk-in coolers and freezers, reach-in equipment, and ice machines may or may not employ the dual-voltage system for operation and control, depending on the equipment design. Some equipment in this category may employ ECM technology for air handling.

DUAL-VOLTAGE SCHEMATIC DIAGRAMS IN COMFORT COOLING EQUIPMENT

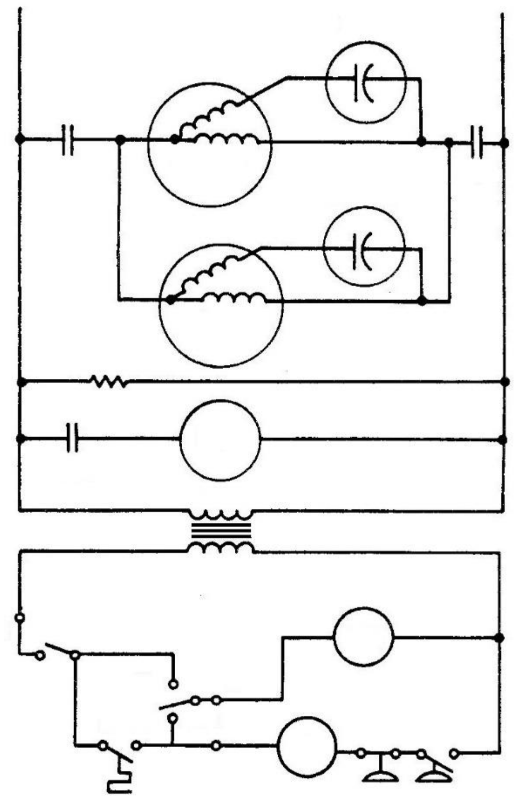


Figure 9-1 A simplified dual-voltage schematic diagram for a comfort cooling system without legend identifiers.

In order to explain the process of learning how to read and interpret schematic diagrams, the illustration above is shown without any legend identifiers. Reading this diagram strictly from a schematic symbol perspective, we can apply common knowledge regarding comfort cooling equipment and determine the following ten factors:

1. The symbol for the step-down transformer defines the diagram as dual-voltage.
2. The equipment voltage is 240-volt, single-phase.
3. The control voltage is 24-volts.
4. This unit has a crankcase heater that is energized constantly.
5. The compressor and outdoor fan motor are PSC.
6. The indoor fan motor is not PSC.
7. The compressor and outdoor fan motor are controlled by a two-pole contactor.
8. The indoor fan motor is controlled by a fan relay consisting of a single-pole switch and a 24-volt controlled coil.
9. The thermostat contains a system switch, fan switch, and close-on-temperature rise switch.
10. The compressor is protected by high and low pressure switches wired in series with the contactor coil.

Another aspect of determining whether or not the thermostat or the thermostat wiring is the source of a "Sitting Dead" complaint is to check directly at the low voltage wiring harness connections directly at the equipment. (See Figure 9-13)

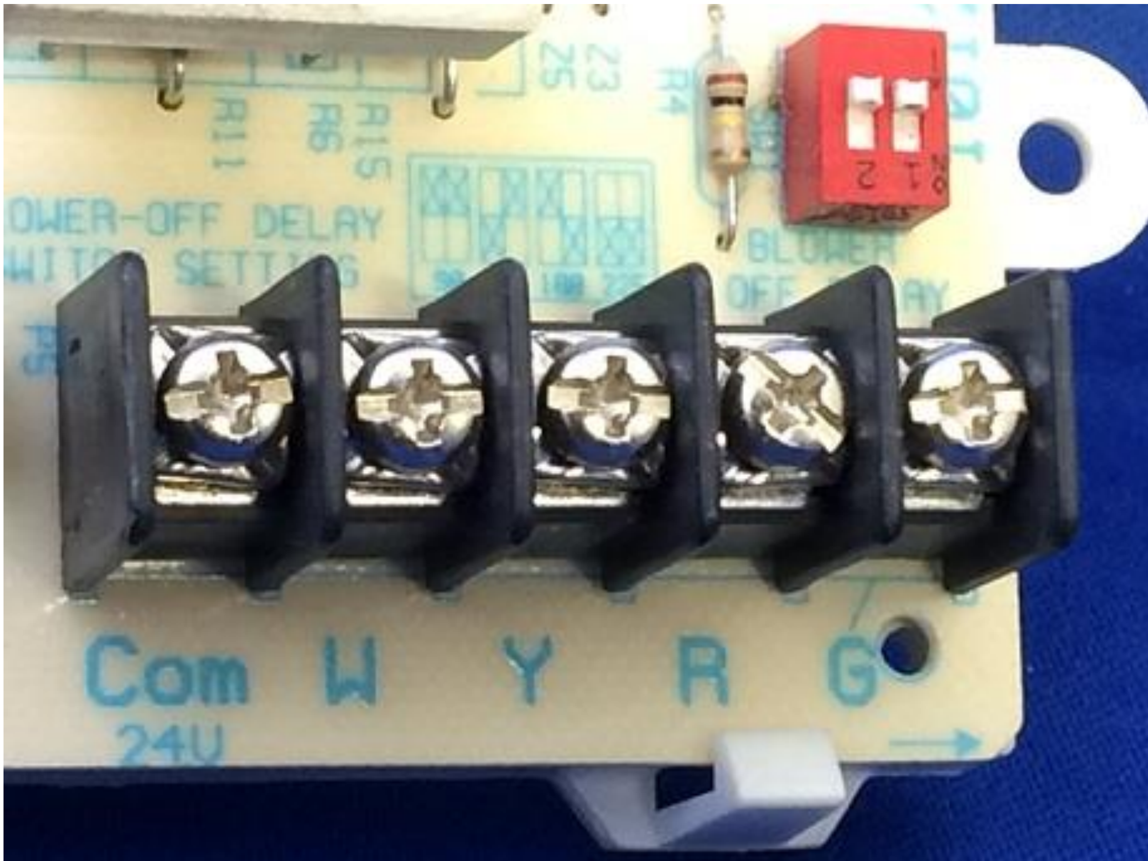


Figure 9-13 The terminal wiring connections on the equipment printed circuit board allow for connection of the low voltage control wiring harness. When the wiring harness is removed, jumpers can be installed on the appropriate wiring connections to eliminate the thermostat and the wiring from the equipment to the thermostat and operate the equipment manually.

CAUTION!:

When using jumper wires to manually operate equipment, always be sure that the thermostat assembly is not connected to the circuit. Jumping wiring with a thermostat in the circuit could damage the device.

Figure 9-13 shows the wiring connections and color code for the low voltage harness to an equipment control board. Also note that this illustration shows the dip switches for selecting the desired time for the blower off delay in the heating cycle of the equipment.

UNIT
10

Wiring Diagram Review: Heat Pumps

Learning Objectives:

After studying this unit, you will be able to:

1. Identify the three operating modes of a heat pump electrical system.
2. Explain the fundamental troubleshooting procedures that apply to heat pump defrost control operation.

This unit focuses on the electrical circuits in heat pumps that allow the equipment to cool and heat a conditioned space, employing both a refrigeration system, and when necessary for the heating and defrost modes, supplemental electric heating elements.

As with comfort standard heating and cooling equipment and refrigeration systems, the dual-voltage schematic diagram that shows the applied equipment voltage and a 24 VAC control system is a key element in explaining the operation of heat pump components and the sequence of operation of the equipment, providing the technician with the information necessary in order to troubleshoot.

When the air pressure drops, the AS switch closes, energizing the defrost relay (DFR) coil. (Figure 10-8)

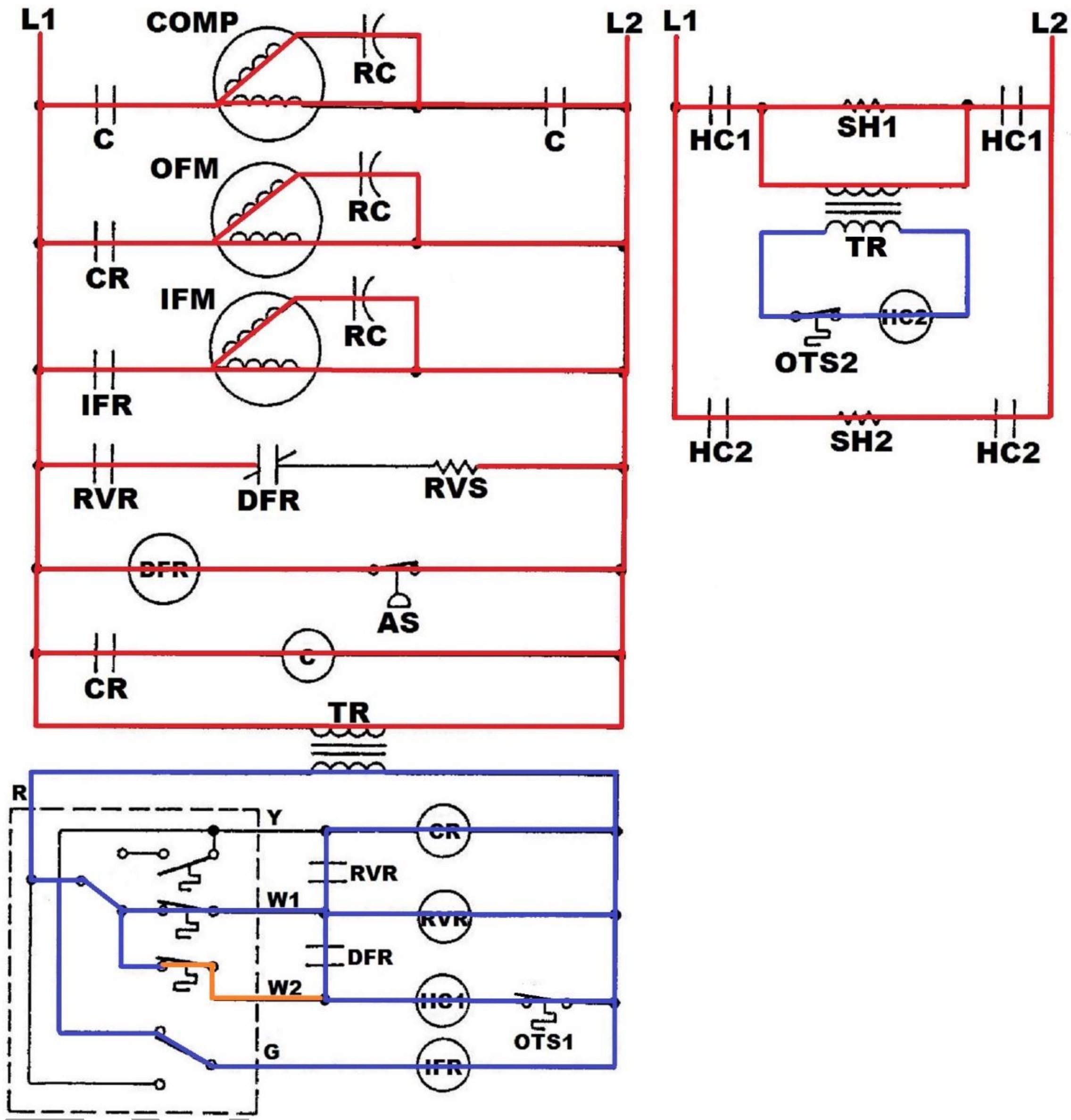


Figure 10-8 In the defrost mode, the 230-volt DFR coil is energized when the air switch closes due to low air pressure through the outdoor coil. The 230-volt N.C. DFR contacts open, breaking the circuit to the reversing valve solenoid, and the 24-volt DFR contacts close to make a circuit through the HC1 coil.

When this unit is in the defrost mode, the W2 circuit doesn't have to be made in order for the supplemental heat strips to be energized. Defrosting can occur when only one stage of the thermostat is calling for heat.

Also, if a defrost mode is necessary, the OTS1 and OTS2 outdoor thermostats will be closed, ensuring the operation of both heat strips.

HVACR Troubleshooting Fundamentals
Electricity and Wiring Diagrams

Appendix A

Troubleshooting Problems

Student Review and Workbook Pages

Appendix A contains a series of troubleshooting problems in which various scenarios are presented. In order to accomplish your diagnosis of the problems, you may be required to reread sections of this book and complete additional research beyond what is found in this text.

Explain your diagnoses by filling in the blanks in your workbook pages at the end of Appendix A.

TROUBLESHOOTING PROBLEM #1

A HEAT PUMP THAT'S NOT KEEPING A BUILDING COMFORTABLE

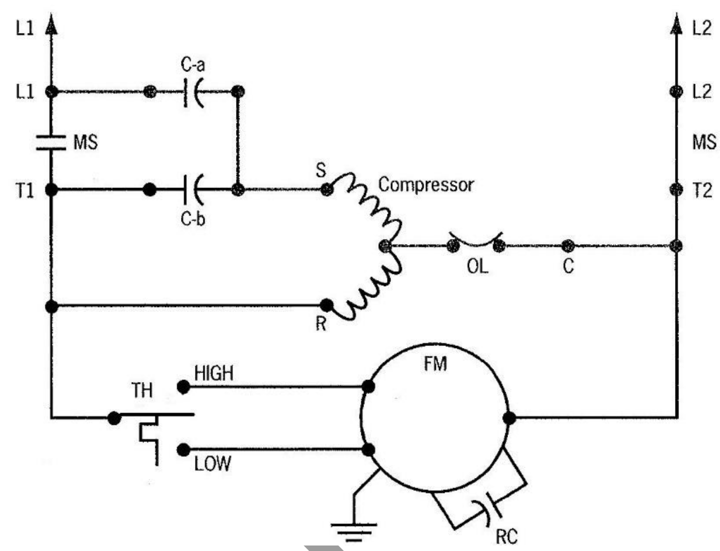


Figure A-1 A partial wiring diagram that shows the compressor and outdoor fan motor circuits of a split system heat pump. The customer's complaint is that the equipment has not been keeping the building comfortable since the weather turned warmer in the summer season.

In this troubleshooting situation, summer is in full swing and the outdoor temperature has been in the low 90's for more than a week. The equipment you are called to service is a ten-year-old split system heat pump. The customer's description of the problem is that the building was being kept comfortable at the beginning of the cooling season, but they have noticed that lately while there is air flow from the registers, the building is too warm for comfort, especially in the afternoon.

When you arrive at 2PM, you confirm that the indoor air handler is operating. And you also note that since preventive maintenance has been performed regularly on this system, the filter is clean and the air flow throughout the building is sufficient. The thermostat has been turned down to 70-degrees, but the temperature in the building is near 83-degrees.

Moving to the outdoor section, you find that the outdoor fan motor blade is moving air, and the compressor, which is hot and off on its internal overload, cycles on after a short time.

(The diagram in Figure A-1 shows the circuitry for the compressor and outdoor fan motor of this system.)

After a brief run time, the compressor again kicks off on overload.

In order to be sure that there is sufficient air flow you decide to check the outdoor fan motor circuit. Your voltage check from T1 connection to HIGH on TH shows 240 VAC, and a test from T1 to LOW shows 0-volts.

Your troubleshooting question: What is the next step you need to take in servicing this equipment?

Explain your answer by filling in the blank for Troubleshooting Problem #1 in your workbook pages.

TROUBLESHOOTING CHARTS

Another aspect of troubleshooting HVACR equipment involves manufacturer's charts that may offer both general information as well as specific procedures in various formats to allow the technician to find the source of the problem.

Complaint	No Cooling							Unsatisfactory Cooling					System Operating Pressures				
POSSIBLE CAUSE DOTS IN ANALYSIS GUIDE INDICATE "POSSIBLE CAUSE" — SYMPTOM	System will not start	Compressor will not start - fan runs	Compressor and Condenser Fan will not start	Evaporator fan will not start	Condenser fan will not start	Compressor runs - goes off on overload	Compressor cycles on overload	System runs continuously - little cooling	Too cool and then too warm	Not cool enough on warm days	Certain areas to cool others to warm	Compressor is noisy	Low suction pressure	Low head pressure	High suction pressure	High head pressure	Test Method Remedy
Pow er Failure	●																Test Voltage
Blow n Fuse	●		●	●													Impact Fuse Size & Type
Loose Connection	●			●		●											Inspect Connection - Tighten
Shorted or Broken Wires	●	●	●	●	●	●											Test Circuits With Ohmmeter
Open Overload	●	●		●	●												Test Continuity of Overloads
Faulty Thermostat	●			●					●								Test continuity of Thermostat & Wiring
Faulty Transformer	●		●														Check control circuit w ith voltmeter
Shorted or Open Capacitor		●			●	●											Test Capacitor
Internal Overload Open	●																Test Continuity of Overload
Shorted or Grounded Compressor		●				●											Test Motor Windings
Compressor Stuck	●					●											Use Test Cord
Faulty Compressor Contactor	●	●			●	●											Test continuity of Coil & Contacts
Faulty Fan Relay				●													Test continuity of Coil And Contacts
Open Control Circuit				●													Test Control Circuit w ith Voltmeter
Low Voltage		●				●	●										Test Voltage
Faulty Evap. Fan Motor				●									●				Repair or Replace
Shorted or Grounded Fan Motor					●											●	Test Motor Windings
Improper Cooling Anticipator						●	●		●								Check resistance of Anticipator
Shortage of Refrigerant							●	●					●	●			Test For Leaks, Add Refrigerant
Restricted Liquid Line							●	●					●	●			Replace Restricted Part
Undersized Liquid Line								●		●			●				Replace Line
Undersized Suction Line													●				Replace Line
Dirty Air Filter								●		●	●		●				Inspect Filter-Clean or Replace
Dirty Evaporator Coil								●		●	●		●				Inspect Coil - Clean
Not enough air across Evap Coil								●		●	●		●				Speed Blow er, Check Duct Static Press
Too much air across Evap Coil															●		Reduce Blow er Speed
Overcharge of Refrigerant						●	●					●			●	●	Release Part of Charge
Dirty Condenser Coil						●	●			●						●	Inspect Coil - Clean
Noncondensibles							●			●						●	Remove Charge, Evacuate, Recharge
Recirculation of Condensing Air							●			●						●	Remove Obstruction to Air Flow
Infiltration of Outdoor Air								●		●	●						Check Window s, Doors, Vent Fans, Etc.
Improperly Located Thermostat						●			●								Relocate Thermostat
Air Flow Unbalanced									●		●						Readjust Air Volume Dampers
System Undersized								●		●							Refigure Cooling Load
Broken Internal Parts												●					Replace Compressor
Broken Values												●					Test Compressor Efficiency
Inefficient Compressor								●						●	●		Test Compressor Efficiency
High Pressure Control Open			●														Reset And Test Control
Unbalanced Pow er, 3PH		●				●	●										Test Voltage
Wrong Type Expansion Valve						●	●			●							Replace Valve
Expansion Valve Restricted						●	●	●		●			●	●			Replace Valve
Oversized Expansion Valve												●			●		Replace Valve
Undersized Expansion Valve						●	●	●		●			●				Repaice Valve
Expansion Valve Bulb Loose												●			●		Tighten Bulb Bracket
Inoperative Expansion Valve						●		●					●				Check Valve Operation
Loose Hold-down Bolts												●					Tighten Bolts

Figure A-19: This example of a troubleshooting chart for the remote condensing unit of a split system employs dot indicators to identify possible causes and solutions.