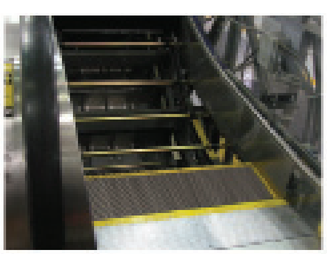

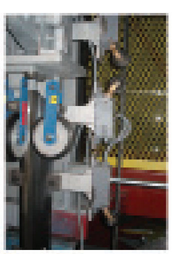

Escalator Specific Electrical Systems

Course 209

PARTICIPANT GUIDE

Transit Elevator/Escalator Training Consortium

Escalator: Electrical Systems

Participant Guide

Transit Elevator/Escalator Maintenance Training Consortium

COURSE 209

REVISION INDEX

Any additions, deletions, or revisions are to be listed below.

Revision No.	Date	Section	Description of Change	Revision Author
1.	08-25-2015		Final edits of 10-31-2012 version	Transportation Learning Center – Amri Joyner

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HOW TO USE THE PARTICIPANT GUIDE

Purpose of the Course

The purpose of the *Escalator: Electrical Systems Course* is to assist the participant in demonstrating proper safety procedures and a working knowledge of the functions of various escalator and elevator components, controls, and assemblies.

Approach of the Book

Each course module begins with an outline, a statement of purpose and objectives, and a list of key terms. The *outline* will discuss the main topics to be addressed in the module. A list of *key terms* identifies important terminology that will be introduced in this module. *Learning objectives* define the basic skills, knowledge, and abilities course participants should be able to demonstrate to show that they have learned the material presented in the module. A list of *key terms* identifies important terminology that will be introduced in each course module.

MODULE 1

General Electrical Safety Procedures

Outline

1-1 Safety Oversight Resources

1-2 Electrical Safety

1-3 Physiological Effects of Electrical Energy

1-4 Reducing Occupational Hazards

1-5 Safe Practices

1-6 Emergency Response

1-7 Summary

Purpose and Objectives

The purpose of this module is to provide participants with a basic knowledge of safety procedures and to demonstrate best practice safety behaviors during the testing and maintenance of vertical transportation electrical systems.

Following the completion of this module, the participant should be able to complete the objectives with an accuracy of 75% or greater:

- Identify safety oversight sources
- Discuss and list the safety rules for avoiding electrical shock
- Explain shock protection boundaries of energized electrical equipment
- Describe the types of PPE which may be required when working on live equipment
- Describe several causes of electrical burns
- Demonstrate Lockout/Tagout (LOTO) Procedures
- Explain the reason for grounding of electrical equipment
- Determine dangerous levels of electrical current as it relates to the human body
- Identify general safety practices

Key Terms

- Approach Boundary
- Arc Blast
- Arc Flash
- American Society of Mechanical Engineers (ASME)
- ASME A17.1
- Electrical Shock
- Elevator Industry Field Employees' Safety Handbook (EIFESH)
- Lockout/Tagout (LOTO)
- National Electrical Code (NEC)
- National Fire Protection Association (NFPA)
- Occupational Safety & Health Administration (OSHA)
- Personal Protective Equipment (PPE)
- Qualified Person
- Ventricular Fibrillation
- Zero Energy State

1-1 SAFETY OVERSIGHT RESOURCES

Organizations

- The **National Fire Protection Association (NFPA)** is an independent, US-based, voluntary-membership nonprofit organization whose mission is to reduce the worldwide burden of fires and other hazards on the quality of life. NFPA accomplishes this goal by creating and maintaining scientifically-based minimum standards and requirements for fire prevention and suppression activities, training, and equipment, as well as other life-safety codes and standards. This includes the creation of NFPA 70E – **National Electrical Code (NEC)**. The code is purely advisory as far as the NFPA is concerned, but the NEC has been adopted by the 50 states and various local jurisdictions for regulatory and standardization purposes. It is made available for both public and private use in the interest of life and property protection.

- The **Occupational Safety and Health Administration (OSHA)** is an agency of the United States Department of Labor. OSHA regulations are often described as the “Shall” and NFPA 70E NEC as the “How” for electrical safety in the workplace. OSHA’s interpretation is: “Industry consensus standards, such as NFPA 70E, can be used by employers as guides to making the assessments and equipment selections required by the standard. Similarly, in OSHA, enforcement can be used as evidence of whether the employer acted reasonably.”

- The **American Society of Mechanical Engineers (ASME)** is one of the oldest standards-developing organizations in the world. One of the standards it produces is the A17.1 Safety Code for Elevators and Escalators. The Code is written concisely without examples or explanations making it suitable for enforcement by state, municipal, and other jurisdictional authorities. For these reasons, ASME determined that a handbook would be useful to augment the Code by providing a commentary on the Code requirements. This Handbook contains the rationale for Code requirements; explanations, examples, and illustrations of the implementations of the requirements; plus excerpts from other nationally recognized standards which are referenced by the Code. This information is intended to provide the users of the **ASME A17.1** Code with a better understanding of, and appreciation for, the requirements contained in the Code.

Publications

- The **National Electrical Code (NEC) [NFPA 70E]** codifies the requirements for safe electrical installations into a single, standardized source. It is part of the National Fire Code series published by the National Fire Protection Association (NFPA), and while not a US law, the NEC use is commonly mandated by state or local law. The "authority having jurisdiction" inspects for compliance with these minimum standards. ("National Electrical Code" and "NEC" are registered trademarks of the NFPA). Article 620 covers the electrical standards for elevators, dumbwaiters, escalators, moving walks, platform lifts, and stairway chairlifts.

- The **Elevator Industry Field Employee's Safety Handbook (EIFESH)** is intended to promote safety on the job through adherence to OSHA safety regulations affecting the elevator/escalator industry. The following sections are to be used as a supplement to the transit agencies safety program:
  - Section 5 – Electrical Safety
  - Section 6 – Proper Use of Jumpers
  - Section 7 – Lockout and Tagout

1-2 ELECTRICAL SAFETY

An estimated 30,000 non-fatal electrical shock accidents occur each year. Over 200 people die from electrocution each year on average in the United States. Electrocution remains the fourth highest cause of industrial fatalities and approximately 3000 flash burn incidents are reported annually along with approximately 200 deaths.

Electricity is an ever-present energy agent to which many workers in different occupations and industries are exposed to daily in the performance of their duties. Many workers know that the principal danger from electricity is that of electrocution, but few really understand just how minute a quantity of electrical energy is required for electrocution. In reality, the current drawn by a tiny 7.5 watt, 120-volt lamp, passed from hand to hand or hand to foot across the chest is sufficient to cause electrocution. The number of people who incorrectly believe that normal household current is not lethal or that power lines are insulated and do not pose a hazard is alarming. Electrocutions may result from contact with an object as seemingly innocuous as a broken light bulb or as lethal as an overhead power line. Electrocutions have affected workers since the first electrical fatality was recorded in France in 1879 when a stage carpenter was killed by an alternating current of 250 volts.

An electrically safe condition shall be achieved by completing all of the following:

1. Determine all sources of electrical supply (drawings, diagrams).
2. Open disconnecting device for each source.
3. Visually verify all blades of disconnecting devices are fully open or drawout-type breakers are withdrawn.
4. Apply lockout/tagout devices in accordance with policy.
5. Test each phase conductor using an adequately rated voltage detector.
6. Ground phase conductors where the possibility exists for induced or stored energy.

An electrically safe work condition does not exist until all of the six steps have been completed. Until then, workers might contact an exposed live part. If an electrically safe work condition does exist, no electrical energy is in proximity of the work task(s). All danger of injury from an electrical hazard has been removed, and neither protective equipment nor special safety training is required. However, other hazards might remain.

1-3 PHYSIOLOGICAL EFFECTS OF ELECTRICAL ENERGY

Electrical injuries consist of four main types:

1. Electrocution
2. Electric shock
3. Burns
4. Falls caused as a result of contact with electrical energy

Electrocution

Electrocution results when a human is exposed to a lethal amount of electrical energy and is subsequently killed. To determine how contact with an electrical source occurs, characteristics of the electrical source before the time of the incident must be evaluated (pre-event). For death to occur, the human body must become part of an active electrical circuit having a current capable of over stimulating the nervous system or causing damage to internal organs. The extent of injuries received depends on the current's magnitude (measured in Amps), the pathway of the current through the body, and the duration of current flow through the body (event). The resulting damage to the human body and the emergency medical treatment ultimately determine the outcome of the energy exchange (post-event).

Electrical Shock

Electric shock occurs there is a direct contact with electrical energy resulting in an individual becoming part of a live electrical circuit. **Arc flashes** create electricity arcs - a flow of electrons through a gas, such as air. These arcs may connect to a victim or other equipment supplying an alternative path to ground. Direct contact and arcing injuries produce similar effects. Arc flashes may result in an electrical explosion known as an **arc blast** that results from a low impedance connection to ground or another voltage phase in an electrical system (Figure 1.1).

Figure 1.1 Arc Blast –©Tri-Tech Engineering

The following table shows four case studies of injuries from arc flashes.

Case Studies for Arc Flash Injuries	
Case 1	A Journeyman Electrician was working on an electrical panel when an arc flash/blast occurred. He was pushed back by the force of the blast and his shirt caught fire. He sustained burns to 20% of his body, including deep burns to his wrists and hands.
Case 2	An Electrical Foreman with over 20 years' experience was working on a high-voltage circuit that he thought was de-energized. Unfortunately, he had de-energized the wrong circuit. He was thrown back by an arc flash/blast and received burns to his arm, neck, and face.
Case 3	A Journeyman Lineman was holding an energized 2,200 volt wire when it grounded out through his leg. He sustained electric shock burns to his trunk and leg and associated flash burns to his hands.
Case 4	A Journeyman Electrician was installing a high voltage panel when an arc blast occurred for unknown reasons. The explosion caused the worker to lose consciousness. He sustained burns to his hands, wrists, and face.
Summary	Each of these workers was hospitalized, some required multiple hospitalizations and surgeries. In addition, at least two of these workers suffered psychological symptoms, including post-traumatic stress disorder as a result of the arc flash incidents
Source: Washington State Department of Labor and Industries. www.lni.wa.gov/safety/research/files/arcflashhazardreport.pdf. Accessed August 25, 2015	

Burns

Burns at the point of contact with electrical energy can be caused by arcing to the skin, heating at the point of contact by a high resistance contact, or higher voltage currents. Contact with a source of electrical energy can cause external as well as internal burns. Exposure to higher voltages will normally result in burns at the site, where the electrical current enters and exits the human body. High voltage contact burns may display only small superficial injury; however, the danger of these deep burns destroying tissue subcutaneously exists.

Figure 1.2 Arm with Third Degree Burn from a High-Voltage Line

Additionally, internal blood vessels may clot, nerves in the area of the contact point may be damaged, and muscle contractions may cause skeletal fractures either directly or in association with falls from elevation. It is also possible to have a low voltage electrocution without visible marks to the body of the victim.

Flash burns and flame burns are actually thermal burns. In these situations, electrical current does not flow through the victim and injuries are often confined to the skin. Contact with electrical current could cause a muscular contraction or a startle reaction that could be hazardous if it leads to a fall from elevation (ladder, aerial bucket, etc.) or contact with dangerous equipment.

The NEC describes high voltage as greater than 600 volts. Most utilization circuits and equipment operate at voltages lower than 600 volts, including common household circuits (110/120 volts); most overhead lighting systems used in industry or office buildings and department stores; and much of the electrical machinery used in industry, such as conveyor systems, and manufacturing machinery such as weaving machines, paper rolling machines or industrial pumps. Voltages over 600 volts can rupture human skin, greatly reducing the resistance of the human body, allowing more current to flow and causing greater damage to internal organs. The most common high voltages are transmission voltages (typically over 13,800 volts) and distribution voltages (typically under 13,800 volts). The latter are the voltages transferred from the power generation plants to homes, offices, and manufacturing plants.

Standard utilization voltages produce currents passing through a human body in the milliampere (mA) range (1,000 mA=1 Amp). Estimated effects of 60 Hz AC currents that pass through the chest are shown in Figure 1.3 and in the following table. As a frame of reference, a common household circuit breaker may be rated at 15, 20, or 30 amps.

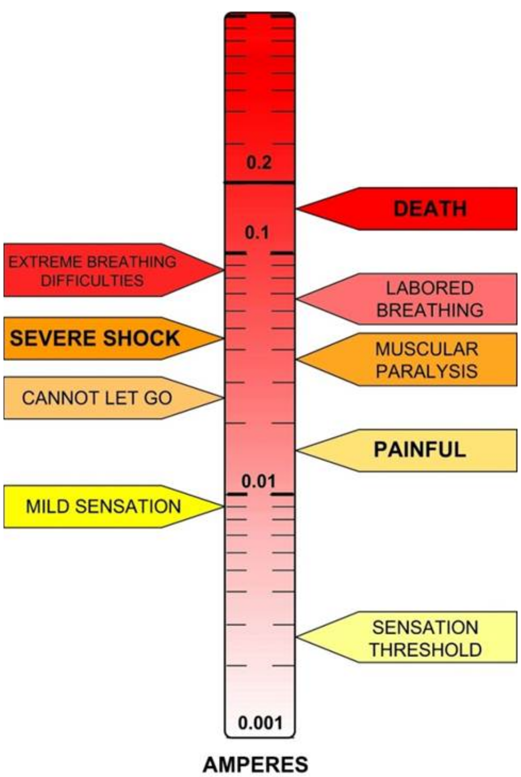

Figure 1.3 Effects of Electrical Shock

ESTIMATED EFFECTS OF 60 HZ AC CURRENTS	
1 mA	**Sensation Threshold**. Up to this point, the electricity is barely perceptible
16 mA	**Cannot Let Go**. Maximum current an average person can grasp and "let go." When current greater than the 16 mA "let go current" passes through the forearm, it stimulates involuntary contraction of both flexor and extensor muscles. When the stronger flexors dominate, victims may be unable to release the energized object they have grasped as long as the current flows.
20 mA	**Muscular Paralysis**. If current exceeding 20 mA continues to pass through the chest for an extended time, death could occur from respiratory paralysis.
50-60mA or more	**Possible Death.** From this point on, death can occur at any time.
100 mA	**Ventricular fibrillation threshold**. After this point, there will be difficulty breathing.
2 Amps (or 2,000 mAs)	**Extreme difficulty breathing, cardiac standstill and internal organ damage**. Currents of 100 mA or more, up to 2 Amps, may cause **ventricular fibrillation**; probably the most common cause of death from electric shock. Ventricular fibrillation is the uneven pumping of the heart due to the uncoordinated, asynchronous contraction of the ventricular muscle fibers of the heart that leads quickly to death from lack of oxygen to the brain. Ventricular fibrillation is terminated by the use of a defibrillator, which provides a pulse shock to the chest to restore the heart rhythm. Cardiopulmonary resuscitation (CPR) is used as a temporary care measure to provide the circulation of some oxygenated blood to the brain until a defibrillator can be used.[23] The speed with which resuscitative measures are initiated has been found to be critical. Immediate defibrillation would be ideal; however, for victims of cardiopulmonary arrest, resuscitation has the greatest rate of success if CPR is initiated within 4 minutes and advanced cardiac life support is initiated within 8 minutes (National Conference on CPR and ECC, 1986).

The presence of moisture from environmental conditions such as standing water, wet clothing, high humidity, or perspiration increases the possibility of a low-voltage electrocution. The level of current passing through the human body is directly related to the resistance of its path through the body. Under dry conditions, the resistance offered by the human body may be as high as 100,000 Ohms. Wet or broken skin may drop the body's resistance to 1,000 Ohms. The following illustrations of Ohm's law demonstrate how moisture affects low-voltage electrocutions.

Under dry conditions: Current=Volts/Ohms = 120/100,000 = 1 mA, a barely perceptible level of current. Under wet conditions: Current=Volts/Ohms = 120/1,000 = 120 mA, sufficient current to cause ventricular fibrillation. Wet conditions are common during low-voltage electrocutions.

High-voltage electrical energy quickly breaks down human skin, reducing the human body's resistance to 500 Ohms. Once the skin is punctured, the lowered resistance results in massive current flow, measured in Amps. Again, Ohm's law is used to demonstrate the action. For example, at 1,000 volts, Current=Volts/Ohms = 1000/500 = 2 Amps, which can cause cardiac standstill and serious damage to internal organs.

1-4 REDUCING OCCUPATIONAL HAZARDS

There are two processes that should be used to reduce hazards while working on electrical equipment. These two processes are directly related to, and determined by the particular risk/hazard of the work activity.

- The first part of the assessment is the identification and analysis of electrical risks/hazards for the purpose of determining appropriate controls (procedures, permits, etc.) and PPE required for particular work activities.
- The second is a shock hazard analysis to determine the boundary limitations.

Using Hazard Analysis to Determine Personal Protective Equipment

Personal Protective Equipment (PPE) refers to protective clothing, helmets, goggles, or other garment or equipment designed to protect the wearer's body from injury by blunt impacts, electrical hazards, heat, chemicals, and infection, for job-related occupational safety and health purposes, and in sports, martial arts, combat, etc. (see Figure 1.4). The terms "protective gear" and "protective clothing" are in many cases interchangeable; "protective clothing" is applied to traditional categories of clothing, and "gear" is a more general term and preferably means uniquely protective categories, such as pads, guards, shields, masks, etc. Items such as fire extinguishers and first aid kits are equipment to support the personal protection of the subject.

Figure 1.4 General PPE

PPE is used to reduce employee exposure to hazards when engineering and administrative controls are not feasible or effective to reduce these risks to acceptable levels. These include the type of clothing (untreated natural fiber such as cotton, fire retardant, and fire protective), hard hat, eye protection, face and head protection, hand protection, and foot protection. (Never wear clothing made from polyester or plastic as the clothing will melt as the electricity flows through the body).

Potential Danger	Appropriate PPE
Head injury from electric shock or burns due to contact with live parts or from flying objects resulting from electrical explosion.	Nonconductive head protection.
Exposure to electric arcs or flashes or from flying objects resulting from electrical explosion.	Nonconductive protective equipment for the: Face, neck, chin – Face shield and Kevlar Hood or suit Eyes – Safety glasses
Electric arc flash above the threshold incident-energy level for a second-degree burn.	Flame-resistant clothing (and items listed above). Make sure that when flame-resistant clothing is worn to protect an employee, it should cover all ignitable clothing and allow for movement and visibility.
Hand and arm injury from electric shock due to contact with live parts.	Rubber insulating gloves.
Possible exposure to arc flash burn.	Hand and arm protection.
Where insulated footwear is used as protection against step and touch potential.	Dielectric overshoes (e.g, leather work boot shown in Figure 1.5).

Figure 1.5 PPE for Hazard Level 4

PPE requirements for technicians working on electrical equipment are directly derived from the identified hazards and risks for the particular work activity. In this case, through the NFPA's studies of electrical hazards. Through the use of the PPE requirements of NFPA the need for a detailed electrical hazard analysis is not necessary. The NFPA lists the items that should be used for the protection of a technician working on electrical equipment. The items are recommended based on the Category of the Hazard Risk with which the technician is confronted. Hazard risk level ranges from 0 to 4 – 4 being the most at risk for injury.

Determining Approach Boundary Level to Live Parts

It is imperative that a shock hazard analysis be conducted prior to working on a particular piece of equipment. A shock hazard analysis determines the voltage to which personnel will be exposed, boundary requirements, and the PPE necessary in order to minimize the possibility of electric shock to personnel. The Hazard/Risk Categories are Level 1 to 4 shown in the following table.

Hazard Risk Category	Work-Wear Description (1/2/3/4) refers to the number of clothing layers	ATPV** Rating cal/cm2
0	Untreated Cotton (1)	n/a
1	FR* Shirt and FR Pant (1)	5
2	Cotton Undergarments + FR Shirt/Pant (2)	8
3	Cotton Undergarments + FR Shirt/Pant + FR Coveralls (3)	25
4	Cotton Undergarments + FR Shirt/Pant + Double Layer Switching Coat	40

* FR (Flame Retardant)
**ATPV (Arc Thermal Protective Value) refers to the maximum incident energy (in calories per centimeter squared) that protective equipment can be exposed to and prevent to onset of a second-degree burn. Ratings are based upon the total weight of the fabric. Appropriate clothing ranges from untreated cotton, wool, rayon, or silk materials with a fabric weight of at least 4.5 ounces per square yard to flame retardant (treated) clothing worn in layers.

The charts on the following page identify the shock protection boundaries as "limited", "restricted", and "prohibited" (see Figure 1.6). **Approach Boundaries** are applicable to the situation in which approaching personnel are exposed to live parts. As distances are reduced from the Limited to Prohibited Approach Boundary points, shock risk increases. Only qualified persons are permitted within the specified boundaries, specifically the Restricted and Prohibited Boundary Approaches. Note that a **qualified person** is one who has the skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid hazards involved.

Voltage Range					
Nominal System Voltage Range, Phase to Phase	**LIMITED APPROACH BOUNDRY** **Exposed Movable Conductor**	**Exposed Fixed Circuit Part**	**RESTRICTED APPROACH BOUNDRY**	**PROHIBITED APPROACH BOUNDRY**	**FLASH PROTECTION BOUNDARY**
Less than 50	Not Specified	Not Specified	Not Specified	Not Specified	On the subject of arc-flash, NEC requires a flash hazard analysis. This analysis shall determine a flash protection boundary and the personal protective equipment (PPE) requirements when working within that boundary
50 to 300	10 feet, 0 inches	3 feet, 6 inches	1 foot, 0 inches	0 feet, 1 inch	
301 to 750	10 feet, 0 inches	3 feet, 6 inches	2 feet, 2 inches	0 feet, 7 inches	
750 to 15000	10 feet, 0 inches	5 feet, 0 inches	2 feet, 7 inches	0 feet, 10 inches	
15000 to 36000	10 feet, 0 inches	6 feet, 0 inches	2 feet, 9 inches	1 foot, 5 inches	

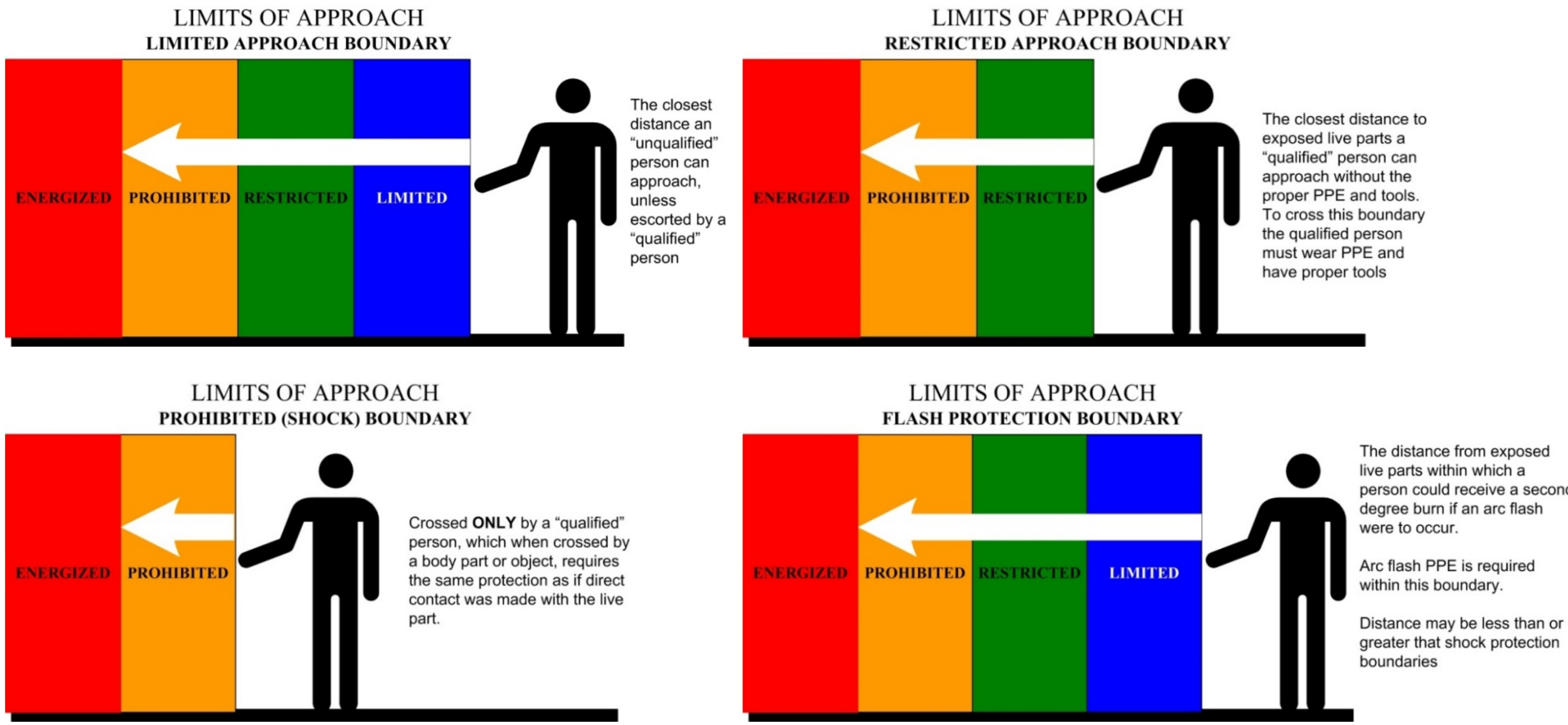

Figure 1.6 Approach Boundaries

1-5 SAFE PRACTICES

Removing Power

If at all possible, shut off the power to a circuit before performing any work on it. You must secure all sources of harmful energy before a system may be considered safe to work on. In industry, securing a circuit, device, or system in this condition is commonly known as placing it in a de-energized or **zero energy state**. The focus of this lesson is, of course, electrical safety. However, many of these principles apply to non-electrical systems as well.

Securing something in a zero energy state means ridding it of any sort of potential or stored energy, including but not limited to:

- Dangerous voltage
- Spring pressure
- Hydraulic (liquid) pressure
- Pneumatic (air) pressure
- Suspended weight
- Chemical energy (flammable or otherwise reactive substances)
- Nuclear energy (radioactive or fissile substances)

Voltage by its very nature is a manifestation of potential energy. A pair of wires with high voltage between them does not look or sound dangerous even though collectively they harbor enough potential energy to push deadly amounts of current through your body. Even though that voltage is not presently doing anything, it has the potential to, and that potential must be neutralized before it is safe to contact those wires.

All properly designed circuits have "disconnect" switch mechanisms for securing voltage from a circuit. Sometimes these "disconnects" serve a dual purpose of automatically opening under excessive current conditions, in which case we call them "circuit breakers." Other times, the disconnecting switches are strictly manually-operated devices with no automatic function. In either case, they are there for your protection and must be used properly. Please note that the disconnect device should be separate from the regular switch used to turn the device on and off. It is a safety switch to be used only for securing the system in a de-energized state.

With the disconnect switch in the "open" (no continuity) position, as shown in Figure 1.7, the circuit is broken and no current will exist.

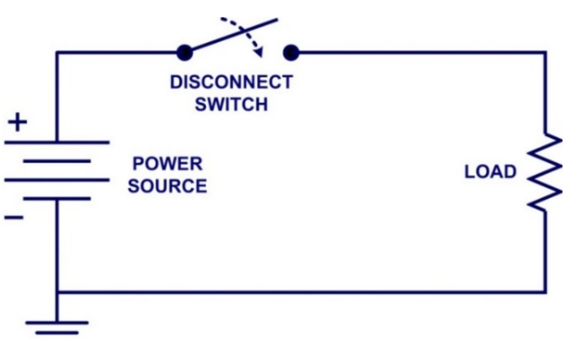

Figure 1.7 Disconnect in "Open" Position

There will be zero voltage across the load, and the full voltage of the source will be dropped across the open contacts of the disconnect switch. Note how there is no need for a disconnect switch in the lower conductor of the circuit. Because that side of the circuit is firmly connected to the earth (ground), it is electrically common with the earth and is best left that way.

For maximum safety of personnel working on the load of this circuit, a temporary ground connection could be established on the top side of the load (Figure 1.8), to ensure that no voltage could ever be dropped across the load. With the temporary ground connection in place, both sides of the load wiring are connected to ground, securing a zero energy state at the load.

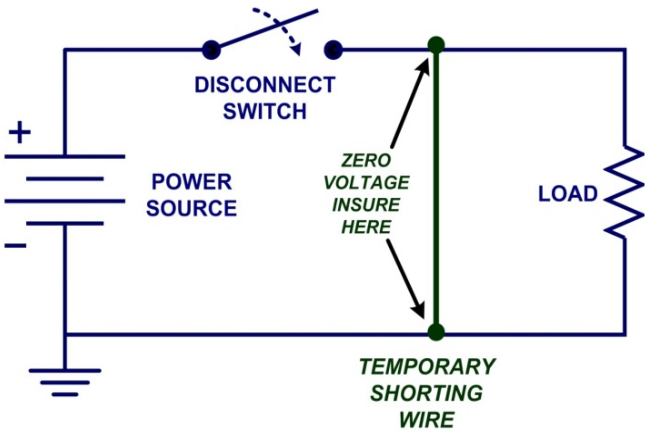

Figure 1.8 Temporary Ground Connected at the Top Side of the Load

Since a ground connection made on both sides of the load is electrically equivalent to short-circuiting across the load with a wire that is another way of accomplishing the same goal of maximum safety.

Either way, both sides of the load will be electrically common to the earth, allowing for no voltage (potential energy) between either side of the load and the ground on which people stand. This technique of temporarily grounding conductors in a de-energized power system is very common in maintenance work performed on high voltage power distribution systems.

A further benefit of this precaution is protection against the possibility of the disconnect switch being closed (turned "on" so that circuit continuity is established) while people are still contacting the load. The temporary wire in Figure 1.9 connected across the load would create a short circuit when the disconnect switch was closed, immediately tripping any overcurrent protection devices (circuit breakers or fuses) in the circuit, which would shut the power off again. Damage may very well be sustained by the disconnect switch if this were to happen, but the workers at the load are kept safe.

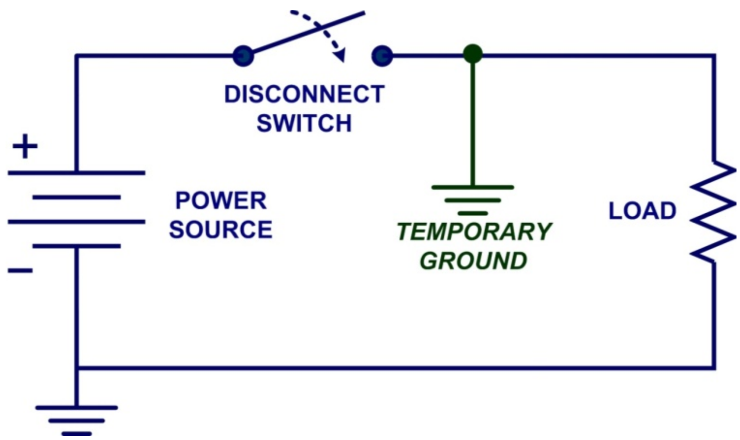

Figure 1.9 Temporary Shorting

It would be good to mention at this point; that overcurrent devices are not intended to provide protection against electric shock. Rather, they exist solely to protect conductors from overheating due to excessive currents. The temporary shorting wires just described would indeed cause any overcurrent devices in the circuit to "trip" if the disconnect switch were to be closed, but realize that electric shock protection is not the intended function of those devices. Their primary function would merely be leveraged for the purpose of worker protection with the shorting wire in place. Examples of overcurrent devices are shown in Figure 1.10.

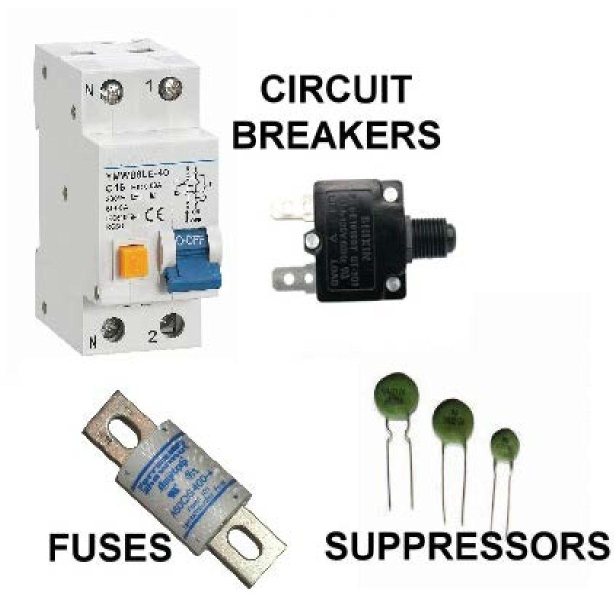

Figure 1.10 Examples of Overcurrent Devices

Since it is obviously important to be able to secure any disconnecting devices in the open (off) position and make sure they stay that way while work is being done on the circuit, there is need for a structured safety system to be put into place.

Lockout/Tagout **(LOTO)**

A lockout/tagout procedure works like this: all individuals working on a secured circuit have their own personal padlock or combination lock that they set on the control lever of a disconnect device prior to working on the system. Examples of LOTO equipment are shown in Figure 1.12 and Figure 1.12 shows LOTO procedure being implemented.

Individuals must fill out and sign a tag that they hang from their lock describing the nature and duration of the work they intend to perform on the system. If there are multiple sources of energy to be "locked out" (multiple disconnects, both electrical and mechanical energy sources to be secured, etc.), the worker must use as many of his or her locks as necessary to secure power from the system before work begins. This way the system is maintained in a zero energy state until every last lock is removed from all the disconnect and shutoff devices; that means every last worker gives consent by removing their own personal locks. If the decision is made to re-energize the system and one person's lock(s) still remain in place after everyone present removes theirs, the tag(s) will show whom that person is and what it is they are doing.

Figure 1.11 Lockout/Tagout Equipment

Figure 1.12 Electrical Cabinet with Lockout/Tagout Procedure Implemented

Even with a good LOTO safety program in place, there is still need for diligence and common-sense precaution. This is especially true in industrial settings where several technicians may be working simultaneously on a device or system. Some technicians may not know the proper lockout/tagout procedure or may be too complacent to follow it.

Warning: Safety Precautions!

- Do not assume that everyone has followed the safety rules.
- Follow your transit agency's procedures regarding lockout/tagout procedures.
- Be sure to review Section 7 of the Elevator Industry Field Employees' Safety Handbook which covers Lockout/Tagout procedures in detail.

After an electrical system has been locked out and tagged with your own personal lock, you must then double-check to see if the voltage really has been secured in a zero state. One way to check is to see if the machine (or whatever it is that is being worked on) will start up if the start switch or button is actuated. If it starts, then you know you haven't successfully secured the electrical power from it.

Additionally, you should always check for the presence of dangerous voltage with a measuring device (see Figure 1.13) before actually touching any conductors in the circuit. To be the safest, you should follow these procedures of checking, using, and then re-checking your meter:

1. Check to see that your meter indicates properly on a known source of voltage.
2. Use your meter to test the locked-out circuit for any dangerous voltage.
3. Check your meter once more on a known source of voltage to see that it still indicates as it should (i.e., a wall outlet in the machine or in a pit for which you know the voltage.)

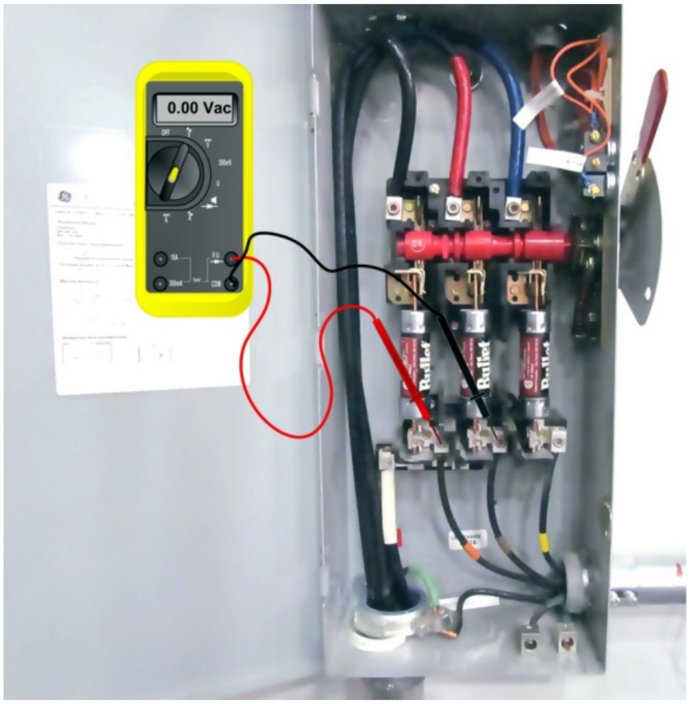

Figure 1.13 DMM Testing for Voltage Phase to Phase

While this may seem excessive or even paranoid, it is a proven technique for preventing electrical shock. A meter failing to indicate voltage on a live circuit could lead to serious consequences. There is always the chance that your voltage meter will be defective just when you need it to check for a dangerous condition. Following these steps will help ensure that you're never misled into a deadly situation by a broken meter.

Finally, the electrical worker will arrive at a point in the safety check procedure where it is deemed safe to touch the conductor(s). Bear in mind that after all of the precautionary steps have been taken, a possible (although very unlikely) dangerous voltage may be present. If you ever have reason to doubt the trustworthiness of your meter, use another meter to obtain a "second opinion."

Electrical Cords and Equipment

The following are basic rules to consider when using extension cords and extension boxes while performing maintenance.

- Electrical cords and air lines should be free of loops and kinks when in use and shall be properly stored after use.
- Extension cords and electrical cables passing through work areas, walkways, or passageways should be covered or elevated to protect them from physical damage that would create a hazard to employees or the public.
- Worn, frayed or defective electrical cords should not be used and must be recycled.

- All extension cords and cords to portable electrical equipment and tools should be provided with ground fault circuit interrupters when used in damp or wet locations.
- All waterproof covers of electrical receptacles should be closed when not in use.
- Employees should disconnect receptacle plugs by grasping the plug and not pulling the cord.
- Portable extension lights should be inspected before use. Lamp guards should be used on all extension lamps and non-metallic lamp guards should be used where there is a possibility of contact with exposed electrical circuits.

1-6 EMERGENCY RESPONSE

Despite lockout/tagout procedures and multiple repetitions of electrical safety rules in industry, accidents still do occur. The vast majority of the times, these accidents are the result of not following proper safety procedures. However, they may occur, they still do happen, and anyone working around electrical systems should be aware of what needs to be done for a victim of electrical shock.

If you see someone lying unconscious or "froze on the circuit," the very first thing to do is shut off the power by opening the appropriate disconnect switch or circuit breaker. If someone touches another person being shocked, there may be enough voltage dropped across the body of the victim to shock the would-be rescuer, thereby "freezing" two people instead of one. Do not be a hero. Electrons don't respect heroism. Make sure the situation is safe for you to step into, or else you will be the next victim, and nobody will benefit from your efforts.

One problem with this rule is that the source of power may not be known, or easily found in time to save the victim of shock. If a shock victim's breathing and heartbeat are paralyzed by electric current, their survival time is very limited. If the shock current is of sufficient magnitude, their flesh and internal organs may be quickly roasted by the power the current dissipates as it runs through their body.

If the power disconnect switch cannot be located quickly enough, it may be possible to dislodge the victim from the circuit they're frozen on to by prying them or hitting them away with a dry wooden board or piece of nonmetallic conduit such as a leather belt or a nonconductive safety vest, common items to be found in industrial construction scenes. Another item that could be used to safely drag a "frozen" victim away from contact with power is an extension cord. By looping a cord around their torso and using it as a rope to pull them away from the circuit, their grip on the conductor(s) may be broken. Bear in mind that the victim will be holding on to the conductor with all their strength, so pulling them away will not be easy!

Once the victim has been safely disconnected from the source of electric power, the immediate medical concerns for the victim should be respiration and circulation (breathing and pulse). If the rescuer is trained in cardiopulmonary resuscitation (CPR), they should follow the appropriate steps of checking for breathing and pulse, then applying CPR as necessary to keep the victim's body from deoxygenating. The cardinal rule of CPR is to keep going until you have been relieved by qualified personnel (see Figure 1.14)

Figure 1.14 Performing CPR

If the victim is conscious, it is best to have them lie still until qualified emergency response personnel arrive on the scene. There is the possibility of the victim going into a state of physiological shock – a condition of insufficient blood circulation which is different from electrical shock – and should be kept as warm and comfortable as possible using only cotton material. An electrical shock insufficient to cause immediate interruption of the heartbeat may be strong enough to cause heart irregularities or a heart attack up to several hours later, so the victim should pay close attention to their own condition after the incident, ideally under supervision.

1-7 SUMMARY

This module highlighted the critical nature of working around electricity making the case safety is everyone's responsibility. This module offered a review of general safety requirements for escalator maintenance and, while inclusive of all safety requirements, it makes the point all local and manufacturer's guidelines and requirements must be followed in order to ensure the safety of all escalator workers and transit passengers

Safety Reminders

- Safety is everyone's responsibility.
- Follow your transit agency's safety guidelines.
- Become familiar with your agency's safety handbook.
- Make sure you understand each of the handbook's rules and practices.
- BE SAFE!!

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APPENDIX A SAFETY AROUND ELECTRICAL CIRCUITS

Warning: Safety Precautions!

- Zero energy state: When a circuit, device, or system has been secured so that no potential energy exists to harm someone working on it.
- Disconnect switch devices must be present in a properly designed electrical system to allow for convenient readiness of a zero energy state.
- Temporary grounding or shorting wires may be connected to a load being serviced for extra protection to personnel working on that load.
- Lockout/tagout works like this: When working on a system in a de-energized or zero energy state, the worker places a personal padlock or combination lock on every energy disconnect device relevant to his or her task on that system. In addition, a tag is hung on every one of those locks describing the nature and duration of the work to be done, and who is doing it.
- Always verify that a circuit has been secured in a zero energy state with test equipment after "locking it out." Be sure to test your meter before and after checking the circuit to verify that it is working properly.
- When the time comes to actually make contact with the conductor(s) of a supposedly dead power system, do so first with the back of one hand, so that if a shock should occur, the muscle reaction will break contact with the conductor.
- A person being shocked needs to be disconnected from the source of electrical power. Locate the disconnecting switch/breaker and turn it off. Alternatively, if the disconnecting device cannot be located, the victim can be pried or pulled from the energized circuit by an insulated object such as a dry wood board, piece of non-metallic conduit, or rubber electrical cord.
- Victims need immediate medical response: check for breathing and pulse, then apply CPR as necessary to maintain oxygenation.
- If a victim is still conscious after having been shocked, they need to be closely monitored and cared for until trained emergency response personnel arrive. There is danger of physiological shock, so keep the victim warm and comfortable.
- Shock victims may suffer heart trouble up to several hours after being shocked. The danger of electric shock does not end after pulling the fingers away from the conductor

APPENDIX B COMMON SAFETY WARNINGS

Figure 1.15 Common Safety Warnings

MODULE 2

Escalator Electrical Power Systems

Outline

2-1 Overview
2-2 Main Power Distribution
2-3 Auxiliary Power Distribution
2-4 Wiring Configurations
2-5 System Power Supplies
2-6 Electrical Measurement Techniques
2-7 Summary

Purpose and Objectives

The purpose of this module is to provide the participants with a basic knowledge of the electrical power distribution systems within a modern escalator. This module will include electrical power control, protection, diagrams, power supplies as well as electrical measurement techniques.

Following the completion of this module, the participant should be able to complete the objectives with an accuracy of 75% or greater:

- Discuss escalator-specific power distribution systems
- Identify the different types of single phase transformers
- Identify the different connection methods of three-phase transformers
- Identify the major sections of a typical DC power supply
- Discuss the basic function of a power supply
- Utilizing a schematic diagram, locate and discuss specific components in a system power supply
- Utilizing a schematic diagram, identify and take measurements at specific circuit locations in a power supply using various types of electrical test equipment

Key Terms

- Auxiliary Power Distribution
- Block Diagram
- Circuit Breaker
- Circuit Diagram
- Continuity Test
- Control Transformer
- Disconnect Panel
- Electrical Disconnect
- Insulated Gate Bi-Polar Transistors
- Knife Switch
- Main Power Distribution
- One-Line Diagram
- Pictorial Layout Diagram
- Power Fuses
- Modulation (PWM)
- Pulse Width
- Time Delay Fuses
- Time Delay Relay
- Wiring Diagram
- Wye-Delta Method

2-1 OVERVIEW

The electrical power distribution system on a modern escalator is separated into two major sections in this module:

1. The **main power distribution**, also known as the *escalator drive circuit*, is responsible for providing the source voltage and current to the main drive control circuits, brake control circuits and motor(s). Typically, the source for the power circuit is three-phase 480 VAC @ 60 Hz.
2. The control circuits for the escalator drive will receive their low-level voltage from a step-down **control transformer** within the main electrical drive system.
3. The **auxiliary power distribution**, also known as the *auxiliary electrical circuits*, is single phase 120 VAC @ 60 Hz. It provides power to the auxiliary lighting, heaters, communication, and annunciators.

The two systems are independent of each other (see Figure 2.1.) For example, if the electrical source is disconnected from the escalator drive circuits, the auxiliary voltage will still be present within the system. Also, be aware if the power is removed from the auxiliary electrical system; voltage will remain present in the drive circuits. It is essential that maintenance personnel performing electrical tests or measurements on the electrical systems of the escalator be aware of this condition and to always check to ensure that all unnecessary power is removed prior to commencing work.

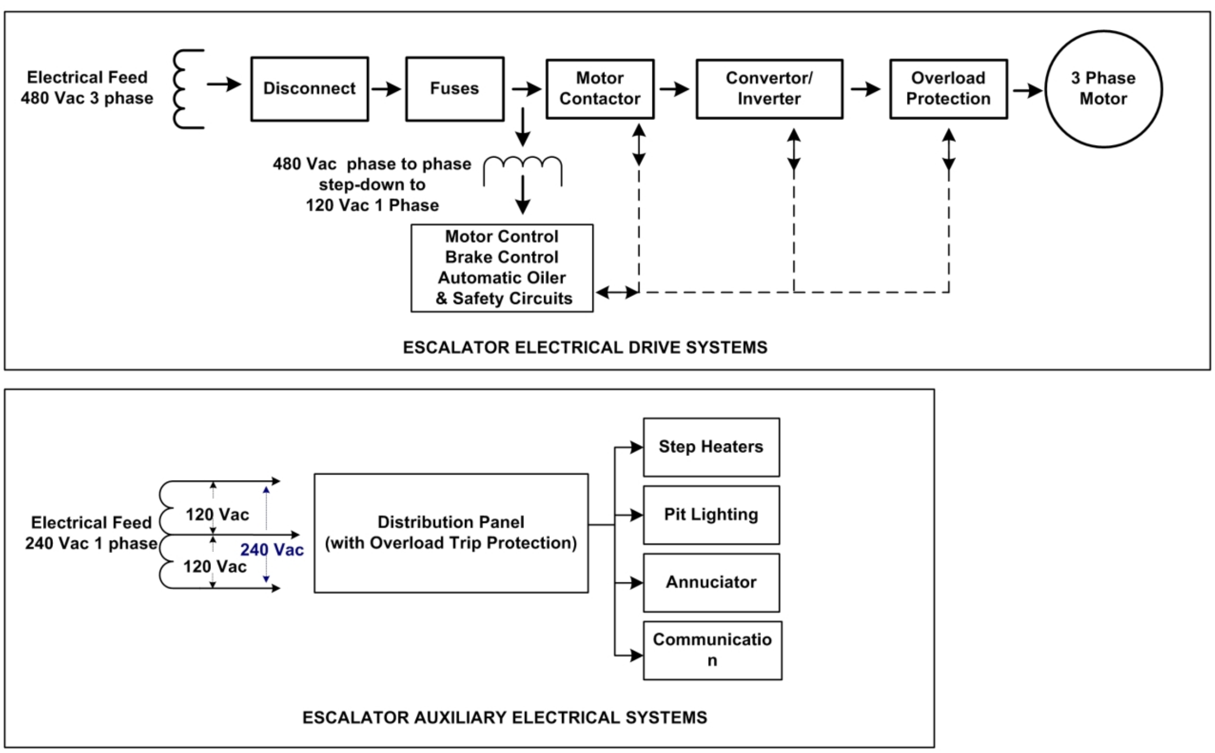


Figure 2.1 Electrical Distribution Overview

2-2 MAIN POWER DISTRIBUTION

Electrical Disconnect

The main power feed to the escalator drive circuits are supplied through an **electrical disconnect** such as a 3-phase 480 VAC 60 Hz supply. The purpose of the electrical disconnect is to break the connection between the electrical feed and the escalator drive circuits.

The electrical disconnect switchgear is housed in a steel enclosure, Figure 2.2, which is capable of being secured during maintenance if a lockout/tagout is required.

Figure 2.2 External View of 3-Phase Disconnect Panel

Inside the panel are a 3-phase **knife switch** and normal power fuses in each of the three phases. The knife switch may also include an operating spring to assist in opening and closing. Its insulated handle is located externally on the enclosure. See Figure 2.3 and Figure 2.4. This switch does not serve as a safety interrupt device in the same way a **circuit breaker** operates. It does not sense abnormal circuit conditions. The **power fuses** protect the electrical system from catastrophic failure such as a short circuit. They are **Time Delay Fuses (TDFs)** capable of detecting and removing a short circuit almost instantly but able to withstand the small overload which is present during startup. All of these items are housed in a **disconnect panel**.

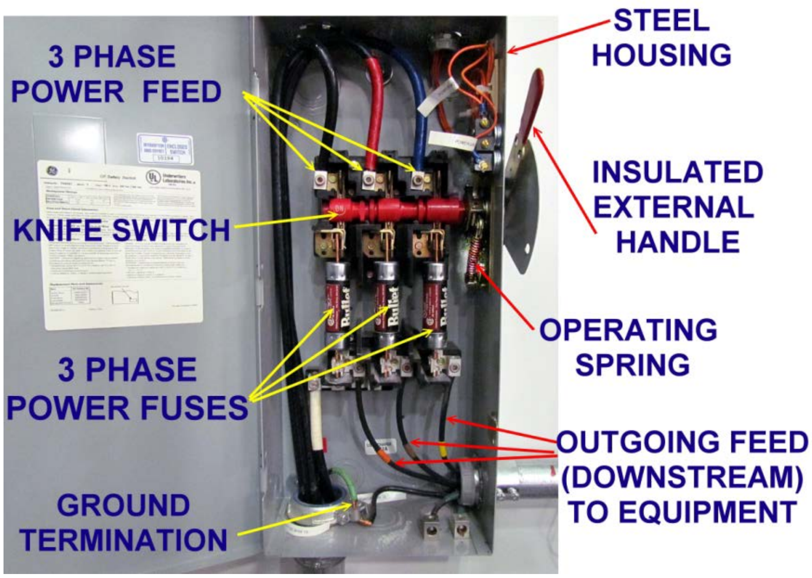


Figure 2.3 Internal View of 3-Phase Disconnect Panel

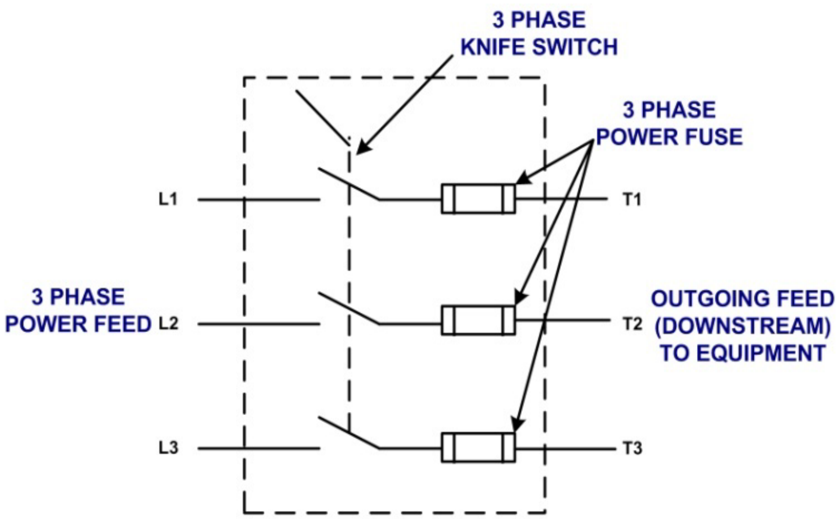


Figure 2.4 Schematic of 3-Phase Disconnect Panel

The inputs on the electrical devices discussed are normally labeled L1, L2, and L3 while their outputs are label T1, T2, and T3. The actual wire numbers will be determined by the "as built" drawings for the system.

The feeder source for the 3-Phase 480 VAC 60 Hz supply may vary from system to system and is maintained by the transit agency's electrical maintenance technicians. Any problem with the electrical feed that has been verified will usually require a response from technicians from the electrical maintenance department. Typical electrical feed problems include loss of feed, loss of phase, phase-to-phase voltage discrepancies, phase detection monitoring, and low voltage levels. It is the responsibility of the maintenance personnel performing the testing on the escalator electrical systems to be aware of the symptoms for each of the faults as well as the methods used to determine these types of faults.

Circuit Breaker

The output of the electrical disconnect is fed into the circuit breaker for the power circuit. The circuit breaker may include either thermal or magnetic overloads. It is designed to automatically open at a predetermined current without damage to itself, when correctly operated within its rating. It is designed to introduce a delay in the tripping action that would decrease in time as the level of current increases.

Figure 2.5 Escalator Drive Circuit

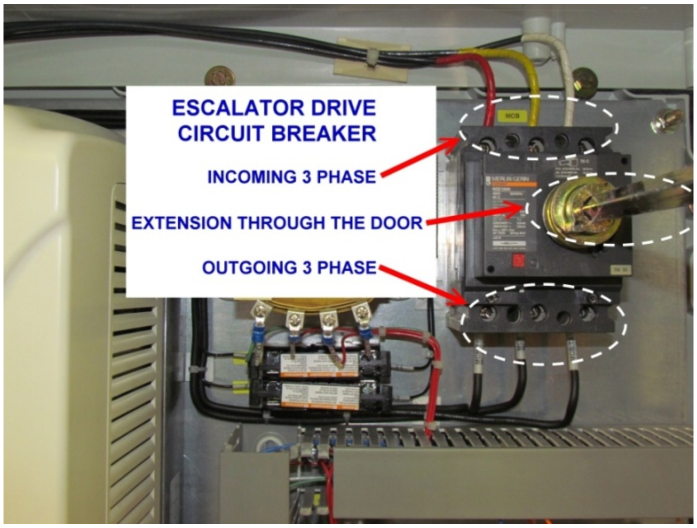


Figure 2.6 Escalator Drive Circuit Breaker

2-3 AUXILARY POWER DISTRIBUTION

Electrical Distribution Panel

The auxiliary distribution panels provide power to single-phase components within the escalator electrical system. Typically, this power is supplied from a single phase 3-wire power system The nominal voltage levels in this type of setup are 240VAC when measured across both live conductors and 120VAC between either of the live conductors and neutral. The distribution panel will include a main breaker and individual breakers for each branch circuit. (See Figure 2.6 and Figure 2.7 The step heater circuit, which is fed from this panel, requires the full 240VAC in some transit escalators. The other auxiliary circuits are normally supplied power on individual 120VAC circuit. The ratings of the main breaker and that of each individual branch circuit breaker will vary with system requirements.

Figure 2.7 Circuit Breaker Panel

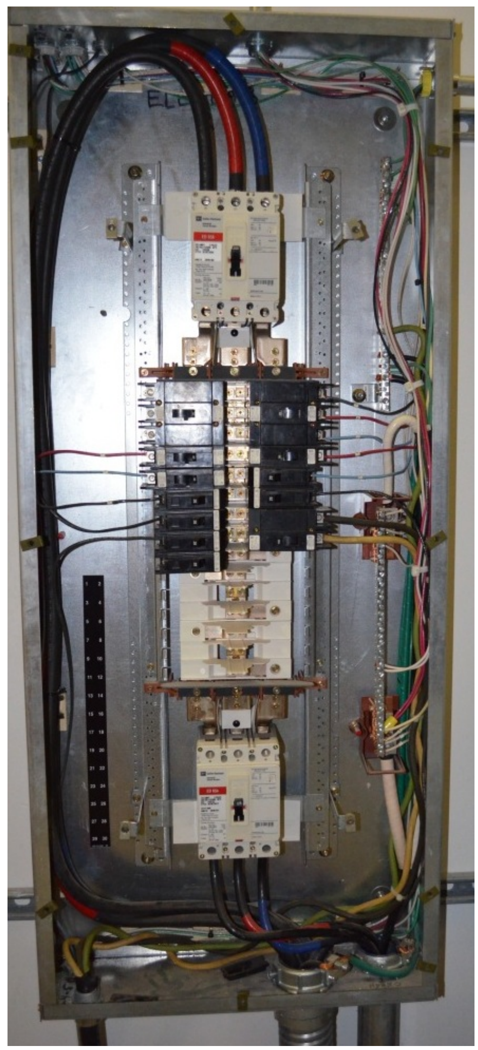


Figure 2.8 Typical 120/240 AC Single Phase- 3Wire Panelboard with a Main Breaker

Heaters: Mode of Operation

Depending on the environmental location of the transit escalator, step heater units (Figure 2.9) may be required to enable service during times of inclement weather. The specific configuration of the heaters varies by manufacturer but they all operate on the same principle. They are thermostatically controlled resistive heating elements. They may require 240VAC for operation.

Figure 2.9 Step Heater. Source: http://best-b2b.com

Some heaters may receive power from a separate 208VAC system. The heating system in most installations works only when the escalator controller is powered. The heater control boxes are typically equipped with a heating disconnect switch. If they are operated in continuous mode, the on/off cycle of the heating elements is controlled by a thermostatic sensor also known as a thermostat.

Lighting

Lighting is controlled by the main controller when the escalator is in operation, which may be fed by the auxiliary panel, may include:

- Direction indicators used to signal to the passengers
- Step gap lighting
- Combplate lighting
- Skirt lighting (newer systems use 24VDC LED lighting supplied by the DC power supply)

Low Voltage DC Power Supply

The fault detection and annunciation, communication system, water deluge system, and system sensors all may receive power from a low voltage DC power supply. A 24VDC level is typical for these types of sensors and systems. The systems served by this power supply may be under monitored by the Programmable Logic Controller (PLC), the main controller or both.

Water Deluge System (Water Level Gauge)

If there is a risk that the escalator's tension station landing area may fill with water, a water level gauge can be installed. When a predefined water level is reached, the water level gauge activates an alarm.
The water level is monitored via a level monitor implemented in the form of a reed relay with float switch. The voltage supplied is 24V. When the water level is rising, the magnetic float moves upward and actuates the switch as soon as the predefined limit value is reached. The total travel between the bottom and top end points measures 5 mm or 0.2 inches. The output of the level monitor, which is implemented in the form of a dry changeover contact, is directly connected to the controller. If the output of the level monitor is activated, the escalator is shut down and the associated relay is triggered and can be used as a dry contact to activate a pump, an alarm device, etc.

2-4 WIRING CONFIGURATIONS

One-Line Diagrams

When performing electrical testing and maintenance on an escalator, one of the types of diagrams the participant will encounter is the one-line diagram, also known as the single-line diagram. It is a simplified notation for representing a three-phase power system. Electrical elements such as circuit breakers, transformers, capacitors, bus bars, and conductors are shown by standardized schematic symbols. Instead of representing each of the three phases with a separate line or terminal, only one line is used to represent the three conductors. It is a form of block diagram graphically depicting the paths for power flow between elements of the system. Elements on the diagram do not represent the physical size or location of the electrical equipment, but it is a common practice to organize the diagram with the same left-to-right, top-to-bottom sequence as the switchgear or other apparatus represented. The one-line diagram that follows is an example of the electrical drive system for an escalator. It is likely that there would also be a one-line diagram for the auxiliary components in the actual manufacturer's drawings. It is necessary to familiarize yourself with the legend in any drawing with which the participant is working. Each object in the diagram is assigned a nomenclature abbreviation. This nomenclature is always manufacturer-specific.

From the one-line diagram, participants should be able to familiarize themselves with an overview of the electrical system. With this information, the participant could break down the circuit even further by using the component schematic diagram for the escalator.

For the discussion that follows, refer to Figure 2.10 on the following page.

On the left-hand side of the diagram, you will notice the 480VAC 3-phase input is reduced to one line. Its nomenclature according to the legend is "TPIF" which stands for "Three-phase Incoming Feed".

According to the diagram the control panel has a ventilation fan that is protected by a circuit breaker. See if you can locate the nomenclature for the ventilation fan circuit breaker.

LEGEND ABBREVIATIONS = DESCRIPTIONS	LEGEND ABBREVIATIONS = DESCRIPTIONS
BJCC = BOTTOM JUNCTION CONTROL CIRCUITS	LVCT = LOW VOLTAGE CONTROL TRANSFORMER
BJEF = BOTTOM JUNCTION ENCLOSURE FUSE	MDS1 = MAIN DISCONNECT SWITCH 1
CPCB = CONTROL PANEL CIRCUIT BREAKER	MF1 = MAIN FUSE 1
CPCC = CONTROL PANEL CONTROL CIRCUITRY	MMOL = MAIN MOTOR OVERLOAD
CPDB = CONTROL PANEL DISCONNECT BREAKER	MSB = MAGNETIC SERVICE BRAKE (LEFT/RIGHT)
CPL = COMBPLATE LIGHTING	MSBA = MAGNETIC SAFETY BRAKE ACTIVE (LEFT/RIGHT)
CPVF = CONTROL PANEL VENTILATION FAN	PPSF = PISTON PUMP SYSTEM FUSE
CT = CONTROL TRANSFORMER CIRCUIT BREAKER	PPLS = PISTON PUMP LUBE SYSTEM
CTCB = CONTROL TRANSFORMER CIRCUIT BREAKER	SC = SAFETY CIRCUITS
DBRB = DYNAMIC BRAKE RESISTOR BANK	SCF = SAFETY CIRCUITS FUSE
ESLF = ESCALATOR LIGHTS FUSE	SDL = SIDE DEMARCATION LIGHTS
TJCC = TOP JUNCTION CONTROL CIRCUITS	TJEF = TOP JUNCTION ENCLOSURE FUSE
LVCB = LOW VOLTAGE CIRCUIT BREAKER	TPIF = THREE PHASE INCOMING FEED
LVCC = LOW VOLTAGE CONTROL CIRCUITS	VFCB = VENTILATION FAN CIRCUIT BREAKER
LVCF = LOW VOLTAGE CONTROL FUSE	VVVF = VARIABLE VOLTAGE VARIABLE FREQUENCY DRIVE

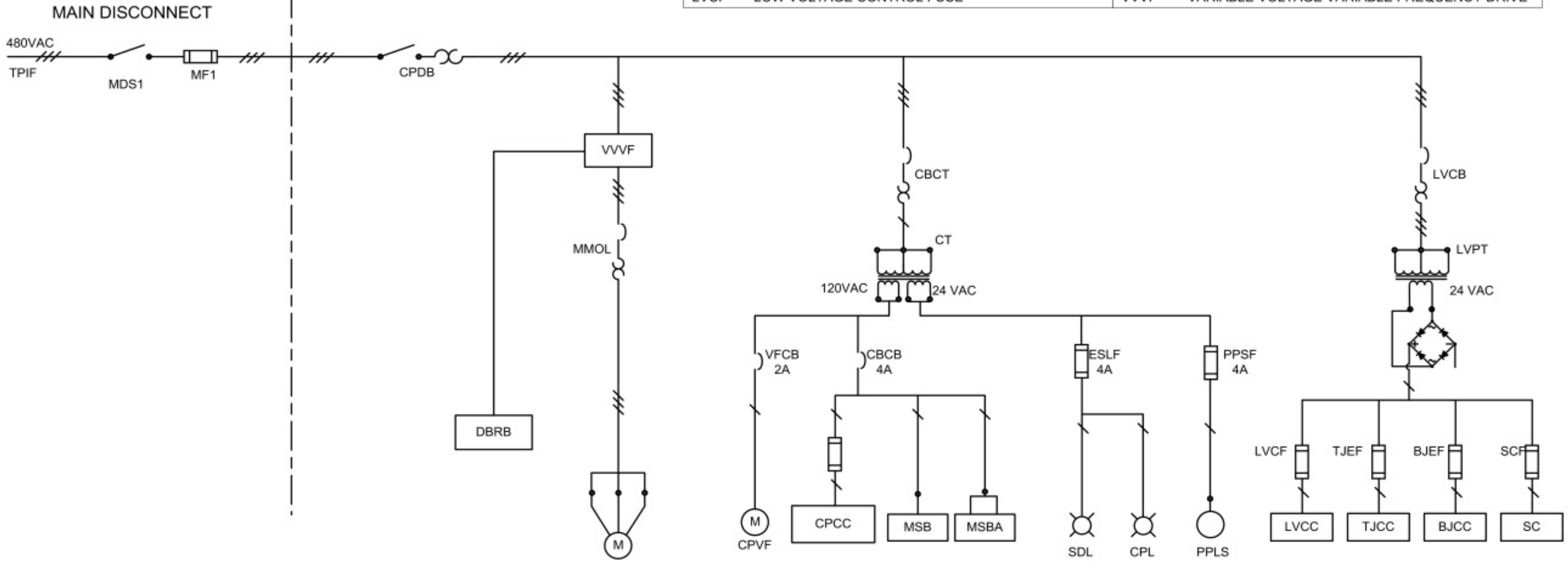


Figure 2.10 Escalator Single Line Diagram Example

Schematic Diagrams

A **schematic** is a diagram that shows the components of a circuit as simplified standard symbols, showing the connections between the devices including power and signal connections. Arrangement of the components' interconnections on the diagram does not correspond to their physical locations in the finished device.

Unlike a single-line diagram, a **circuit diagram** shows the actual wire connections being used. The diagram does not show the physical arrangement of components.

Circuit diagrams are used for the design (circuit design), construction (such as PCB layout), and maintenance of electrical and electronic equipment.

Figure 2.11 and Figure 2.12 are examples of escalator power circuit arrangements for more a modern variable voltage, variable frequency (VVVF) solid-state drive and an older two-part start contactor system, respectively.

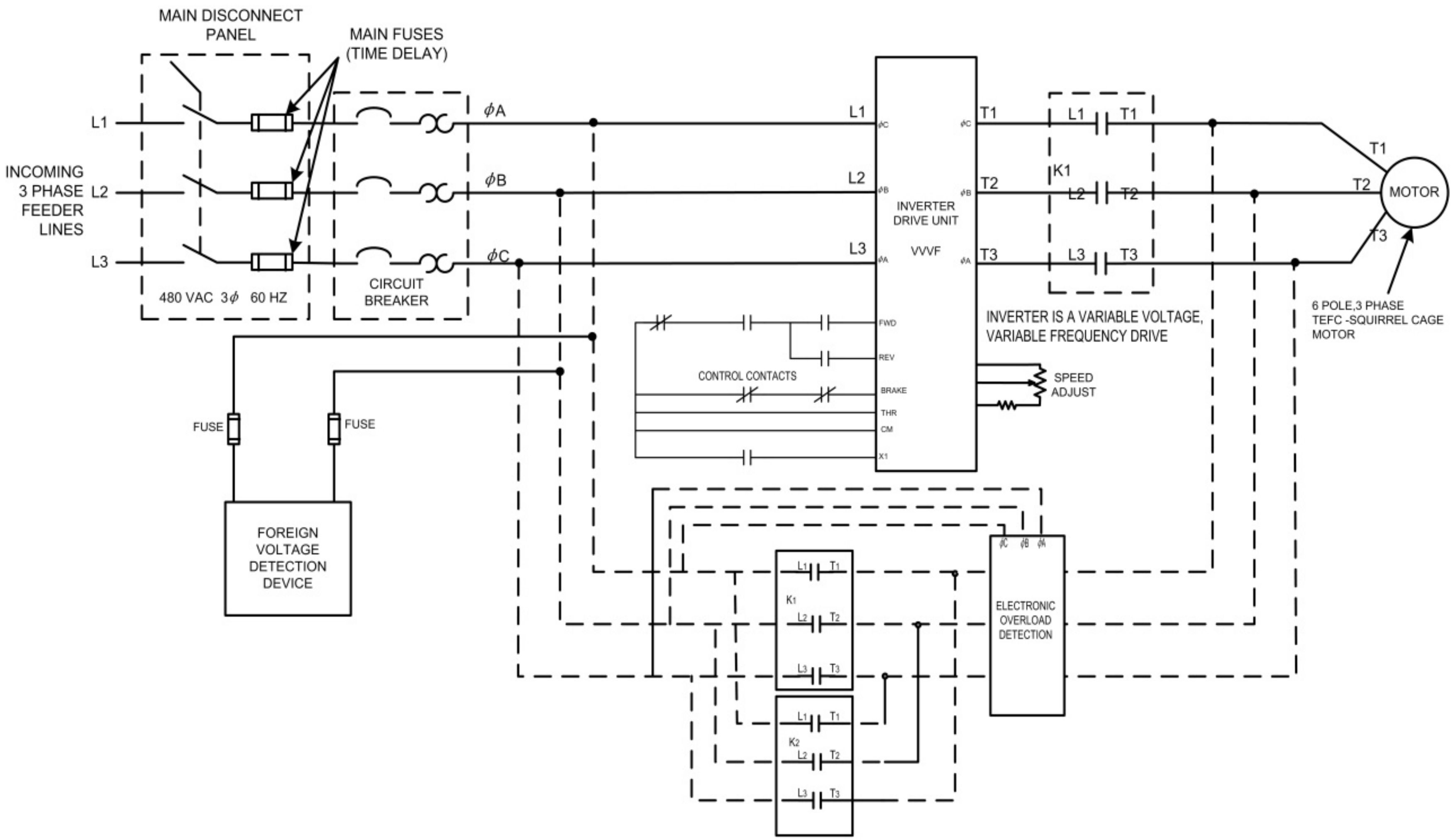


Figure 2.11 Escalator Power Circuit – VVVF Version - Example

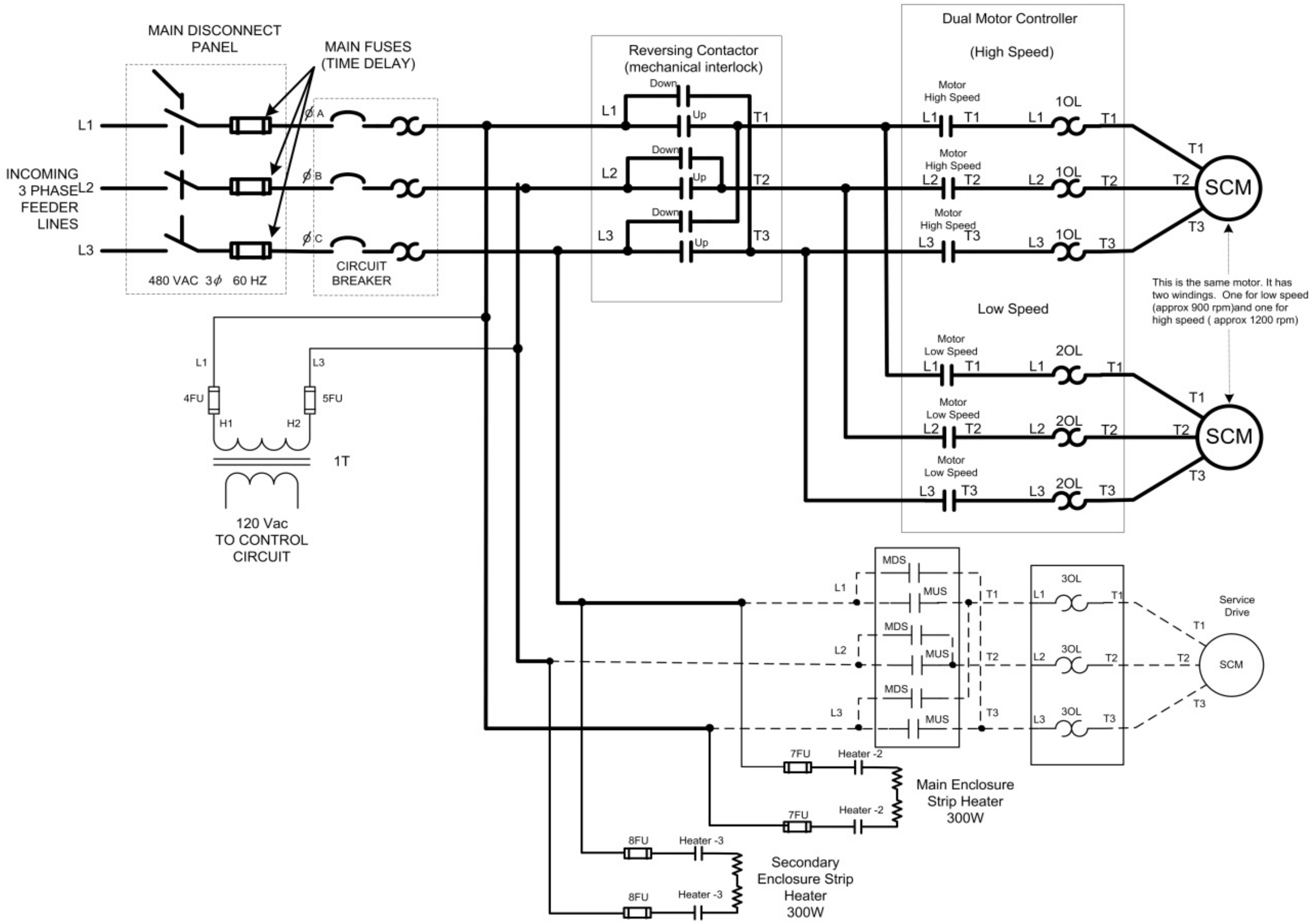


Figure 2.12 Escalator Drive Circuit with Two-Part Start - Example

Block Diagrams

The escalator electrical **block diagram** is a diagram of the system in which the principal parts or functions are represented by blocks connected by lines that show the relationships of the blocks.

Block diagrams rely on the principle of the black box where the contents are hidden from view either to avoid being distracted by the details or because the details are not known. We know what goes in, we know what goes out, but we cannot see how the box does its work. Geometric shapes are used in the diagram to aid interpretation and clarify meaning of the process. The geometric shapes are connected by lines to indicate association and direction/order of travel. Each engineering discipline (electrical, maintenance personnel, hydraulic, etc.) has its own meaning for each shape.

The participant should consider the block diagram a higher level, less detailed description of the electrical system that is aimed more at understanding the overall concepts and less at understanding the details of circuit operation. Recall that the one-line diagram is similar to the block diagram, graphically representing the power flow between the elements of the system.

To make an analogy to the map making world, a block diagram is similar to a highway map of an entire nation. The major cities (functions) are shown, but the minor county roads and city streets are not. When troubleshooting, this high level map is useful in narrowing down and isolating where a problem or fault is located.

The block diagram of an electrical system is not expected to show each wire, relay, or any individual component like the schematic diagram. The block diagram in Figure 2.13 is representative of an electrical system for a generic transit escalator.

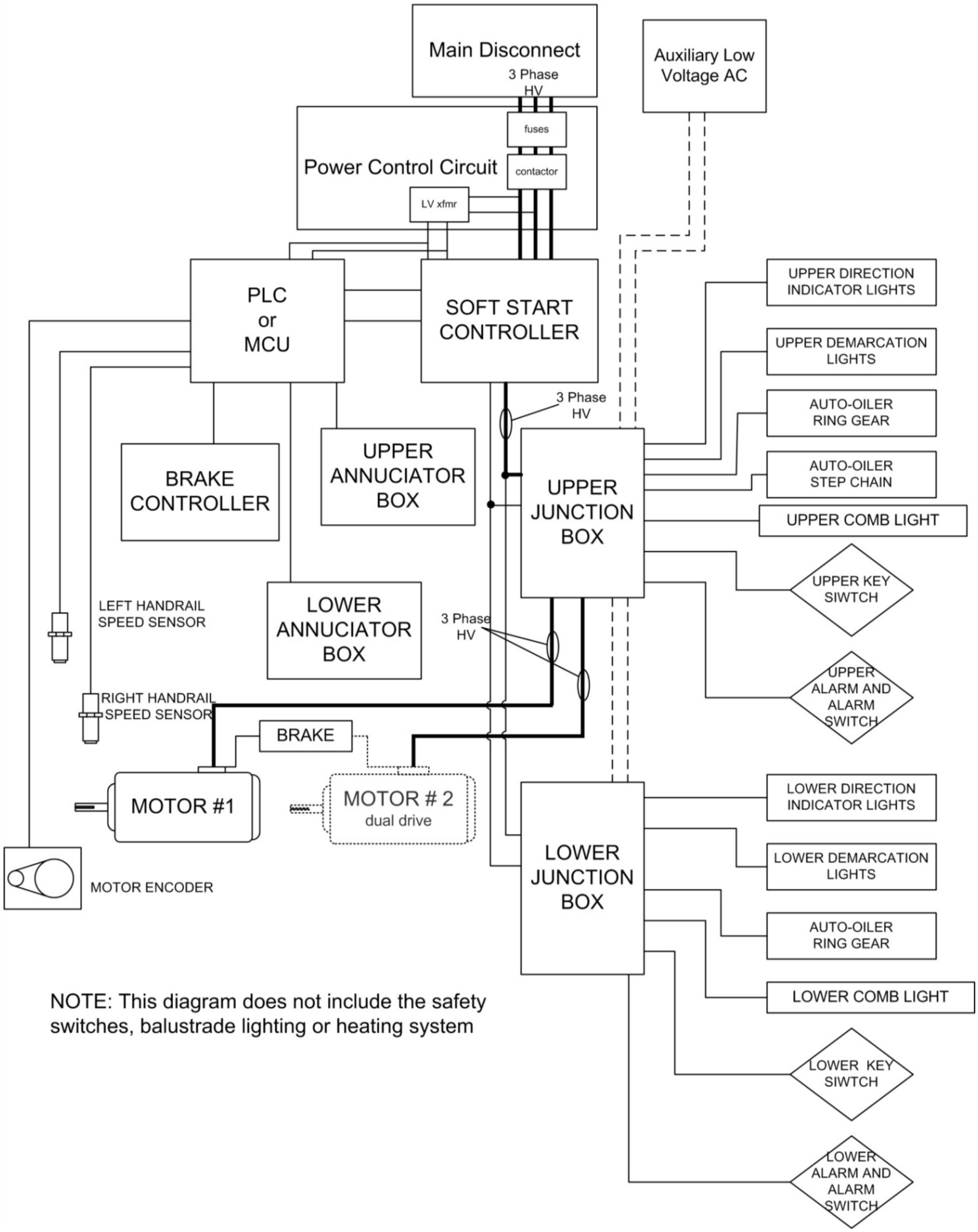


Figure 2.13 Block Diagram of a Generic Electrical System

Pictorial Layout Diagrams

A **pictorial layout diagram** uses simple images (see Figure 2.14) or graphic diagrams of components to display their physical approximation within the system. The pictorial layout could be used for a system device such as the main controller or it could include a layout of the entire truss system in order to show the location of the components. The pictorial layout diagram shown below is for an escalator drive controller panel.

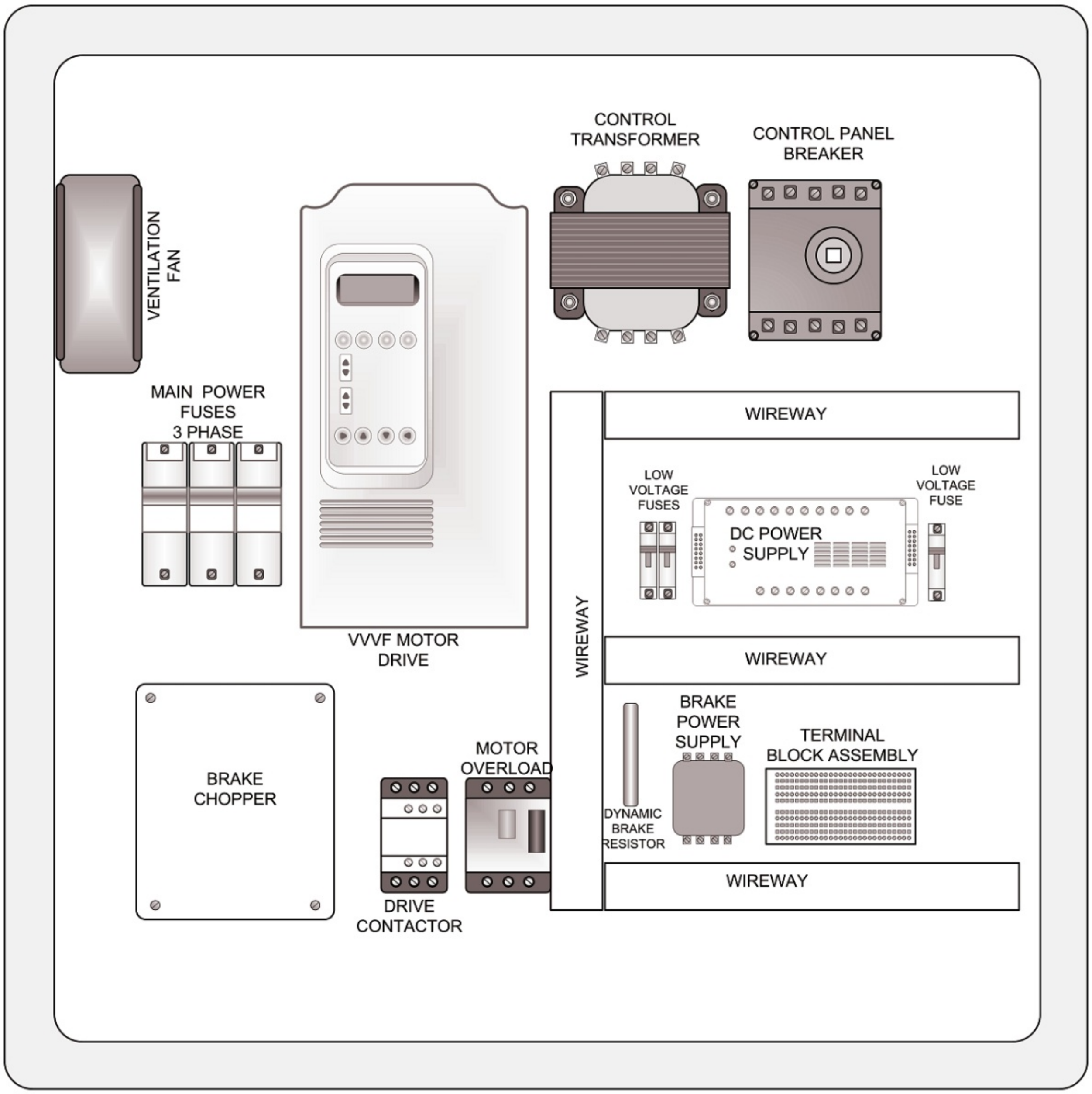


Figure 2.14 Pictorial Layout Diagram

Wiring Diagram

A **wiring diagram** is a simplified conventional pictorial representation of an electrical circuit. It shows the components of the circuit as simplified shapes, and the power and signal connections between the devices. A wiring diagram usually gives more information about the interconnections between devices as well as the type of wiring and nomenclature for the wire. This is unlike a schematic diagram where the arrangement of the components interconnections on the diagram does not correspond to their physical locations in the finished device. A pictorial diagram would show more detail of the physical appearance, whereas a wiring diagram uses a more symbolic notation to emphasize interconnections over physical appearance. A wiring diagram is used to troubleshoot problems and to make sure that all the connections have been made and that everything is present.

Note: Figure 2.11 and Figure 2.12, rather than Figure 2.15, show a better representation of a wiring diagram.

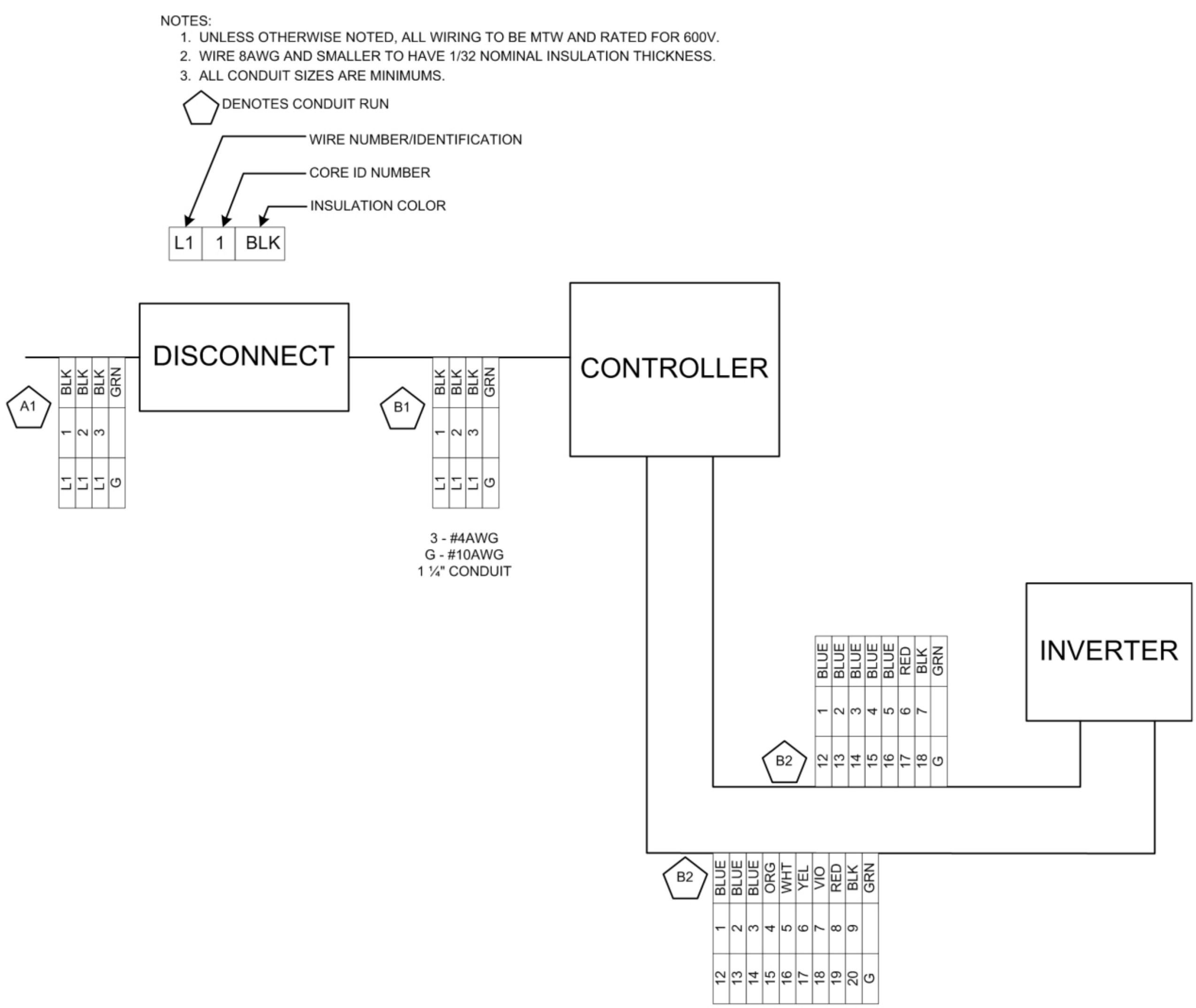


Figure 2.15 Wiring Diagram

WYE-DELTA WIRING CONFIGURATIONS

Across-the line starting of induction motors are accompanied by inrush currents up to ten times higher than running current and starting torque up to three times higher than running torque. The increased torque results in sudden maintenance personnel stress on the machine that leads to a reduced service life. Moreover, the high inrush current stresses the power supply, which may lead to voltage dips.

A method that has been used for years is the **wye-delta method**, also known as the *star/delta method,* of starting the escalator drive motors. This is a starting method that reduces the starting current and starting torque. The device normally consists of several contactors, an overload protection relay and a timer for setting the time in the wye position (star-position).

The motor must be delta connected during a normal run in order to be able to use this starting method. The received starting current is about 30% of the starting current during direct on line (DOL) start and the starting torque is reduced to about 25% of the torque available at a DOL start.

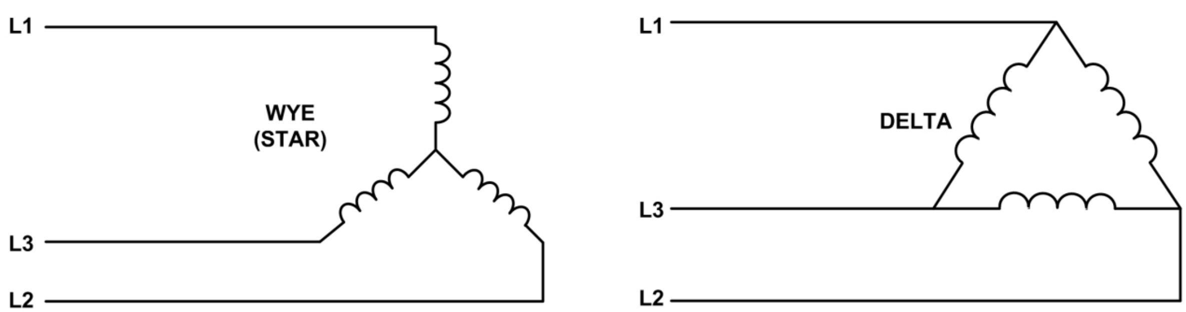


Figure 2.16 Wye-Delta Winding Configurations

This starting method works only when the application is light loaded during the start. If the escalator motor is too heavily loaded, there will not be enough torque to accelerate the motor up to speed before switching over to the delta position.

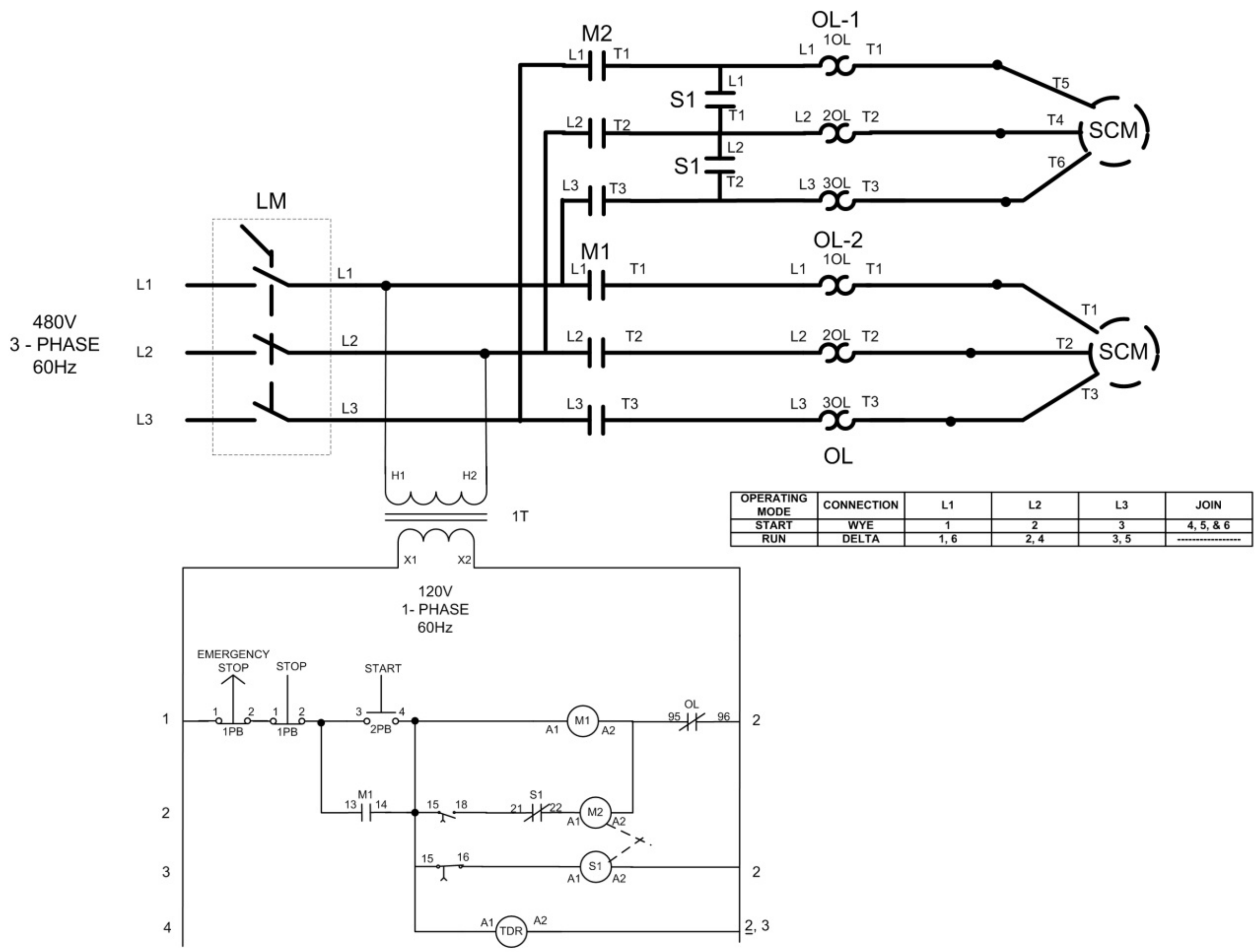
To enable the motor to start, the motor windings are configured in a wye (star) formation to the supply voltage.

Due to the reduced starting torque, the wye-delta-connection is suitable for escalator drives with their high inertia mass and a resistance torque that is low. It is preferable that this type of startup is used in applications where the drive is put under a load only after run-up.

After motor run-up, an automatic timing relay controls the switchover from wye to delta. The run-up, using star connection, normally lasts until the escalator motor has reached the approximate operational speed so that, after switching to delta, as little post-acceleration as possible is required. Post-acceleration in delta connection will instigate high currents as seen with direct on-line starting. This switchover point also helps to minimize any maintenance personnel lurching of the system.

The duration of start in wye connection depends on the motor load. During delta connection, the full mains voltage (normally 480Vac) is applied to the motor windings.

To enable a switchover from wye to delta, the ends of the motor winding are connected onto terminals in the control panel. The contactors of a wye-delta starter switch over the windings accordingly.



OPERATING MODE	CONNECTION	L1	L2	L3	JOIN
START	WYE	1	2	3	4, 5, & 6
RUN	DELTA	1, 6	2, 4	3, 5	----------------

Figure 2.17 Wye-Delta Start Circuit

In the wye-to-delta start circuit shown in Figure 2.17, if the main disconnect is closed, power is fed to the control circuit through the step-down control transformer to the control circuit. If the emergency stop button is closed and no one is pushing the stop button, when the start button is depressed the M1 contactor on line one will close. The M1 holding contact on line two will latch and maintain M1 in a closed state. At the same time, power is fed to contactor S1 on line three and the time delay relay on line 4. The contacts power contacts of M1 and S1 will close simultaneously. The M1 contacts connect L1, L2, and L3 power lines directly to T1, T2, and T3 on the motor while the S1 contacts tie T4, T5, and T6, together thereby forming a wye-connected motor configuration.

The **Time Delay Relay TDR** that also received power at the same time as M1 and S1 began timing out. After a predetermined time, the time delay relay contacts on lines two and three will change states. The normally closed contact on line three will open removing power to S1. The normally open contact on line 2 will close sending power to M2 contactor. Notice that in line three there is an S1 contact that had previously prevented M2 from energizing at the same time as S1. This is the auxiliary contact method of interlock for these two contactors. The dashed line between the two coil symbols represents a maintenance personnel link between the two coils and is another method of interlock.

When S1 de-energizes, the connection between T4, T5, and T6 is broken. At the same time, a connection is made through the M2 contact. T1 is connected to T6; T2 is connected to T4; and T3 is connected to T5, thereby completing the delta power configuration for the motor.

2-5 SYSTEM POWER SUPPLIES

Within the modern escalator drive system, there are requirements for additional power sources at levels other than those supplied by the incoming line feeds. These power supplies may include their own step-down control transformer or they may receive a low level AC voltage from the step-down control transformer in the controller panel.

Low Voltage Power Supply (LVPS)

Low voltage AC to DC converters are used to supply power to auxiliary equipment within the escalator system. Certain types of solid-state sensors require a low level DC voltage to operate. These power supplies are normally self-contained and do not require any field maintenance other than verifying their correct operation. This would include measuring the input and output voltages, as well as checking input and output fuses. (See the Brake Power Supply for an example.)

Figure 2.18 Low Voltage Power Supply

PLC Power Supply

The PLC power supply is an example of another self-contained power supply that requires no field servicing other than testing and verifying its correct operation.

Figure 2.19 PLC Power Supply

Brake Power Supply

As a safety requirement, escalators are provided with an electrically released maintenance brake capable of stopping the up or down traveling escalator with any load up to rated load, as defined in ASME A17.1 – 2010 – 6.1.3.9.3. This brake is located either on the driving machine or on the main drive shaft and is applied automatically if the electrical power supply is interrupted.

The brake is also activated in emergency situations that put passengers in danger, for example, when a step chain breaks or something is caught in the steps or handrail. These braking systems may also be used to stabilize the escalator or walkway when not in motion for extended periods of time, such as when an escalator is used as a stairway where permissible.

The brake is controlled by a solenoid (brake solenoid) which is energized when the escalator is running properly. When energized, the solenoid holds the brake control lever in a release position wherein the brake shoes are held out of engagement with the brake disk. This type of brake is known as a fail-safe brake. If power is lost, the internal springs of the brake re-apply pressure on the brake shoes re-engaging the brake disk.

In Figure 2.20, the solenoids (brake coils) are supplied by the brake power supply. This is a DC power supply which receives its input voltage from the three-phase power feed, which supplies the escalator drive system. The input 480VAC is stepped down by a single-phase transformer to a lower level AC voltage. The level of the voltage may vary with manufacturers. For our example, the secondary voltage on the transformer is 120VAC. The secondary voltage is fed into the bridge rectifier through the two line fuses. These fuses along with the circuit breaker on the primary side of the transformer serve to protect both the power supply and the brake motors from component failure and line voltage surges. The output of the rectifier is fed through a parallel surge protection network to the filter capacitors. The relay contacts bypass this resistive network after a pre-determined time delay at start-up. The filter capacitors remove variations in the rectified DC waveform, thereby supplying a steady-state DC current and voltage to the brake motors. The surge suppressors in parallel with the solenoids serve to protect the power supply from any “inductive kick” once power is removed from the brake motors.

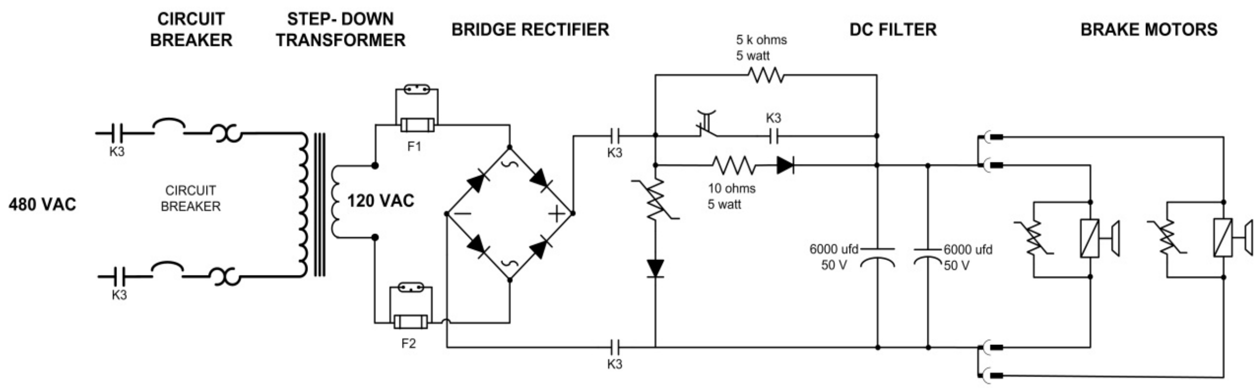


Figure 2.20 Brake Power Supply

Variable Voltage Variable Frequency (VVVF) Drive

As discussed previously in the wye-delta section, single-speed starting methods start motors abruptly, subjecting the motor to a high starting torque and to current surges that are up to ten times the full-load current. The wye to delta start helps to reduce some of that start-up surge but still causes a lurching of the drive when it switches from wye to delta.

VVVF speed drives, on the other hand, gradually ramp the motor up to operating speed to lessen electrical stress, reduce maintenance and repair costs, and extend the life of the motor drive equipment. Full-voltage (across the line) starters can run the motor only at full speed, and reduced voltage soft starters can only gradually ramp the motor up to full speed, and back down to shutdown. Variable speed drives can be programmed to run the motor at a precise speed, to stop at a precise position, or to apply a specific amount of torque. Through the use of its internal processor and programming, the VVVF drive is capable of rapidly responding to changes in passenger load making the change imperceptible to the escalator passengers. In fact, modern AC variable speed drives are very close to the DC drive in terms of fast torque response and speed accuracy. However, AC motors are much more reliable and affordable than DC motors, making them far more prevalent.

The most common type of packaged VVVF drive is the constant-voltage type, using **Pulse Width Modulation (PWM)** to control both the frequency and effective voltage applied to the motor load.

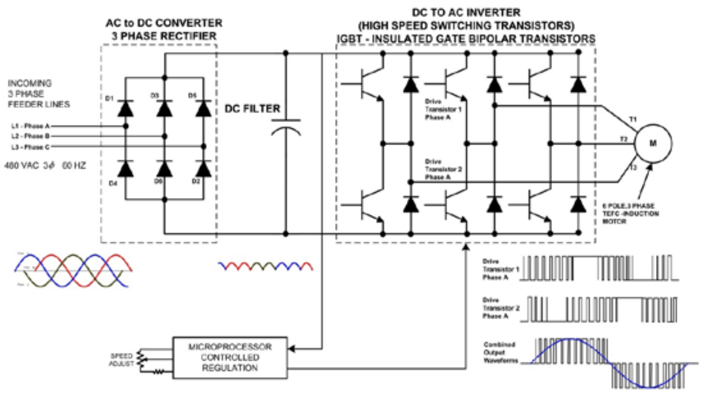


Figure 2.21 VVVF Power Conversion

In the VVVF Power Conversion diagram (Figure 2.21), the three-phase bridge rectifier converts the three- phase incoming line feed to a fixed level DC voltage. The next stage in the drive is the filter that removes variations in the rectified DC waveform. The set of six drive transistors with diodes in the switching (inverter) section of the drive are controlled by the microprocessor. It is in the switching section where the DC power is converted to a "synthesized AC power" which is then fed to the induction motor. The transistors used in this application are typically **Insulated Gate Bi-polar Transistors (IGBTs)**. These devices are capable of switching on and off at high frequency while controlling high levels of current. There are two transistors controlling the inversion of the DC voltage per output phase of the drive:

1. The microprocessor controls the switching action of the inverter section and receives its commands through the speed adjust control, a motor feedback network, speed sensor inputs and its internal programming.

Figure 2.22 shows a simplified block diagram of the microprocessor regulation of a conventional VVVF drive. The speed reference command from the speed adjust is fed to a ramp block to convert step function speed changes to slower-changing ramps that limit current flow and save machine wear and tear. The signal moves to a section that sets both the rate of change (frequency) and strength of the magnetic field of the motor. The single speed control commands both of these variables in a VVVF drive. It is by controlling both the frequency and the voltage that the drive is capable of slowly ramping up and ramping down the speed of the escalator drive motor(s).

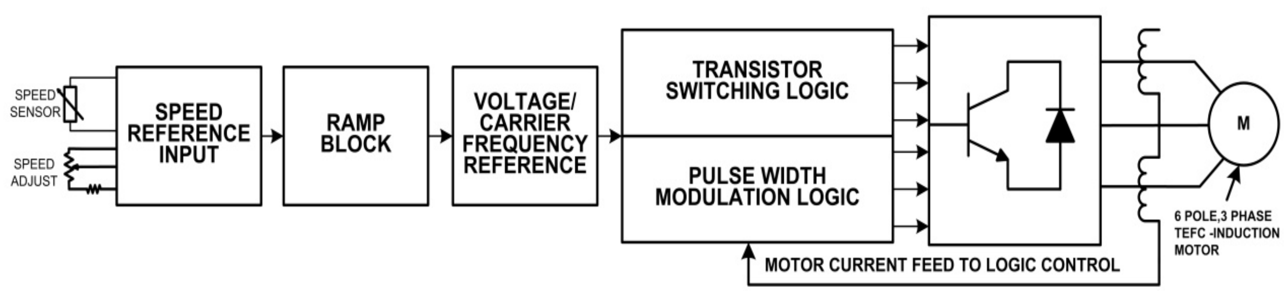


Figure 2.22 VVVF Drive Microprocessor Block Diagram

Some advantages of the VVVF drives are:

- It permits the use of "standard" low cost induction motors. Brushes, commutator, or special magnet motors are not required as in a DC drive.
- High input displacement power factor (above 95%) for lower cost output power versus power consumption.
- Some "inherent" ability to "hold back" loads through power regeneration when used with external circuitry such as a "chopper circuit".
- High speed capability (6000 rpm is easily attainable).
- Variable frequency control means continuously variable speed control.

2-6 ELECTRICAL MEASUREMENT TECHNIQUES

It is the responsibility of the maintenance personnel performing testing and maintenance on the escalator electrical system to be aware of the types of measurements required to ensure the system is operating correctly as well as the safest techniques to employ when making these measurements. In this section, we will cover the safe and correct procedures for performing electrical tests on escalator electrical equipment.

Digital Multimeters

Probably the most common text instrument that maintenance personnel should be familiar with is the Digital Multimeter (DMM). Any DMM suitable for testing should meet the minimum safety standards set forth by the governing agency. The maintenance personnel performing the tests should use the proper personal protective equipment when taking measurements in order to reduce the possibility of injury. **When working with energized ("live") circuits above 208VAC it is necessary to wear protective gloves, a face shield, leather boots, and hearing protection.** This section is not intended as a review of digital multimeter principles. The participant should have been trained in the proper techniques prior to this course.

Types of measurements which maintenance personnel should be capable of performing safely and accurately are:

- Voltage measurements (AC and DC)
- Continuity testing (using the Ohmmeter function)
- Diode testing (meter may be equipped with a separate function for this measurement)
- Resistance measurements
- Current measurements (clamp-on function)

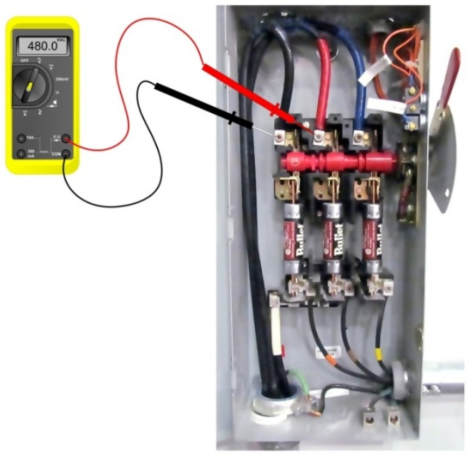


Figure 2.23 Testing a 3 Phase Mainline Disconnect Using a DMM

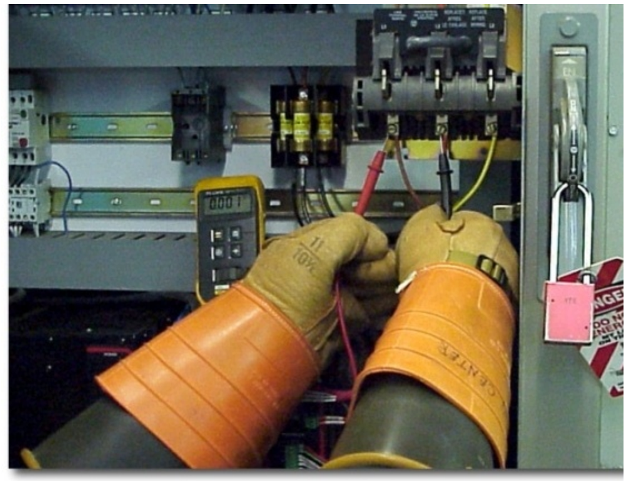


Figure 2.24 Testing a 3 Phase Controller Disconnect Using a DMM

Voltage Measurements

Voltage measurement tests that maintenance personnel will encounter while performing maintenance and testing on an escalator electrical system include:

- Phase-to-phase voltage measurements of the distribution system, motor control circuit, and the motor
- Voltage drop tests on distribution power fuses, motor control fuses, control circuit fuses, motor contactor poles, and overload poles
- Control voltage levels
- DC voltage measurements of power supplies
- Auxiliary systems voltage levels

Current Measurement

Current measurements are necessary when performing troubleshooting and maintenance testing of the electrical system. Current measurement tests may include:

- Incoming line feed (distribution) current (three phases)
- Motor drive circuits and the motor (three phases)
- Individual auxiliary systems
- Motor control circuit (single phase)
- Brake power supply (DC)
- Auxiliary DC power supply (DC)
- PLC power supply (DC)

One method of measuring the current in electrical systems is to use a clamp-on ammeter (Figure 2.25). This device may either be a separate meter or an add-on adapter for a digital multimeter.

Figure 2.25 Clamp-On Ammeter

Typically, if it is an adapter, there is a ratio such as a 1000:1 reduction between the pickup adapter and actual meter reading. For example, if the meter displays1.5 mA, the actual current through the conductor would be 1.5 ampere if the ratio is a 1000:1 reduction.

Whether it is an adapter or a stand-alone clamp-on ammeter, the meter pickup coil is clamped around the conductor, not on the wire, in order to measure the current through it. In order to insure accuracy, the pickup ring should be perpendicular to the conductor when performing this test. The iron core of the pickup ring intersects a magnetic field that radiates from the conductor when current is flowing through it. The magnetic field in turn induces a voltage and current in the iron core and the windings of the pickup ring.

When measuring current in a three-phase system, always measure the current through each individual conductor. **Never clamp the meter pickup around two or more conductors at the same time. This will result in a false reading**. For example: if the pickup is clamped around all three phases of a motor in order to measure the load current, the resulting reading will be approximately zero due to the cancellation of the magnetic fields of each conductor which are out of phase with each other. This same effect will occur when measuring the line and neutral leads simultaneously in a single phase system.

Always use caution when performing this test on a live circuit.

Warning: Safety Precautions!

- If the source voltage is in excess of 208VAC always wear the necessary PPE such as leather gloves, leather boots, hearing protection and a face shield.
- Take care and ensure all conductors are secure before attempting to connect the clamp-on meter. A loose conductor could lead to catastrophic failure if disturbed or displaced during the measurement process.

Continuity and Voltage Testers

In electronics, a **continuity test** is the checking of an electric circuit to see if current flows (that it is in fact a complete circuit). A continuity test is performed by placing a small voltage (wired in series with an LED or noise-producing component such as a piezoelectric speaker) across the chosen path. If electron flow is prevented by broken conductors, damaged components, or excessive resistance, the circuit is "open."

Multimeters are typically used to perform this test, however, specialized continuity testers that are cheaper, more basic devices, generally with a simple light bulb that lights up when current flows can serve to perform quick checks on conductors. Because these devices include and internal voltage source it is possible to damage delicate conductors or solid state devices such as integrated circuits and transistors.

A continuity tester (Figure 2.26) is an instrument that tests for a complete path for current flow. A voltage tester (Figure 2.27) is a device that indicates approximate voltage level and type (AC or DC) by the movement and vibration of a pointer scale. Typically, the voltage tester includes both functions, however a continuity tester can be found as a stand-alone instrument. The voltage tester usually has a crude indication of the voltage level either as series of LED's, neon bulbs, or bar graph. It does not have a meter display.

Figure 2.26 Continuity Tester

Figure 2.27 Voltage Tester

Warning: Safety Precautions!

- These devices should be used only when the circuit being tested is fully de-energized and locked out.

Phase Sequence Indicators

This is an electromagnetic or induction instrument (see Figure 2.28) used to indicate the phase sequence in three-phase electric circuits. The phase sequence of a system determines the direction of rotation of three-phase electric motors. The correct operation of some measuring instruments and automatic control devices within the electrical systems also depends on the phase sequence. A modern digital portable meter is used to perform the phase sequence indication measurement by connecting the standard test leads (a certain order of phase sequence is marked on the terminals of the phase-sequence indicator) on L1, L2, and L3 phases of a generic three-phase system. The meter shows the “R” indication in positive test and “L” indication in the opposite case. General-purpose phase-sequence indicators can be used to determine the power factor and the phase shift between voltage and current.

Figure 2.28 Phase Sequence Indicators

Ground Resistance Tester

This device, shown in Figure 2.29, is used to measure ground connection resistance of electrical installations and is operated vary similar to the clamp-on ammeter. The pickup in this case includes two iron core control transformers. One induces a voltage into the conductor and the other measures the current through the conductor. The internal programming of the device calculates and displays the resistance reading of the ground conductor. Standard with each meter is a test ring that is used prior to measuring a conductor to verify the accuracy of the meter. The resistance of the ground conductor should be less than 25 ohms per industry standards. A faulty ground could permit unwanted electrical noise to be introduced into a system or, in the case of an electrical distribution system or motor drive, the loss of a proper ground could present a safety hazard to personnel during the testing or maintenance.

Figure 2.29 Ground Resistance Tester

Megohmmeter

A megohmmeter, shown in Figure 2.30, is an insulation continuity tester that functions as a specialized ohmmeter. This tester is used to test the insulation of electrical devices, such as motors, to make sure the integrity of the insulation is good and that there is no breakdown of the electrical insulation between a conductor and ground.

Figure 2.30 Megohmmeter. Source: www.aikencolon.com

Typically, these meters will have two sets of ranges. One range is a used for low resistance continuity testing and the other is a high resistance high voltage insulation testing. In its low range setting, it is not much different from the resistance range on a digital multimeter of a volt-ohm meter. When selecting the different ranges in the high resistance function, the participant is selecting different levels of high voltage that the meter will output when performing its resistance test. It is not uncommon for these output voltages to range from as low as 50 Volts to over 2000 Volts.

The types of test leads on this device will vary by manufacturer. One lead is made to be clipped or clamped onto the chassis or frame of the device under test, the other lead is usually a probe with a tip with which the participant makes contact with the conductor under test. Then with one of the high voltage settings, the participant measures the resistance between the chassis/frame and ground. If the insulation is good and there is no breakdown under the voltage test, the participant should measure a very high resistance (high megohm). If there is a breakdown or ground fault, the meter will show a low resistance possibly all the way to zero if there is a hard fault to ground.

The high voltage test is activated by either pressing a button that activates a solid-state voltage multiplier or by turning a hand crank high voltage DC generator mounted within the tester. When using the megohmmeter, be careful not to exceed the rating of the insulation of the device or conductor cable under test. If the rating is exceeded the participant may actually cause damage to the insulation while performing the test. Never use the high voltage settings on this device to test a semiconductor device such as a VVVF or soft-start motor drive on an escalator. If this tester is connected directly to the output terminals of a drive in order to test the insulation of the motor and its wiring without disconnecting the motor leads from the electronic drive, the high voltage output of megohmmeter will be simultaneously applied to the switching transistors within the electronic drive. An error such as this could destroy the output of the drive.

Warning: Safety Precautions!

- The megohmmeter uses a high level of voltage and it is possible to receive an electrical shock if the proper precautions are not made.
- Always read the manufacturers safety recommendations before using this type of test instrument.
- These devices should be used only when the circuit being tested is fully de-energized and locked out.

2-7 SUMMARY

The electrical power system for a modern transit escalator encompasses both the electrical requirements for the drive system as well as the auxiliary electrical equipment and lighting associated with the unit.

The electrical source for the escalator drive system is typically a three-phase 480 VAC system. This distribution system is controlled by a three-phase electrical disconnect and supplies power to the motor control circuits, the drive systems, the braking system, and the safety circuits. The auxiliary power distribution system, a 3-wire, single-phase, mid-point neutral system, which supplies both 120 VAC and 240 VAC provides electrical power for auxiliary and ancillary equipment associated with the escalator. This may include heaters, lighting, annunciators, communication equipment, as well as landing area lighting and service outlets.

When working with these distribution systems and the associated equipment that they serve, it is important for the maintenance personnel to be familiar with the different types of electrical diagrams that may be available for testing or maintaining this equipment. These drawings may include one-line diagrams, block diagrams, schematic diagrams, pictorial diagrams, and wiring diagrams.

One of the wiring arrangements maintenance personnel may encounter is the wye to delta motor control circuit. This type of motor control configuration has been used for years with six wire induction motors as a method of reducing electrical and mechanical stresses on the escalator driver motor during its start-up. The motor contactors are wired in such a way as to switch the motor from a wye to a delta configuration. The wye configuration allows for a low torque start-up under load. Through a timing circuit, the contactors switch the motor configuration to a delta arrangement to provide an even torque during operation.

With the advent of new types of semiconductors and the evolution of AC motor controls, more modern transit escalators utilize a solid-state drive control for the motor(s). This type of drive may be either a soft-start controller or a variable frequency drive controller. The variable voltage variable frequency drive is becoming more prevalent in new systems due to its ability to provide a smooth ramp-up and ramp-down of the escalator drive under load. An additional advantage of the VVVF drive is when it is used in conjunction with another type of electronic controller, known as a chopper: it is possible to achieve a dynamic braking effect and regenerative power output during the stopping sequence.

Additional power supplies that maintenance personnel will encounter with the escalator electrical system are the brake solenoid DC power supply, the PLC power supply, as well as auxiliary DC power supplies for sensors and relays found within the control and safety circuits.

In order to maintain this type of electrical equipment, it is recommended that the maintenance personnel performing maintenance and testing are familiar with the various types of electrical test instruments required. This may include a digital multimeter, voltage testers, ground testers, insulation testers, continuity testers, and phase measurement devices. When using testing instruments, follow the manufacturer’s safety warning regarding testing procedures. (i.e., know when power must be de-energized).

MODULE 3

Escalator Safety Circuits

Outline

Purpose and Objectives

The purpose of this module is to provide the participants with a basic knowledge of the various types of electrical safety circuits which protect the passengers, as well as the mechanical and electrical systems of a transit escalator.

Following the completion of this module, the participant should be able to complete the objectives with an accuracy of 75% or greater:

- Identify the function of different types of safety circuits
- Locate various safety devices in a schematic diagram
- Explain the function of specific types of safety circuits
- Test and verify the operation of various types of safety circuits
- Discuss the circuit fault conditions as they relate to safety circuits
- Identify the upper and lower safety circuits of a transit escalator

Key Terms

- Broken Step Chain
- Capacitive Coupling
- Combplate Impact Devices
- Contactor Dropout Check
- Controlled Access
- Conventional "Limit" Switch
- Direct Method
- Electrical System Safety Circuits
- Foreign Voltage Detection
- Governor Speed Device
- Ground Fault Detection
- Handrail Entry Device
- Mechanical System Safety Circuits
- Overload Protection
- Passenger Safety Circuit
- "Positive-Break" Safety Interlock
- Phase Monitoring
- Redundancy
- Remote Monitoring System
- Self-Checking
- Short Circuit Protection
- Single Fault Tolerance
- Speed Monitoring
- System Safety Circuit
- Zero Sequencing

3-1 OVERVIEW

Transit escalator safety is governed by the American Society of Mechanical Engineers' *Safety Code for Elevators and Escalators* (ASME A17.1). Per section 6.1.7.4.1, all electrical equipment and wiring must conform to NFPA 70 (NEC). As transit escalators have modernized they have been equipped with various electrical circuits to enhance the safety of passengers (ASME 6.1.6.3.1 thru 6.1.6.3.16). These electrical safety features include both passenger safety devices and systems safety devices. The **passenger safety circuits** focus on removing power from the escalator and preventing it from being restarted until a qualified person investigates the cause of the shutdown. The reason for removing the power from the escalator is to minimize any potential bodily harm to the passenger. The **system safety circuits** are intended to prevent or minimize damage to the escalator and its associated equipment.

Safety Circuit Switches

Safety circuit switches are designed for repeatability, reliability, and a smooth actuation. These are precision snap-action switches, sealed in rugged housings, used to detect presence or absence in areas of the escalator where physical contact sensing is required.

Conventional "limit" switches are typically designed to use a spring force (resilient mechanism) to open normally closed electrical contacts. Such designs are subject to two potential failure modes:

- Spring failure
- Inability of the spring force to overcome "stuck" or "welded" contacts

When "actuated", either situation may result in an unsafe condition due to failure to open normally closed contacts. Consequently, such designs are not certified or recognized as suitable for safety applications. Figure 3.1 illustrates how conventional normally-closed contacts open by resilient mechanical mechanism (spring). Contacts may not open due to spring failure or welded contacts.

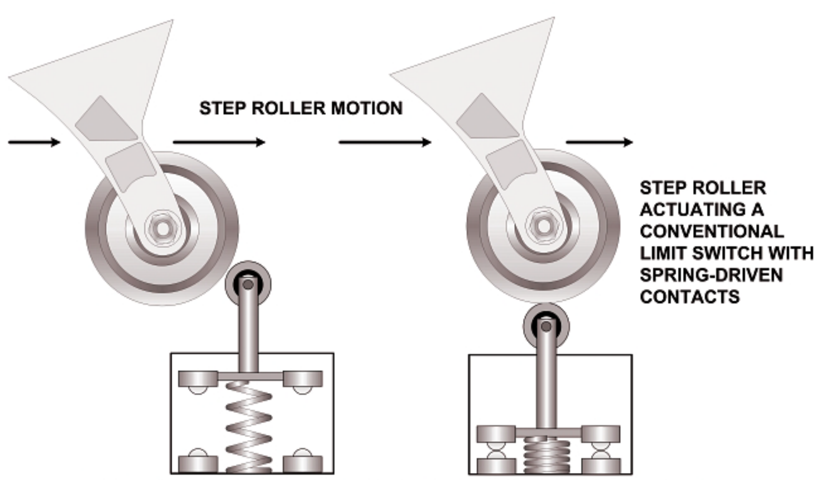


Figure 3.1 Conventional Contacts

"Positive-break" safety interlocks are electromechanical switches designed with normally-closed (NC) electrical contacts which, upon switch actuation, are forced to open by a non-resilient mechanical drive mechanism such as a step roller. (Spring actuators are not considered positive-break mechanisms.) Figure 3.2 illustrates how positive-break normally closed contacts are forced to open by a non-resilient mechanical mechanism (step roller).

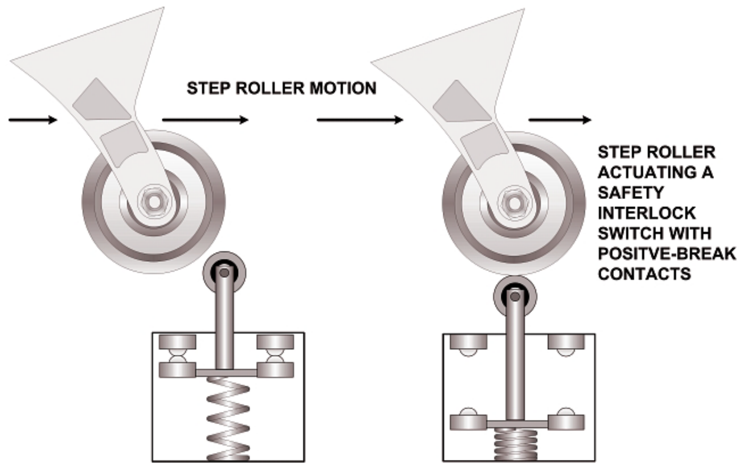


Figure 3.2 Positive-Break Contacts

Self-checking: In modern transit escalators with a logic controller, periodic self-diagnostics on safety control circuits are performed to ensure critical individual components are functioning properly. Faults or failures in selected components and switches will result in system shut down. Most systems perform self-checks at start up and/or at timed intervals.

Redundancy: In certain safety applications redundancy is built into the system to ensure that if one component/circuit should fail, the other (redundant) component/circuit will still be able to generate a stop signal. When coupled with a "self-checking" feature, a safety circuit component failure, or component failure within the safety circuit monitoring module, will be automatically detected and the machine shut down until the failure is corrected.

Single-fault tolerance: A safety circuit is considered to be single-fault tolerant if no foreseeable single fault will prevent normal stopping action from taking place.

3-2 ELECTRICAL SYSTEM SAFETY CIRCUITS

The system safety circuits incorporate protective interlocks which either shut down or remove power entirely from the system when a sensor or switch indicates a mechanical or electrical problem with the escalator. As an example, a safety shutdown would occur if a mechanic were to inadvertently open the door to the escalator drive controller without going through the proper shut down procedures. Another example is a ground fault within the electrical distribution system could cause a complete loss of electrical power to the drive systems.

The safety circuits themselves are either direct acting, as in the door panel switch, or indirectly acting, as in a sensor which feeds a signal to the PLC which in turn shuts the system down. The majority of electrical safety features in modern escalators are fed through the PLC which in turns makes the decision to provide a fault warning on an annunciation panel or through a communication network, as well as shutting the system down if the fault so warrants. Through the PLC, the escalator self-diagnostic system monitors the operative status of various input and output components and upon sensing an error initiates action to bring the escalator to a safe operating state. The system then logs the error. The diagnostic system then analyzes the error and the conditions prevailing at the time the error occurred and, if necessary, a corrective action is then taken to resolve the error. This allows the escalator system to be brought back into service more quickly than would otherwise be possible once the mechanic has accessed the information through the PLC interface panel. Specifically, a number of internal tests are serially performed on various escalator components, such as the motor drive, the position sensors, etc. When an error or fault arises in a system component, a self-diagnostic system logs a preselected error level which has been assigned to the particular fault. A preselected action is then taken according to the particular error. By accessing the log, the mechanic can more readily determine the corrective action needed to place the escalator back into service.

Electrical system safety circuits are designed to protect the electrical system and the riders/maintenance personnel of a transit escalator. The most common type of input device used within the escalator safety system is a switch. The safety switches in modern PLC-controlled transit escalators have two independent contacts, one normally closed (NC) for the safety circuit and one normally open (NO) for signaling. In each switch, the NO contact is wired directly to an input point to enable the PLC to monitor each safety device. For the purpose of redundancy, all NC contacts of the safety devices are wired in series, providing a hard-wired safety circuit to the controller. Each set of contacts within the switch operates independently. The escalator can be stopped either by the NC or the NO contact.

In addition to the safety switches, the controller monitors the speed of the motor, the left and right handrails and the step band; each device must operate within predetermined limits to allow the escalator to run.

Overload protection is used to protect the motor drive circuit in the event that escalator load limitations are exceeded. The overload detection occurs with the motor control panel. A three-phase overload relay with full load amperage rating not greater than 125%, senses the excess current through the power feed conductors. The current rating or the overcurrent protection setting should not exceed the rating of the feeder power lines. If the current settings of the overload relay are exceeded for an extended period of time, which is determined by the rating of the relay, the power to the motor will be disconnected by either a direct-on-line interruption or through auxiliary contact feedback from the overload relay to the motor control circuit. The three-phase induction drive motor may also include internal overload protection with an automatic reset. In the case of internal motor overload protection, the motor will not restart until the load condition has been resolved and/or the motor has reached an internal temperature which will allow it to restart. Some modern variable frequency drives use an over temperature protection relay which receives a signal from sensors imbedded in the motor housing which will not permit a restart until the motor's temperature has returned to normal.

Figure 3.3 and Figure 3.4 are examples of overload protection devices.

Figure 3.3 Three-Pole Contactor with Auxiliary Contacts

Figure 3.4 Three-Phase Manual Motor Starter with Thermal Overload Protection

Short circuit protection is provided in both the drive control circuit as well as the auxiliary power circuit. The type and rating of the devices will vary with the circuit load design for the components they are feeding. In the case of the motor drive circuit, it is not uncommon for the three-phase supply to be fused in both the main disconnect and within the drive control unit. The fuse ratings however will be different for these two locations. The three-phase feeder fuses will have a larger current rating than the three-phase motor control fuses. This is due to the fact the three-phase feeder may be supplying power to other elements within the escalator system other than the drive controller.

Figure 3.5 Single- and Multiple-Pole Fuse Holders

Ground fault detection is required (NEC Article 230.95) for equipment such as the wye electrical feed to an escalator drive system. Although ground-fault protectors are not required on service disconnects that are less than 1000 amperes, depending on the installation, they still may be desirable. Ground fault interrupters designed to provide life protection must open a circuit at 5 milliamps (± 1 milliamp). Ground fault protection for equipment must open a circuit when ground fault current reaches 30 milliamps. Modern escalator drive systems incorporate a ground fault protection system in order to protect both.

One way a ground fault protector works is to install a sensor around one conductor, normally the neutral-to-ground strap. This is referred to as the **direct method**. When an unbalanced current from a line-to-ground fault occurs, current will flow from ground to neutral. When the current reaches the setting of the ground fault sensor, the shunt trip opens the circuit breaker, removing the load from the line.

Another way a ground fault protector works is with a sensor installed around all the circuit conductors, including the neutral on 4-wire systems. This is referred to as **zero sequencing.** During normal current flow, the sum of all the currents detected by the sensor is zero. However, a ground fault will cause an unbalance of the currents flowing in the individual conductors. When this current reaches the setting of the ground-fault sensor, a signal is fed to the PLC removing power from the escalator.

Foreign voltage detection is provided to detect and warn of the presence of potentially dangerous voltage levels on conductors such as power cables, metal utility boxes, metal truss frames, and the like. The detector comprises a capacitive sensor that is charged through **capacitive coupling** when mounted near a conductor. Capacitive coupling is a method of a connecting to a circuit without a direct electrical connection, much like inductive coupling. Some manufacturers include this monitoring device as part of the motor control circuitry. Its output is supplied to the PLC.

Phase monitoring relays protect electrical equipment against failures due to phase loss, phases out of sequence, and phase imbalance issues. If a motor is powered by an incorrect phase sequence it will cause the motor to turn in the opposite intended directional rotation, which could cause serious damage to product and personnel. A phase monitoring relay is designed to detect an incorrect phase sequence and keep the motor starter from starting.

Figure 3.6 Examples of Phase Monitoring Relays

Contactor dropout check: Each main and auxiliary contactor provides a signal via a normally closed contact to the PLC for a dropout check which is carried out every time the escalator stops. The contactors are controlled by the PLC. When the safety circuit is closed and the dropout check is completed successfully, a command is issued for starting the escalator in either direction.

Controlled access generally refers to a movable machine guard that is designed such that it can be opened only under specific conditions. Controller panels and landing plates will incorporate this method of safety interlock. With more stringent access control, such movable guards restrict access to an area of a machine, which continues to present a hazard to the operator immediately upon the removal of power. In these situations, opening of the guard is prevented until the hazardous condition has abated. This is usually achieved by a solenoid-latching interlock switch controlled by a motion detector, position sensor, time-delay or other machine-status monitor which releases the interlock (allowing the operator to open the guard) only after safe conditions exist.

Speed monitors are used in escalator systems where it is necessary not to exceed rated speeds such as the motor, handrail, and step chain. The measuring principle is to compare frequencies. The output of a proximity, Hall Effect (*see note below), or optical sensor is supplied to the PLC and the speed is converted to a speed proportional frequency. This frequency is compared to an internal adjustable frequency reference. If the measured frequency is higher or lower than the reference by a preset percentage, the PLC would send a command to shut down the escalator drive.

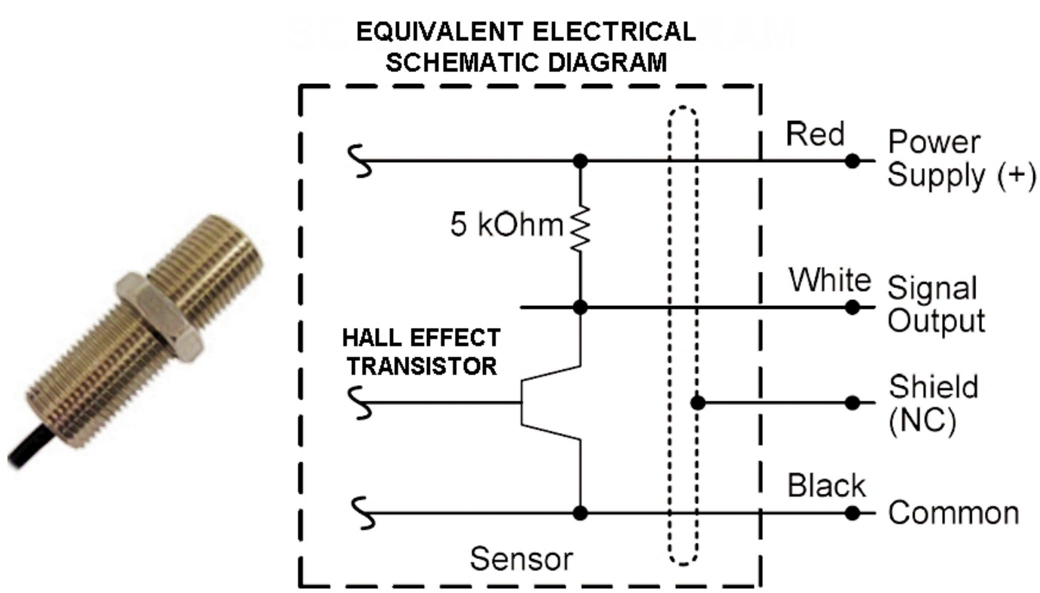


Figure 3.7 Hall Effect Zero Speed Sensor

*The **Hall Effect**, discovered by Edwin Hall, is the generation of an electric potential perpendicular to both an electric current flowing along a conducting material and an external magnetic field applied at right angles to the current upon application of the magnetic field.

The **governor speed device** is attached to the high-speed (input) shaft of the gear reducer, just beyond the machine brake in the drive machine. It consists of a proximity sensor and pulsar disc. The pulsar disc has magnetic strips that are evenly spaced within the disc. As the disc rotates, these magnetic strips pass by the proximity sensor. As this happens, a signal is created and sent to a switch. The switch has upper and lower set points to stop the escalator at +/- 20% of the nominal motor speed. The signal is a square wave, ON when detecting the magnet and OFF when no magnet is found.

Figure 3.8 illustrates several speed sensing systems.

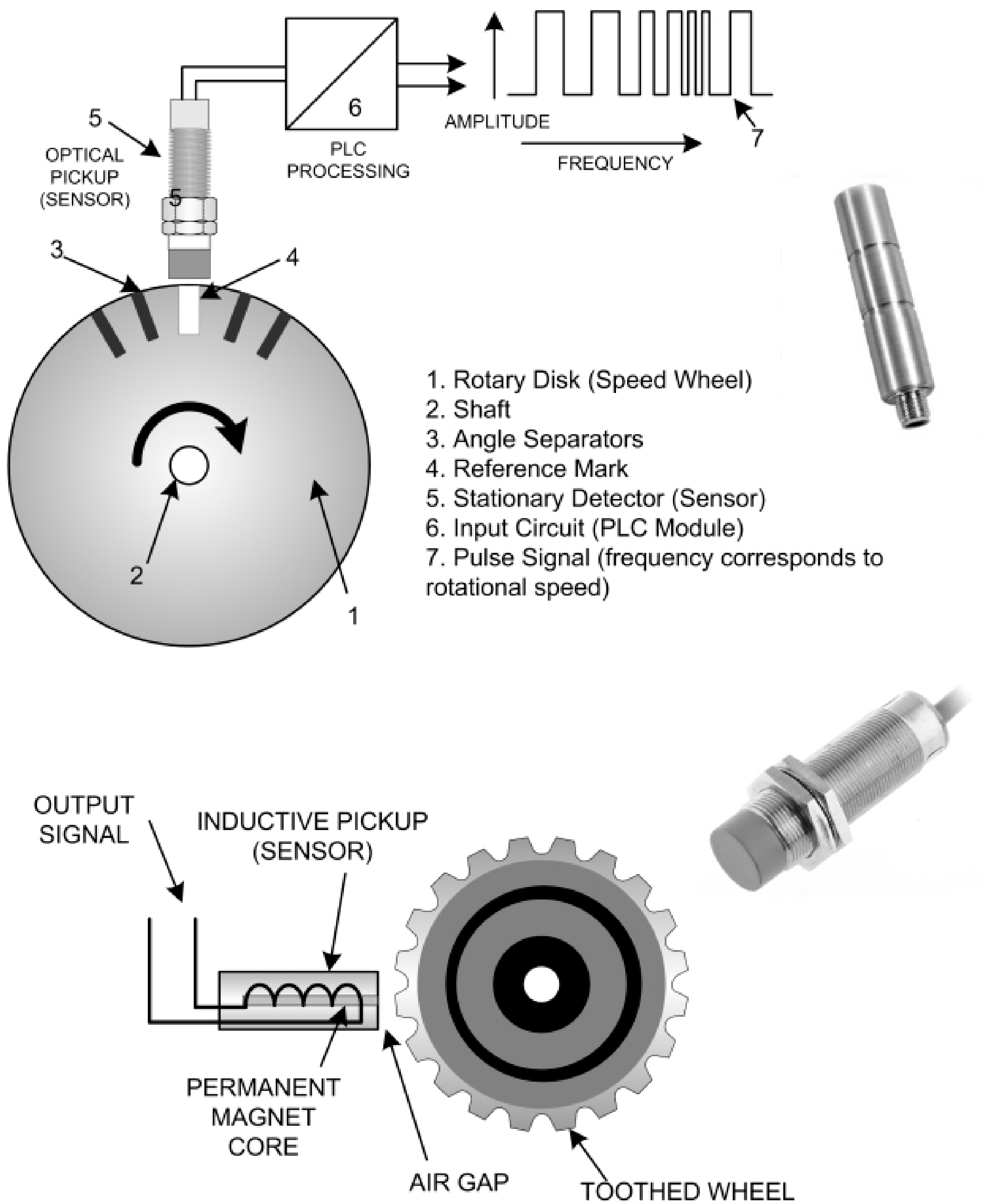


Figure 3.8   Examples of Speed Sensing Systems

Mechanical System Safety Circuits

Mechanical system safety circuits are incorporated in the escalator to protect the mechanical systems of a transit escalator. This type of protection shuts down electrical power to the escalator drive to prevent extensive damage to the mechanical parts.

The **step upthrust** safety device stops the escalator when a step is forced upward before entering the combplate. This device prevents the step from crashing into the combplate, causing damage to the step, comb fingers and, possibly, other components. When the riser end of the step is displaced upward more than 5mm (0.20 in.), it will trip a lever arm on the limit switch. The switch cuts off electrical power to the motor and brake, stopping the escalator before the step enters the combplate with any load up to the brake rated load with the escalator running.

The **broken step chain** device cuts electrical power to the escalator motor and brake, stopping the escalator in the event of drive chain breakage or excessive sag in either of the step chains. This limit switch must be manually reset before the reset at the controller can occur. In modular systems this device may be attached to the tension carriage in the lower truss of the escalator and it will cause the escalator to stop if the tension carriage moves too far forward or backward. The modular system device consists of a plunger-type limit switch mounted on a bracket attached to the truss and a kicker that will actuate the switch if moved too far in either direction.

Step lateral displacement devices detect when a step experiences a sideward displacement at either side of the step riser or at the step chain axle due to wear or failure. Typically, this type of device is a rotary-style limit switch. The switch cuts electrical power to the motor and brake, stopping the escalator and the limit switch must be manually reset.

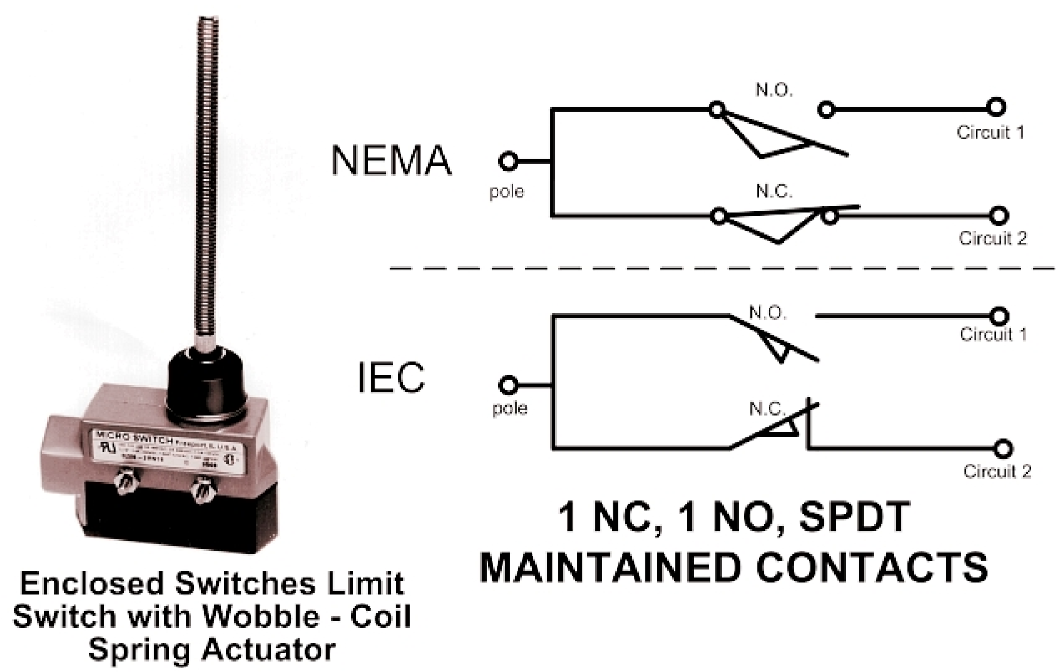


Figure 3.9 Mechanical System Safety Circuits

The **handrail entry device** stops the escalator (by removing electrical power) when an object becomes lodged between the handrail and the handrail guard or if an object nears the space between the handrail and the handrail guard. The switch and mechanism is located within the interior of the escalator at the bottom of each newel. The switch cuts power to the motor and brake, stopping the escalator. The limit switch must be manually reset.

This limit switch is an example of the type of switch which could be used for the following device contacts:

- Step chain tension contact
- Combplate contact
- Drive chain contact, mechanical
- Handrail entry contact
- Handrail rupture contact
- Step level contact
- Step chain locking device contact

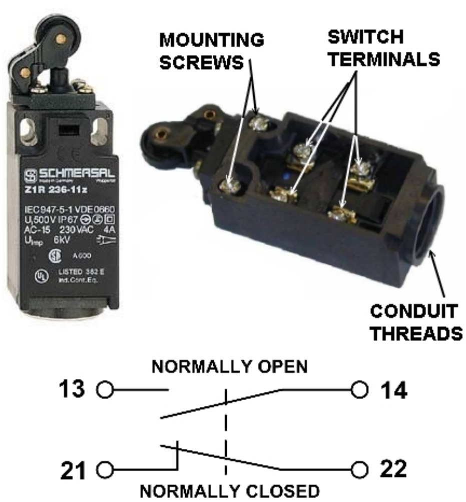


Figure 3.10 Limit Switches

3-3 PASSENGER SAFETY CIRCUITS

Skirt obstruction devices: If an object becomes caught between the step and the skirt as the step approaches the upper or lower combplate, the detector (skirt safety switch) stops the escalator before that object reaches the combplate. Skirt safety switches are plunger-type limit switches located behind the skirt panel at the upper and lower transition points and at intervals along the incline. They cut off electrical power to the drive motor and brake motor when a foreign object is wedged between the skirt panel and step or when pressure is applied to the skirt panel. This type of limit switch is a pin plunger style; its circuitry is an SPDT, with conduit mounting.

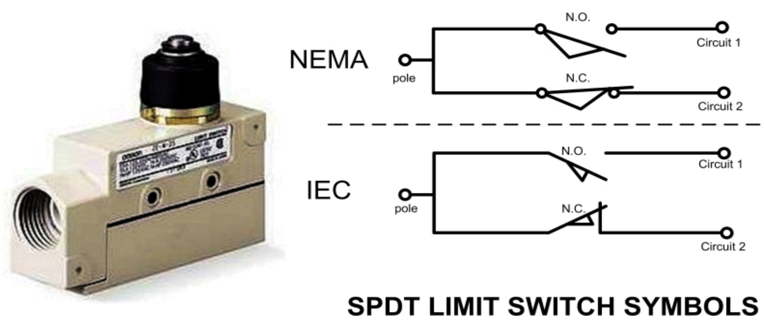


Figure 3.11 Skirt Obstruction Devices

Combplate impact devices stop the escalator if an excessive horizontal or vertical force is applied to either side or to the center of the front of the combplate. The comb impact switches and mechanism are located behind the skirt panel. When horizontal force exceeds 400 pound-feet at either side of the combplate or exceeds 800 pounds at the center of the combplate, the combplate will slide until the lever depresses the switch. When a vertical force exceeds 150 pound-feet at the center of the combplate, it will rotate slightly until the lever depresses the switch. Either event will cut off electrical power to the motor and the brake thereby stopping the escalator. The device will have to be manually reset.

The **handrail speed device** is located within the interior of the truss and consists of a solid state sensing system. In one type, an inductive pickup proximity sensor and a pulsar disc are used. The pulsar disc has magnetic strips that are evenly spaced within the disc. As the disc rotates, these magnetic strips pass by the proximity sensor the resulting signal is a square wave. If the handrail is moving at a constant speed, the resulting frequency of the pulses will remain constant. The signal is sent to the control processor or to a set point switch and the frequency rate is compared to a speed output signal from the steps. If the speed of the handrail deviates by a maximum of 15% or more from the speed of the steps, an alarm will be activated. If the speed variation is continuous for a time range of two to six seconds, the escalator motor and brake will lose electrical power and a manual reset is required. Another type of sensing system used is an optical sensor and a rotational disk that has reflective material located at one point on the disk circumference. New rotational devices incorporate a hall-effect magnetic sensor which detects Ferro-magnetic material near the sensing tip such as a gear, sprocket, or a hole pattern in a ferrous plate. Sensing is accomplished by the interruption of a magnetic field, providing a non-contact speed sensing capability down to zero speed. The resulting signals of the optical and the hall-effect sensors provide a cleaner signal input to the processor than the inductive pickup device. These devices require a DC voltage supply for their operation.

Emergency stop buttons are located under clear covers at the upper and lower landings on the right-hand side (when facing the escalator). When the cover is moved, a warning alarm sounds and when closed, it is self-resetting. The emergency switches are operated manually by either authorized personnel or the public to stop the escalator immediately for an emergency. These buttons are red momentary push buttons with multiple contacts mounted to the curved newel framework on high deck units and on low deck units it is located below the handrail height between one and a half and three and a half inches from the bottom of the handrail. The operation of either of the emergency buttons removes electrical power from the escalator drive and brake. Manual reset is required normally by the operation of the key switch.

Step lighting: The escalator lighting system includes the step gap lighting, the combplate lighting and the skirt lighting. The step gap lighting, the combplate lighting, and the skirt lighting are switched on when the unit is in continuous operation. The step gap lighting is either fluorescent or led lights (traditionally green in color) located inside the truss. The illumination between the steps improves the passengers' awareness of the step divisions.

Indicator lighting: Direction indicator lights are used to signal the passengers when they can enter the escalator from the respective landing. The green direction indicators are activated for the corresponding direction when the unit is in continuous operation and no errors or stop commands have occurred. The red direction indicators for the corresponding direction are illuminated when the unit is in continuous operation and no errors or stop commands have occurred, or when the unit is at a standstill.

Missing step devices are located in the upper and lower trusses at the turnaround in order to detect a missing step before the missing step section emerges from the comb. This device cuts off electrical power to the escalator motor and brake, stopping the escalator, and the limit switch must be manually reset. On some systems, these devices are inductive proximity sensors and detect if a step is missing by not reading a metallic presence within a predetermined amount of time. These devices are mounted just above the bottom edge of the aluminum riser. As the steps pass, the sensor detects the riser edge. When the sensor does not detect a riser for pre-set time (example: 1.2 seconds), the circuit opens to shut down the escalator.

3-4 REMOTE MONITORING AND ANNUCIATION

New programmable logic controllers are designed to work in conjunction with other new safety devices to provide correct information processing and proper escalator control. Escalator faults are identified by the control and illuminated in a display on the control cabinet or the upper and lower annunciators for easy troubleshooting.

The annunciator panel is an electronic device which annunciates (indicates) status of various devices to assist the technician in understanding their conditions. The manufacturer and agency decides which devices must be tracked and indicated. The indications can be real data, code, or lights, depending on manufacturer.

The purpose of the **remote monitoring system** is to collect information from the escalators and elevators in the transit agency's stations. The connected escalators' information is collected by means of hardware interfaces that are connected to the Agency's network. This information is sent to a database for storage. This data is used to determine the status of the connected escalators and elevators. Based on patterns (bits level), a simple change to a complex event (or error) can be displayed on a web-based or an internal intranet system to show the working status of the connected escalators and elevators.

The main advantage of the remote monitoring system is the information shows the time and date of changes in the condition of the escalators and elevators. The remote system can give the end users (technicians, supervisors, on-site and off -site management of the connected vertical transportation equipment) the status of the equipment including date and time.

This information can be sent via email, cellular phone and pager to selected personnel. The technician will have knowledge of the problem prior to arriving on site.

The master PLC module is a central processor unit that, through logic, links the system together and analyzes instructions, and takes action correspondingly. It processes the individual data it receives via bus line, the Transmission Control Protocol (TCP) and the Internet Protocol (IP)[1], from the slave PLC, the drive, the two communication bus couplers in the top and bottom junction boxes, and the operator's interface terminal. The PLC then issues commands accordingly.

The slave PLC module acquires data from the peripherals (contacts, sensors, displays), distributes data to the peripherals, and forwards the appropriate data to the master PLC. The PLC system also checks whether the starting and stopping of the escalator correspond with redundancy requirements. The CPUs are supplied with flash memory storage. For this reason this design doesn't require battery backup.

There is a connection from the escalator Programmable Logic Controller (PLC) inside the escalator controller to a computer on site. The connection can be a telephone cable (CATV- reads "cat five"), fiber optic cable, or small 12-18 gauge telephone wires. The computer on site sends the information via the Internet or Intranet to a computer (server) which stores and processes the information.

The connection inside the escalator and the annunciator panel are the only two items you must check if the remote monitoring system is out of service. How will you know the system is down? The end users will not be receiving their reports. If the annunciator panel is not functioning properly, it must be inspected for electrical problems and the problem may be due to the escalator not sending the information out.

[1] The TCP/IP model, or Internet Protocol Suite, describes a set of general design guidelines and implementations of specific networking protocols to enable computers to communicate over a network. TCP/IP provides end-to-end connectivity specifying how data should be formatted, addressed, transmitted, routed and received at the destination. Protocols exist for a variety of different types of communication services between computers.

3-5 SUMMARY

The escalator electrical safety circuits are governed by the American Society of Mechanical Engineers safety code along with any local jurisdictional requirements. These electrical safety features include both safety devices to protect passengers and systems safety devices to protect the electrical and mechanical equipment. Mechanical system safety circuits are incorporated in the escalator to protect the mechanical systems of a transit escalator. This type of protection shuts down the escalator drive to prevent extensive damage to the mechanical parts. Electrical safety circuits are designed to protect the electrical systems of a transit escalator in case of a catastrophic failure within the wiring or components of the system.

Most safety circuits incorporate protective interlocks which either shut down or remove power entirely from the system when a sensor or switch indicates a mechanical or electrical problem with the escalator. The safety circuits themselves are either direct acting or indirectly acting as in a sensor which feeds a signal to the PLC which in turn shuts the system down. The majority of electrical safety features in modern escalators are fed through the PLC which in turns makes the decision to provide a fault warning on an annunciation panel or through a communication network, as well as shutting the system down if the fault so warrants.

The most common type of input device used within the escalator safety system is a switch. Safety circuit switches are having either conventional contacts or positive break contacts and they are designed for rugged use. In a conventional contact switch, the circuits make or break relies on the internal spring. In a positive break switch, an external force provides greater reliability that the contacts will open.

Most modern transit escalators have redundant system controllers, safety circuits and self-check diagnostics. For example, each switch in the safety string supplies two inputs to the PLC. One input is direct feedback to the PLC which allows the processor to determine on/off state of the switch. For the purpose of redundancy the other input is its function within the safety circuit. This type of arrangement insures greater reliability.

In addition to the safety switches, the controller monitors the speed of the motor, the left and right handrails and the step band; each device must operate within predetermined limits to allow the escalator to run. Solid-state sensors provide voltage/frequency signals to the control device corresponding to the speed of the system they are monitoring.

Passenger safety circuits along with the step, landing and combplate lighting are designed to reduce the risk of injury due to either a malfunction of the equipment or because of an accident a passenger sustains while riding the escalator.

Remote monitoring systems provide information on the status of the escalator drive, safety circuits, and peripheral equipment in real time allowing for increased maintenance oversight as well as maintenance personnel access record to the equipment. Escalator faults are identified by the control and illuminated in a display on the control cabinet or the upper and lower annunciators for easy troubleshooting.

MODULE 4

Escalator Control Circuits

Outline

Purpose and Objectives

The purpose of this module is to provide the participants with a basic knowledge of the various types of electrical control circuits and components; and how they are interrelated in a transit escalator system.

Following the completion of this module, the participant should be able to complete the objectives with an accuracy of 75% or greater:

- Describe the methods of starting and stopping an escalator
- Describe the method of controlling speed, reversing, and braking an escalator
- Given a system schematic, locate the major components of the control system and describe their function
- Operate and test a working escalator control system
- Describe the function of an escalator PLC
- Identify the major components of a PLC
- Demonstrate the ability to remove and replace a PLC module

Key Terms

- Auxiliary Contact Interlocking
- Fail-Safe Circuit
- Interlock Circuit
- Isolation
- Latch, Holding, and/or Seal-in Circuit
- Mechanical Interlock
- Permissive Circuit

4-1 OVERVIEW

Control circuits for escalator systems are vital to the proper performance and protection of modern equipment. A complete motor circuit is usually divided into control and power sections. The power circuit includes the motor and therefore, operates under higher voltage. On the other hand, the control part mostly contains the switching devices and typically operates under lower voltage of the control transformer or a separate low voltage dc power supply.

Control devices, such as the maintenance inspection control pendant station pushbuttons, limit switches, sensors, or key switches, all command the operation of the drive and braking motors via their open or closed contacts, which convey a control current. Contactors and control relays are devices that use electromagnetic induction to open and close contacts. Contactors are part of the motor starter power switching devices. Control relays are used as control switching devices, because they are designed to withstand lower electrical currents. Motor starters are systems comprising switching and overload-protection components.

The type of control circuit used is either a permissive, interlock, or both. Fail-safe circuitry is incorporated to ensure the system defaults to the safest mode in the event of a wiring or circuit failure. Circuit breakers and fuses protect the motor from very high currents. Overload protection devices are safeguards against prolonged, relatively high current levels.

The PLC (programmable logic controller) is the heart of the control system for a modern transit escalator. It interfaces with all the safety, maintenance, and operator controls to ensure safe accurate control of the drive and braking systems. The PLC is also capable of interfacing with a maintenance supervisory monitoring system for remote monitoring of the status of the system. Through the operator’s interface controls of the PLC, the mechanic is provided a means to test and troubleshoot the control parameters of the escalator.

4-2 CONTROL TRANSFORMERS

The control transformer in the escalator controller is an electromagnetic device that steps down the incoming phase to phase voltage to a single-phase level which is useable by loads in a control circuit. Control transformers also provide electrical isolation. The transformer accomplishes the transfer of energy through mutual inductance. Mutual inductance is where the magnetic flux (magnetic lines of force) of two or more inductors are “linked” so that voltage is induced in one coil proportional to the rate-of-change of current in another. A transformer is a device made of two or more inductors, one of which is powered by AC, inducing an AC voltage across the second inductor. If the second inductor is connected to a load, power will be electromagnetically coupled from the first inductor’s power source to that load. The powered inductor in a transformer is called the primary winding. The unpowered inductor in a transformer is called the secondary winding.

Aside from the ability to convert between different levels of voltage and current in AC and DC circuits, transformers also provide an extremely useful feature called **isolation**, which is the ability to couple one circuit to another without the use of direct wire connections.

The control transformer used in an escalator control panel typically has multiple windings on both the primary and secondary side. The primary side of these power transformers is labeled H1, H2, H3, etc. and the secondary side is labeled X1, X2, X3, etc. The "H" corresponds to the "High" side or input and the "X" represents the "Control" side of transformer. The multiple windings serve to make the transformer adaptable in order to function in different circuits. This type of transformer could be fed more than one level of voltage on the high side and step-down the voltage to more than one voltage level on the secondary depending on how the windings are configured (Figure 4.1 and Figure 4.2). However, once the circuit winding options have been chosen for the transformer, there is usually no need to vary the location of the connections to these terminals (taps).

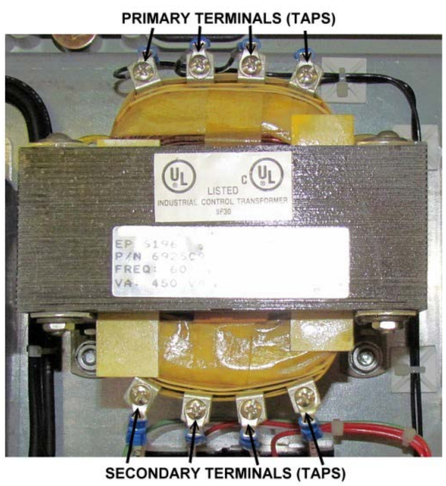


Figure 4.1   Step-Down Transformer for an Escalator Control Unit

Figure 4.2   Step-Down Transformer 120 VAC to 36 VAC

Warning: Safety Precautions!

- Use extreme caution when troubleshooting a live control panel.
- The terminals on the transformers are exposed and if physical contact occurs, electrical shock could result.
- The power rating of the transformer is sufficient to cause bodily injury and/or death.
- Follow your agency's electrical safety guidelines and wear the proper PPE when working with voltages of this level. (Voltage in the controller may be as high as 480 VAC.)

Other transformers may exist within the escalator control system. These transformers, however, are normally fed power from the main control transformer. The main control transformer not only provides power for the control circuit, but it may supply power to other sub systems such as the brake/clutch power supply and the auxiliary dc power supply for the solid-state sensing systems and relays within the escalator control circuitry.

4-3 PERMISSIVE AND INTERLOCK CIRCUITS

Permissive Circuits

For years a practical application of switch and relay logic was used in escalator control systems where multiple conditions have to be met before the escalator is allowed to start. A good example of this is safety string control circuit. In order for the escalator to be started safely, the control system requests "permission" from safety switches and sensors throughout the escalator, including upper thrust switch, lower skirt switch, lower missing step switch, lower and upper combplate switches, lower left-hand handrail inlet switch, lower level step switch, etc. Each safety switch condition is called a *permissive*, and each permissive switch contact is wired in series, so that if any one of them detects an unsafe condition, the circuit will be opened preventing the escalator from starting or shutting it down if an unsafe condition occurs. If all permissive conditions are met, the main contactor will energize and the escalator drive will power up.

Interlock Circuits

Another practical application of relay logic is in escalator control systems where we want to ensure two incompatible events cannot occur at the same time. An example of this is in reversible motor control, where two motor contactors are wired to switch polarity (or phase sequence) to an electric motor; we don't want the forward and reverse contactors energized simultaneously. Switch contacts designed to prevent a control system from taking two incompatible actions at once (such as powering an electric motor forward and backward simultaneously) are called **interlocks**. Figure 4.3 is an illustration of the interlock circuit.

When contactor M1 is energized, the 3 phases (A, B, and C) are connected directly to terminals 1, 2, and 3 of the motor, respectively. However, when contactor M2 is energized, phases A and B are reversed; A going to motor terminal 2 and B going to motor terminal 1. This reversal of phase wires results in the motor spinning the opposite direction.

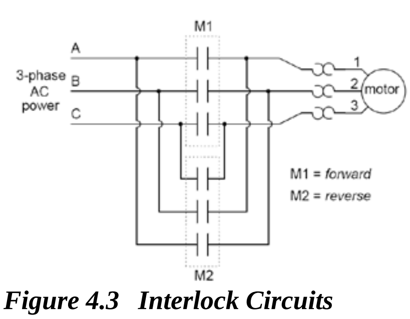


Figure 4.3 Interlock Circuits

Let us examine the control circuit for these two contactors. In the control circuit below the normally-closed "OL" contact, the thermal overload contact is activated by the "heater" elements wired in series with each phase of the AC motor. If the heaters get too hot, the contact will change from its normal (closed) state to being open, which will prevent either contactor from energizing.

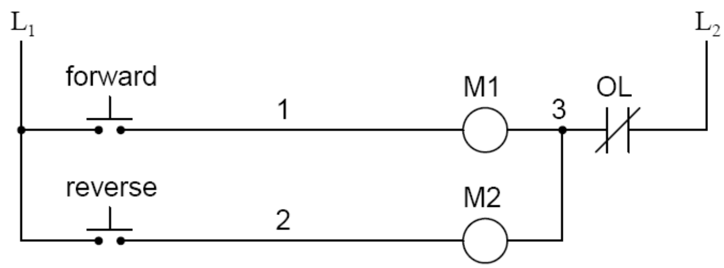


Figure 4.4 Interlock Circuits

This control system will work well, so long as no one pushes both buttons at the same time. If someone were to do that, phases "A" and "B" would be short-circuited together because contactor M1 sends phases "A" and "B" straight to the motor, and contactor M2 reverses them; phase "A" would be shorted to phase "B" and vice versa. Obviously, this is a bad control system design!

To prevent this occurrence from happening, the circuit is arranged so that the energization of one contactor prevents the energization of the other. This is called **auxiliary contact interlocking**, and it is accomplished through the use of auxiliary contacts on each contactor, as such:

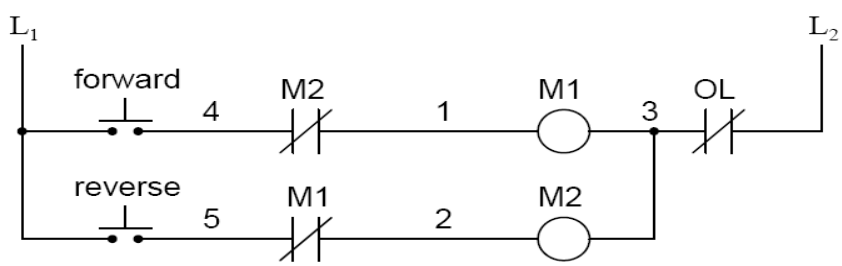


Figure 4.5 Auxiliary Contact Interlocking

When M1 is energized, the normally-closed auxiliary contact on the second rung will be open, thus preventing M2 from being energized, even if the "Reverse" pushbutton is actuated. Likewise, M1's energization is prevented when M2 is energized. Note also how additional wire numbers (4 and 5) were added to reflect the wiring changes.

It should be noted that this is not the only way to interlock contactors to prevent a short-circuit condition. Some contactors come equipped with the option of a **mechanical interlock**: a lever joining the armatures of two contactors together so that they are physically prevented from simultaneous closure. For additional safety, electrical interlocks may still be used, and due to the simplicity of the circuit there is no good reason not to employ them in addition to mechanical interlocks.

Motor Control Circuits

The interlock contacts installed in the motor control circuit work well, but the motor will run only as long as each pushbutton switch is held down. To keep the motor running, even after the operator takes his or her hand off the control switch(es), the circuit could be changed in a couple of different ways: the pushbutton switches could be replaced with toggle switches, or more relay logic could be added to "latch" the control circuit with a single momentary actuation of either switch. The second approach is more commonly used.

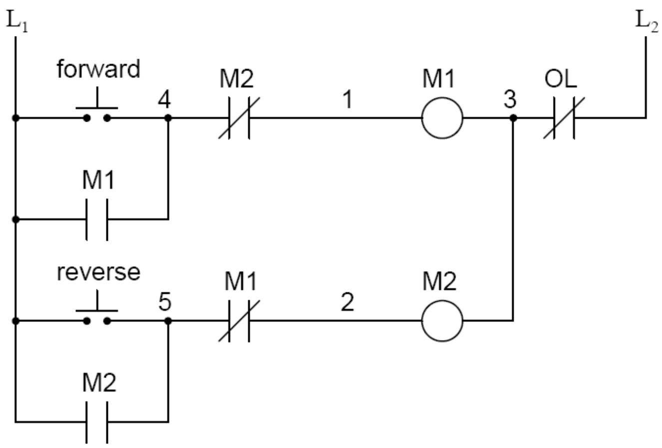


Figure 4.6   Motor Control Circuits

When the "Forward" pushbutton is actuated M1 will energize, closing the normally-open auxiliary contact in parallel with that switch. When the pushbutton is released, the closed M1 auxiliary contact will maintain current to the coil of M1, thus latching the "Forward" circuit in the "on" state. The same sort of thing will happen when the "Reverse" pushbutton is pressed. These parallel auxiliary contacts are sometimes referred to as **holding or seal-in contacts**, the word "seal" meaning essentially the same thing as the word **latch**.

However, this creates a new problem: how to stop the motor! As the circuit exists right now, the motor will run either forward or backward once the corresponding pushbutton switch is pressed, and will continue to run as long as there is power. To stop either circuit (forward or backward), we require some means for the operator to interrupt power to the motor contactors. We'll call this new switch, *Stop*.

Now, if either forward or reverse circuits are latched, they may be "unlatched" by momentarily pressing the "Stop" pushbutton, which will open either forward or reverse circuit, de-energizing the energized contactor, and returning the seal-in contact to its normal (open) state. The "Stop" switch, having normally-closed contacts, will conduct power to either forward or reverse circuits when released.

Consider another practical aspect of this motor control scheme. If our hypothetical motor turned a mechanical load with a lot of momentum, such as a large air fan, the motor might continue to coast for a substantial amount of time after the stop button had been pressed. This could be problematic if an operator were to try to reverse the motor direction without waiting for the fan to stop turning. If the fan was still coasting forward and the "Reverse" pushbutton was pressed, the motor would struggle to overcome that inertia of the large fan as it tried to begin turning in reverse, drawing excessive current and potentially reducing the life of the motor, drive mechanisms, and fan. Some type of a time-delay function, if required, in this motor control system to prevent such a premature startup from happening.

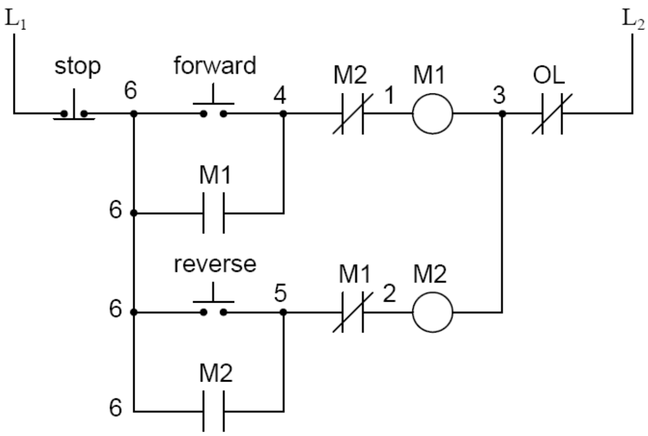


Figure 4.7 Step-Down Transformer for an Escalator Control Unit

In the circuit below, a couple of time-delay relay coils, one in parallel with each motor contactor coil have been added. The contacts on these relays delay returning to their normal state and a "memory" of which direction the motor was last powered to turn. Each time-delay contact will open the starting-switch leg of the opposite rotation circuit for several seconds, while the fan coasts to a halt, preventing the start-up of that circuit.

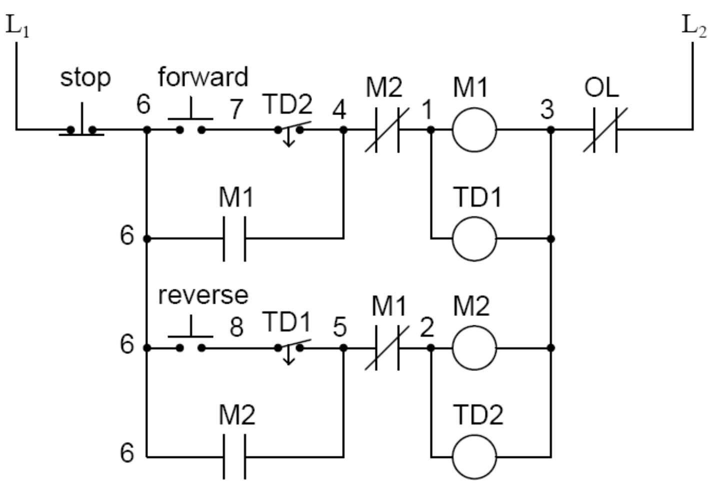


Figure 4.8 Step-Down Transformer with time delay

If the motor has been running in the forward direction, both M1 and TD1 will have been energized. In which case the normally-closed, timed-closed contact of TD1 between wires 8 and 5 will have immediately opened the moment TD1 was energized. When the stop button is pressed, contact TD1 waits for the specified amount of time before returning to its normally-closed state, thus holding the reverse pushbutton circuit opens for the duration so M2 can't be energized. When TD1 times out, the contact will close and the circuit will allow M2 to be energized if the reverse pushbutton is pressed. In like manner, TD2 will prevent the "Forward" pushbutton from energizing M1 until the prescribed time delay after M2 (and TD2) have been de-energized.

Notice that the time-interlocking functions of TD1 and TD2 render the M1 and M2 interlocking contacts redundant. This eliminates the necessity of the auxiliary contacts M1 and M2 for interlocks. Since they immediately open when their respective relay coils are energized, the TD1 and TD2 contacts "lock out" one contactor if the other is energized. Each time delay relay serves a dual purpose: preventing the other contactor from energizing while the motor is running, and preventing the same contactor from energizing until a prescribed time after motor shutdown. The resulting circuit has the advantage of being simpler than the previous example:

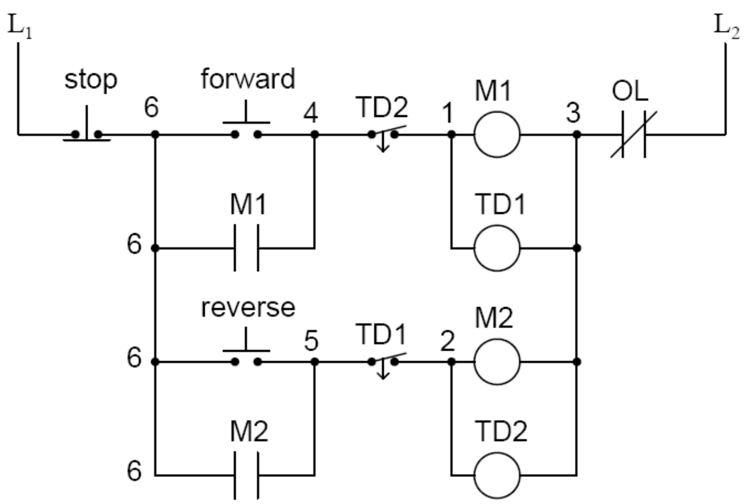


Figure 4.9 Step-Down Transformer with Time-interlocking Functions

Logic circuits, whether comprised of electromechanical relays or the solid-state logic gates of a PLC system, can be built in many different ways to perform the same functions. There is usually no one "correct" way to design a complex logic circuit, but there are usually ways that are better than others.

4-4 FAIL-SAFE CIRCUITS

This design of circuit is referred to as **fail-safe**, due to its intended design to default to the safest mode in the event of a common failure such as a broken connection in the switch wiring. Fail-safe design always starts with an assumption as to the most likely kind of wiring or component failure, and then tries to arrange things so that such a failure will cause the circuit to act in the safest way, the ”safest way” being determined by the physical characteristics of the process.

Take for example an electrically-actuated (solenoid) valve for turning on the oiler to a machine. Energizing the solenoid coil will move an armature which then either opens or closes the valve mechanism, depending on what kind of valve we specify. A spring will return the valve to its “normal” position when the solenoid is de-energized. An open failure in the wiring or solenoid coil is more likely than a short or any other type of failure, so this system should be designed to be in its safest mode with the solenoid de-energized.

If its lubrication oil we are controlling with this valve, chances are it is safer to have the oiler turn on in the event of a failure than to shut off, the consequences of a machine running without oil usually being severe. This means we should specify a valve that turns on (opens up) when de-energized and turns off (closes down) when energized. This may seem “backwards” to have the valve set up this way, but it will make for a safer system.

The goal of fail-safe design is to make a control system as tolerant as possible to likely wiring or component failures. In control systems, safety is an important design priority. If there are multiple ways in which a digital control circuit can be designed to perform a task, and one of those ways happens to hold certain advantages in safety over the others, then that design is the better one to choose.

As an example, suppose that a large laboratory or industrial building is to be equipped with a fire-alarm system, activated by any one of several latching switches installed throughout the facility. The system should work so that the alarm siren will energize if any one of the switches is actuated. At first glance, it seems as though the relay logic should be incredibly simple: just use normally-open switch contacts and connect them all in parallel with each other:

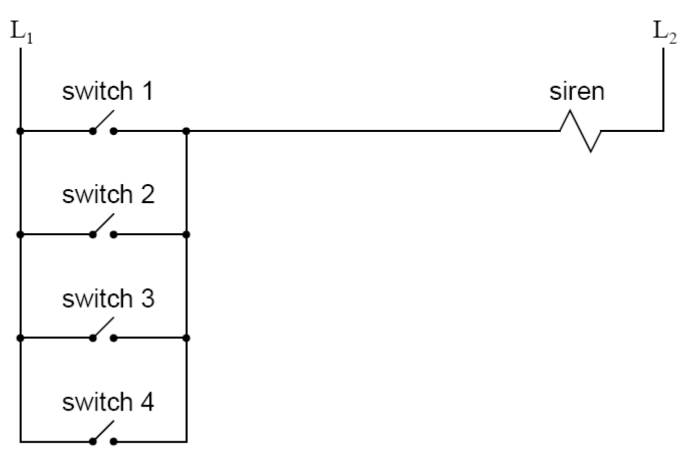


Figure 4.10 Normally Open Parallel Circuit

Essentially, this is the "OR" logic function implemented with four switch inputs. This circuit could be expanded to include any number of switch inputs, each new switch being added to the parallel network, but this example limits it to four in to keep things simple. At any rate, it is an elementary system and there seems to be little possibility of trouble.

Except in the event of a wiring failure, that is. The nature of electric circuits is such that "open" failures (open switch contacts, broken wire connections, open relay coils, blown fuses, etc.) are statistically more likely to occur than any other type of failure. With that in mind, it makes sense to engineer a circuit to be as tolerant as possible to such a failure. Suppose that a wire connection for Switch #2 were to fail open:

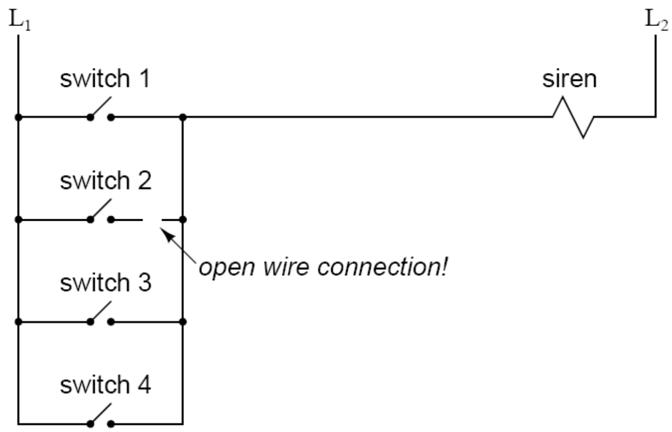


Figure 4.11 Normally Open Parallel with One Open Parallel Wire Circuit

If this failure were to occur, the result would be that Switch #2 would no longer energize the siren if actuated. This, obviously, is not good in a fire alarm system. Unless the system were regularly tested (a good idea anyway), no one would know there was a problem until someone tried to use that switch in an emergency.

What if the system were re-engineered so as to sound the alarm in the event of an open failure? That way a failure in the wiring would result in a false alarm, a scenario much more preferable than that of having a switch silently fail and not function when needed. In order to achieve this design goal, the switches would have to be re-wired so that an open contact sounds the alarm, rather than a *closed* contact. That being the case, the switches will have to be normally-closed and in series with each other, powering a relay coil which then activates a normally-closed contact for the siren:

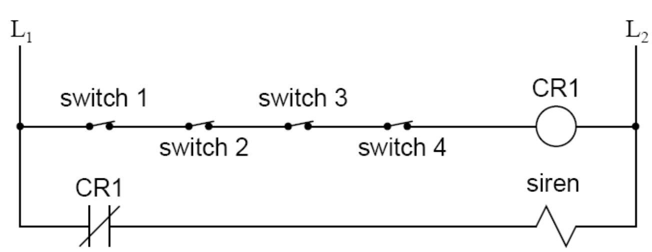


Figure 4.12 Fail-Safe Parallel –Series Circuit

When all switches are unactuated (the regular operating state of this system), relay CR1 will be energized, thus keeping contact CR1 open, preventing the siren from being powered. However, if any of the switches are actuated, relay CR1 will de-energize, closing contact CR1 and sounding the alarm. Also, if there is a break in the wiring anywhere in the top rung of the circuit, the alarm will sound. When it is discovered that the alarm is false, the workers in the facility will know that something failed in the alarm system and that it needs to be repaired.

Granted, the circuit is more complex than it was before the addition of the control relay, and the system could still fail in the ”silent” mode with a broken connection in the bottom rung, but it’s still a safer design than the original circuit, and thus preferable from the standpoint of safety.

An entire book could be written on the principles and practices of good fail-safe system design. A couple of the fundamentals:

- Electrical connections tend to fail by the splices opening up;

- An electrical control system’s (open) failure mode should be such that it indicates and/or actuates the real-life process in the safest alternative mode.

These fundamental principles extend to non-electrical systems as well: always identify the most common mode of failure, and then engineer the system so that the probable failure mode places the system in the safest condition.

4-5 OPERATIONAL CONTROLS

Local Operator: Operate and test a working escalator control system.

- Starting
- Stopping
- Reversing
- Slowing

Types of operational control units:

- Manual controls at controller
- Plug-in Portable Control Station
- On unit controls – traditional controls (key switch and start, alarms, emergency stop) and BART types

Maintenance Controls

ASME Code A17.1 requires all controls to start the escalator allow the user to have the escalator in their line of sight.

- **Portable Plug-In Control Station**. Each escalator is provided with a maintenance inspection control pendant station to operate the escalator during maintenance or service work. Plug-in connection points for the pendant handset are provided at both ends of the escalator within the truss enclosure beneath the landing plates. The handset includes continuous pressure pushbuttons to operate the escalator in either direction. A maintenance stop button is included. When plugged into the receptacle, there should be no means of running the escalator except through the use of the handset.

Figure 4.13 Portable Plug-In Control Station

- **Manual Start.** Each escalator can be started using the normal key switch and start button or switch located at the top and bottom of the escalator.

- **PLC Operator's Interface Terminal (OIT).** Some escalators can be started if the controller is located in the pit and in direct line of sight of the escalator. The technician can start the escalator by scrolling through the menu on the Operator's Interface Terminal (PanelView™ – see below) and finding the start mode. The technician can give a start command through the Interface Terminal to start the escalator.

PanelView™

The PanelView™ is a diagnostic and data reporting tool used as an interface with an Allen Bradley PLC. Similar in functionality to a laptop computer, the PanelView™ is built into the front door panel of a controller that contains an Allen Bradley PLC.

Figure 4.14 PanelView™

PanelView™ provides a time-efficient means for troubleshooting control problems the same as an external laptop but unlike the laptop, it cannot create programs. It allows you to work with the existing PLC program features but does not allow you to create or delete them. It has the capability of monitoring and reporting real-time data on such things as Right and Left Handrail Speeds, Escalator Speed, Motor Speed, Encoder Frequencies, etc. Its main diagnostics benefits are:

- It displays the current fault(s) that caused a shutdown or the condition(s) that is preventing the escalator from starting which in turn eliminates inefficient troubleshooting and minimizes escalator down time.

- It allows you to enable or disable safety devices for diagnostic purposes only and to make changes on the fly to the frequencies of the speed encoders without making permanent changes to the main PLC program.

- For escalators that are equipped with a Soft Start feature, it enables you to bypass the Soft Start when it causes problems on start up.

Main Data Reporting Benefits:

- It constantly monitors the escalator's performance on such things as running speed, motor temperature, and the frequencies of the speed encoders. This provides the participant with a snap shot view of the current running condition of the escalator.
- Keeps a history of all recorded events including safety devices that have tripped and places them into a viewable log. This provides excellent feedback for not only diagnostics but also for trend analysis and preventive maintenance.
- Provides all of the information pertaining to installed components on the escalator including the number of motors, the number of brakes it has, etc. This makes identifying installed components on the escalator much easier and precise.

PanelView™ uses a simple menu structure along with ten function keys for ease of navigation. It can also be password protected to prevent unauthorized users from gaining access to the machine's important features and parameters. Once you gain access into the PanelView™, simply follow the menu selections to navigate to the area of interest. Using the designated Function Keys determined by their onscreen designations or the User's Manual allows you to work with the PLC installed features.

4-6 PROGRAMMABLE LOGIC CONTROLLERS (PLCS)

In earlier escalator systems, it was common to use motor starters consisting of contactors and overload protection relays along with relay logic to control the starting and stopping method for the drive and brake motors. Two-speed starting was accomplished by the wye-delta method or through the use of a dual winding motor.

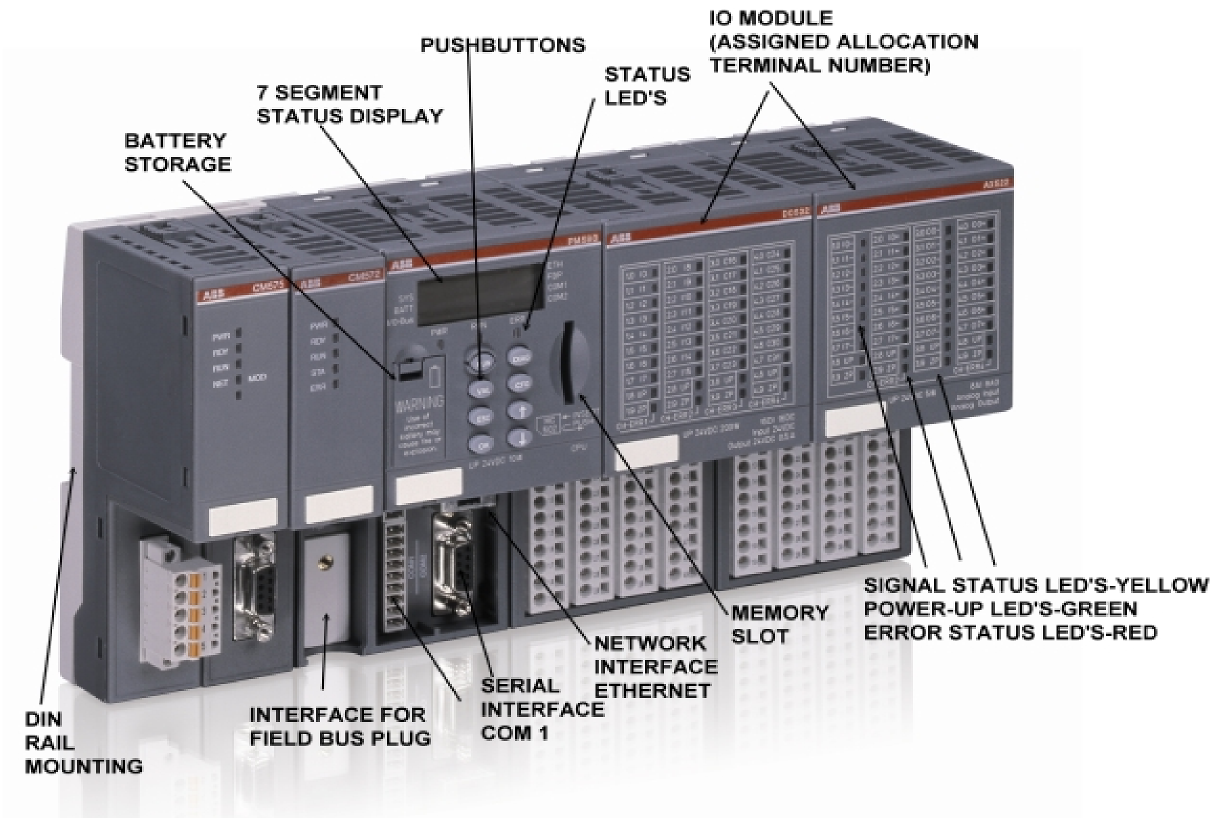


Figure 4.15 Programmable Logic Controller

The main controller in modern escalators typically will use a soft start controller, a variable frequency drive or a VVVF drive along with a PLC to control and monitor the status of the escalator when in key-start mode. The controller itself may be located within the inner decking of the upper or lower end of the escalator as well as in an equipment machine room. A variety of sensors and switches throughout the escalator system ensure that the escalator operates correctly and safely. If improper or unsafe operation is detected, the drive system will automatically shut down. All safety devices are monitored by the PLC control unit located in the main escalator controller.

The escalator controller incorporates an electronic fault diagnostic system which is capable of logging statistical data on the operation of the escalator and includes memory to store the escalator faults that cause shut down. A dial-up remote monitoring system may also be included which transmits faults and operating status to a maintenance supervisory facility. The PLC control system aids in identifying abnormal operations or component failures by displaying fault and operating status on a digital display panel and a fault light indicator panel mounted on or near the controller. Operation of the fault diagnostic system is possible at the display point via menus and keypads adjacent to or contained as part of the display system. System parameters may also be controlled through the use of a laptop computer.

Figure 4.16 PLC Display Screen

An example of a PLC system for a modern transit escalator would be the Asea Brown Boveri (ABB) AC 500 Series Central Processing Unit (CPU) and its associated Input/Ouput Modules (IO), operator panel and low voltage power supply. The particular model number would vary with the installation. See Figure 4.17.

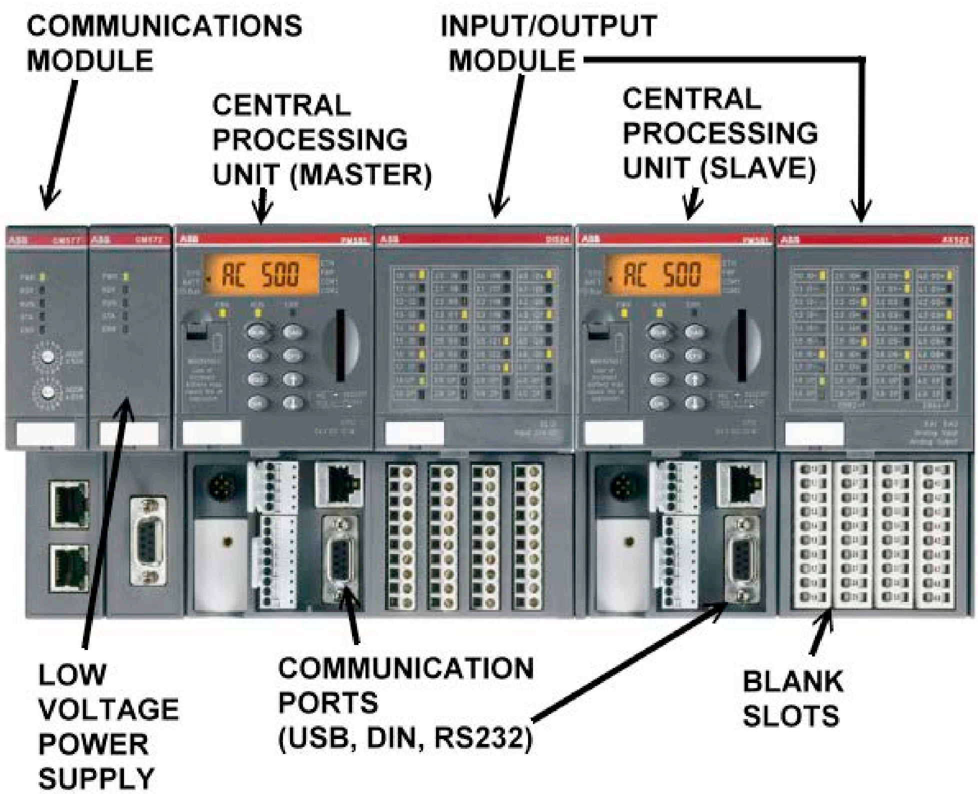


Figure 4.17 ABB AC500 Series PLC

Typically, this type of control system would include the main PLC and an additional backup PLC connected for redundancy. The control logic systems within the PLC's monitor all safety devices, sensors, as well as the communication bus and control all escalator-related operations, such as up and down operation, controlled and emergency stops, event diagnostics, lighting, heating, etc.

As you learned in the previous module, the master PLC module is a central processor unit that through logic, links the system together and analyzes instructions, and takes action correspondingly. It processes the individual data it receives via bus line, the Transmission Control Protocol (TCP) and the Internet Protocol (IP), from the slave PLC, the drive, the two communication bus couplers in the top and bottom junction boxes and the operator's interface terminal and it issues commands accordingly. The slave PLC module acquires data from the peripherals (contacts, sensors, displays), distributes data to the peripherals, and forwards the appropriate data to the master PLC. The PLC system also checks whether the starting and stopping of the escalator correspond with redundancy requirements. The CPUs are supplied with flash memory storage. For this reason this design doesn't require battery back-up.

4-7 SUMMARY

Control circuits for escalator systems are vital to the proper performance and protection of modern equipment. A complete motor circuit is usually divided into control and power sections control transformers provide electrical isolation and distributes emergency through mutual inductance. Permissive and interlock circuits act as safety checks to ensure that the energy is distributed safely, maintaining that incompatible events do not occur within the same time. Within each system are fail safe controls. Fail safe controls are designed to make a control system as tolerant as possible to wiring or component failures. These fail safe controls are set to ensure the safe operation of starting, stopping, reversing, or slowing the escalator. Modern escalators typically will use a soft start controller, a variable frequency drive or a VVVF drive along with a PLC to control and monitor the status of the escalator when in key-start mode. This PLC monitors all safety devices within the escalator.

Module 5

ESCALATOR DRIVE MOTORS

Outline

Purpose and Objectives

The purpose of this module is to provide the participant with a basic knowledge of the operation, testing, and applicable maintenance procedures related to transit escalator drive motors.

Following the completion of this module, the participant should be able to complete the objectives with an accuracy of 75% or greater:

- Identify the types of motors associated with each type of escalator system
- Describe the types of overload protection and their method of operation
- List and describe the different types of motor faults which may occur
- Test and verify load current specifications on a drive motor
- Identify and trace the wiring configuration for a drive motor
- Trace the electrical system pathways of a drive system using a schematic diagram

Key Terms

- Bi-metallic Thermal Overload Relay
- Direct-on-Line (DOL)
- Duty Rating
- Full Load Amperage (FLA)
- Insulation Breakdown Test
- Job Hazard Analysis
- Locked Rotor Amperage
- Pulse Width Modulation (PWM)
- Resistance temperature devices (RTD)
- Service Factor (SF)
- Slip Velocity
- Squirrel-Cage
- Solid-State Overload Relay
- Totally enclosed fan cooled (TEFC)
- Variable frequency drive (VFD)

5-1 OVERVIEW

Modern transit escalators are typically driven by three-phase – four pole AC induction motors.

The AC induction motor is a rotating electric machine designed to operate from a three-phase source of alternating voltage. The stator is a classic three-phase stator with the windings displaced by 120°. The type of rotor is typically a squirrel-cage. The motor housings are ruggedized, **totally enclosed and fan cooled (TEFC)**, shown in Figure 5.1, in order to allow the motor to withstand the extremes of the environment in which it is located.

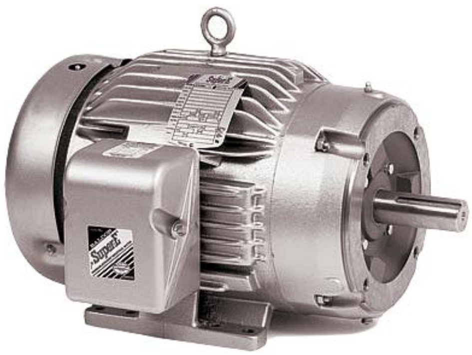


Figure 5.1 Totally Enclosed Fan Cooled (TEFC) Three-Phases Induction Motor

Some other advantages of the three-phase squirrel cage induction motor are:

- Medium construction complexity, multiple fields on stator, cage on rotor
- High reliability (no brush wear), even at very high achievable speeds
- Medium efficiency at low speed, high efficiency at high speed
- Motor speed can be controlled with a variable frequency drive (VFD)
- Low cost per horsepower, though higher than for single phase AC induction motor
- Higher start torque than for single phase
- Easy to reverse motor

5-2 SAFETY PRECAUTIONS

General

In addition to the following general safety instructions, all applicable local and national safety regulations must be observed. Any specific safety instructions given in the manufacturer's publications must be followed.

Only properly trained and authorized personnel shall be permitted to operate or service any portion of the equipment. This also applies to settings, adjustments, inspections and maintenance.

Suitable protective equipment, warning notices, and accessories must be available and maintained in a serviceable condition. This may include insulating protective clothing such as gloves, boots, overalls, and headgear; eye protection, hearing protection, respiratory protection, and applicable tools, equipment and materials. All guidelines on the Material Safety Data Sheets (MSDS) for lubricants must be observed. Loose clothing, long hair, and jewelry can cause serious injury to maintenance personnel when working on escalators. Any loose clothing should be tucked in, long hair should be arranged where it does not create a hazardous situation, and all jewelry should be removed.

Commencement of Work

Before starting to work on a unit, a **Job Hazard Analysis** should be performed by the person(s) assigned to work on the escalator. The person in charge must ensure that all persons involved are familiar with the work to be carried out. Before starting any maintenance work, “tuck” loose-fitting clothing, confine long hair, and remove all jewelry. Barricades must be installed along with the appropriate signage (i.e., “Out of order”).

Once a floor cover has been removed or hinged and before entering the pit, the maintenance operating panel should be connected. A trial run of the escalator should be performed using the maintenance operating panel. Always turn off and lock the main disconnect switch in the machine room when carrying out maintenance work inside the step band.

Completion of Work

Upon completion of work, remove all tools, maintenance signage, accessories and safety devices from the site in a safe manner to ensure no danger arises. Notification of work completion to the appropriate agency personnel will be accomplished per transit agency policy. Complete all required maintenance documentation in accordance with applicable transit agency procedures.

Warning: Safety Precautions!

- Every precaution should be taken to prevent accidents and incorrect operation.

5-3 ESCALATOR DRIVE MOTORS

An induction or asynchronous motor is a type of AC motor where power is supplied to the rotor by means of electromagnetic induction. A **squirrel-cage** induction motor is one in which the rotor is electrically isolated from the stator. In overall shape, the squirrel-cage rotor is a cylinder mounted on a shaft (see Figure 5.2). Internally it contains longitudinal conductive bars (usually made of aluminum or copper) set into grooves and connected together at both ends by shorting rings forming a cage-like shape. The name is derived from the similarity between this rings-and-bars winding and a squirrel cage (or, as it is commonly known, a hamster wheel).

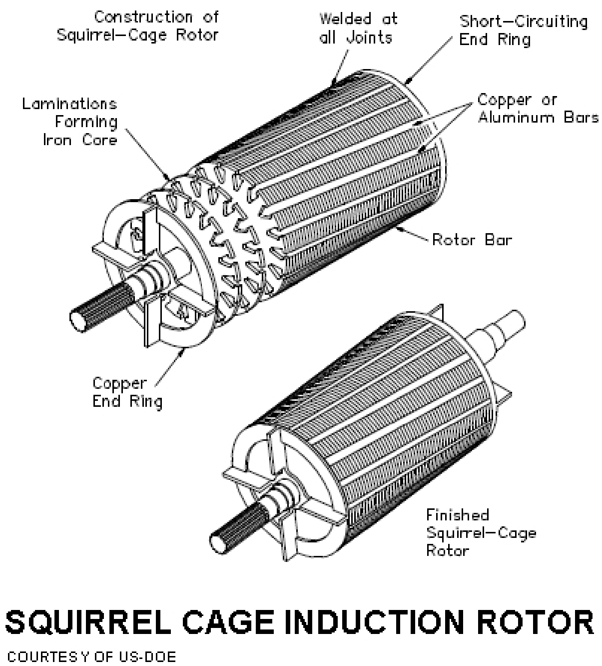


Figure 5.2 Squirrel Cage Induction Rotor

The stator windings of an AC induction motor are distributed at 120º intervals around the stator to produce a roughly sinusoidal distribution. When three-phase AC voltages are applied to the stator windings, a rotating magnetic field is produced. When the three currents flow through the three symmetrically placed stator windings, these sine waves distribute a magnetic flux across the air gap between the stator and the rotor generating sinusoidal currents within the rotor. The interaction of the sinusoidally distributed air gap magnetic flux and induced rotor currents produces a torque on the rotor. The rotating magnetic field of the stator drags the rotor around. The rotor does not quite keep up with the rotating magnetic field of the stator. It falls behind or slips as the field rotates. The mechanical angular velocity of the rotor is lower than the angular velocity of the flux wave by so- called **slip velocity**.

A limited number of internal components mean fewer problems in three-phase AC induction motors. Three-phase motors have fewer components that may malfunction than other motor types. Therefore, three-phase motors usually operate for many years without any problems. If a three-phase motor is the problem, the motor is serviced or replaced. Servicing usually requires that the motor be sent to a motor repair shop for rewinding. An example of a good servicing practice is, if the motor is less than 1 HP and more than five years old, it is replaced. If the motor is more than 1 HP, but less than 5 HP, it may be serviced or replaced. If the motor is more than 5 HP, it is usually serviced.

Induction motors are widely used in transit escalator drives, particularly three-phase induction motors, because they are robust and have no brushes. Their speed can be controlled with a variable frequency drive. With standard **direct-on-line (DOL)**, the speed of an AC induction motor is controlled by two factors:

- Number of pole windings in the motor
- The frequency of the line voltage source

Since it is very difficult to change the number of physical poles in motors larger than ½ horsepower, the only means of controlling the speed is through the use of a variable frequency voltage source. With the advent of newer solid-state devices, variable frequency drives are now capable of developing the power necessary to drive large horsepower motors.

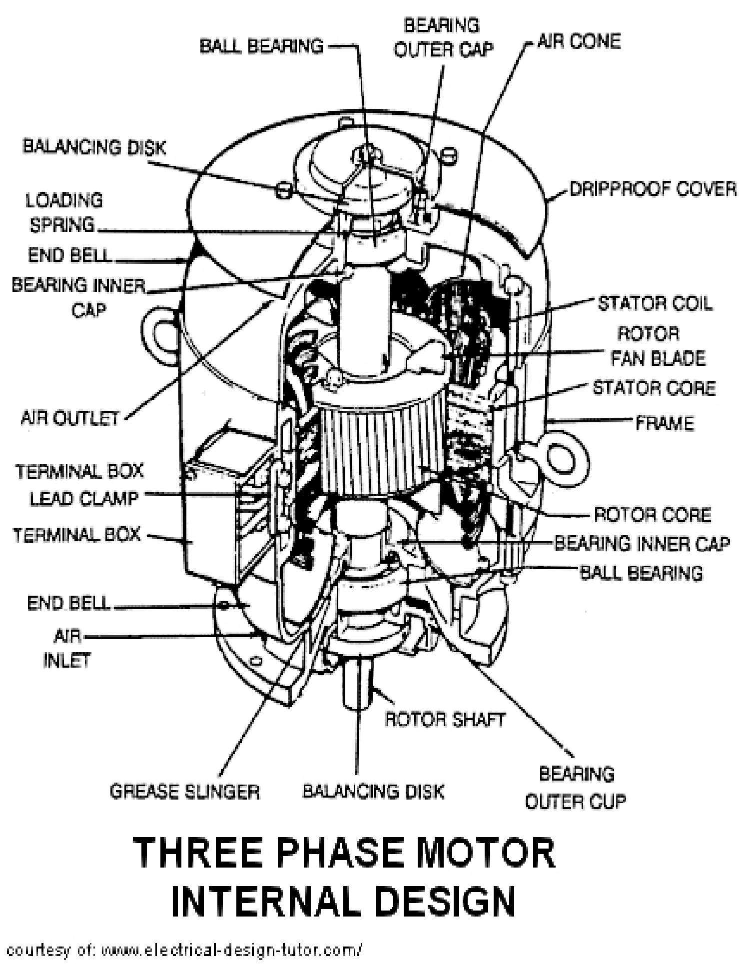


Figure 5.3 Three Phase Motor Internal Design

In adjustable speed applications, AC motors are powered by **variable frequency drives (VFD)**. The VFD converts low frequency (60 Hz) AC to DC and then inverts the DC power to a **pulse width modulated (PWM**) AC power at the required frequency and amplitude. The inverter consists of three half-bridge units (one per phase) where the upper and lower switches are controlled complimentarily. During the switching process, the solid-state power device's turn-off time is longer than its turn-on time. Some dead-time must be inserted between the turn-off of one transistor (or SCR) of the half-bridge and turn-on of its complementary device. The output voltage is created by a pulse width modulation (PWM) technique. The three-phase voltage waves are shifted 120° to one another similar to the incoming line waveforms however, that is where the similarity ends. These simulated drive outputs can now be controlled through the microprocessor's PLC that controls the drive units. With this type of drive, it is now possible to control not only the amplitude of the waveforms but, the frequency of the waveform is variable as well. Thus, a three-phase motor can be supplied.

5-4 SERVICING DRIVE MOTORS

Motor Cleaning and Lubrication

Too many electric motors end up failing long before they should. Usually it is because of inadequate maintenance. A good maintenance program is designed to prevent the development of motor problems and detect motor problems before they lead to a breakdown or lead to expensive damage. Part of proper maintenance includes routine tasks that help keep a motor running properly. The other part involves inspections and tests to tell if the motor is not running right. Typical routine maintenance operations are intended to keep problems from developing. There are two main areas of concern: lubricating bearings and keeping motors clean.

Be sure to follow the recommended lubrication schedule for each particular motor. Check published PMI schedules for your equipment. If a lubrication schedule is not available, inquire from the proper authorities if one can be made available or if it is necessary. A maintenance schedule for these operations is a useful guide. It should include the time duration between lubrications and what type of lubricant to use. Do not lubricate more often that recommended and do not over lubricate. Too much oil or grease in a ball or roller bearing will actually increase friction and heat and will probably leak out. Preferably, the motor should be warm and running. Be sure no dirt gets in the bearing along with the oil or grease and wipe up excess or spilled lubricants. Look and listen while working on the unit. Remember, routine lubrication provides a good opportunity to detect problems that might be developing. For example, suppose the motor began to run quieter when you greased the bearing. This might indicate a bearing problem that should be checked out. Make a note to have the shaft checked for bearing looseness when the machine is not in operation. Look for shiny marks on shafts that may indicate loose bearings or improper alignment. Check the bearings to ensure there is no end thrust and that the rotor in the midpoint of its endplay. Feel the motor housing to see if it is hotter than is should be.

Be sure to thoroughly clean the motor housing of oil, dirt and dust: This helps the motor last longer and run cooler. Dirt interferes with free air convection airflow over the housing by insulating parts so they cannot dissipate heat. A dust layer as small as 1/16 inch in thickness could drastically increase the internal motor temperature thereby decreasing motor life. Vacuum dirt from around the motor if possible. Never use compressed air to blow dirt from the motor housing or the end bearings of the motor. The air blast could force the dirt and grit into the motor bearings and winding turns where it could cause permanent damage. If vacuuming is not possible, take care to wipe the motor down thoroughly with rags. Dirt and oil can also cause deterioration in wiring insulation and cause arcing and premature failure.

Most motors require periodic partial disassembly in order to ensure a thorough cleaning and inspection. Even the totally enclosed fan cooled (TEFC) style of motor can be partially disassembled in the field to ensure proper cleaning. Be sure all power is locked out and begin by removing the fan shroud from the TEFC motor. Clean off the fan, the inside of the shroud and the vents to ensure free airflow. Replace the fan if it is damaged. Replace the shroud and ensure proper torque on all fasteners. Then inspect the connections in the junction box. Dried, burnt, or discolored tape or insulation on a power line splice means that a short is not only likely to develop but, that the connection inside has higher resistance than it should. Remove the insulation and thoroughly inspect and clean the wire ends or wire terminals before reconnecting and re-insulating the wires. Do not use cleaning solvents which could damage or cause breakdown of the insulation.

Warning: Safety Precautions!

- When working around electric motors, remember to listen and observe. Check for vibration, squealing, noise, erratic movement in equipment, and odors that may indicate something is running hot or improperly.

Testing and Inspecting Motors

Warning: Safety Precautions!

- Lockout and tagout the equipment when performing non-voltage and non-current tests on motors.

Check the frame temperature for proper operation. Inspect wiring for insulation damage due to contamination, vibration or overheating. Inspect and repair any damaged connections.

Routine measurements that should be performed on all motors when being installed include:

- Perform insulation breakdown tests on all wires to the motor with reference to the frame (megohmmeter), resistance readings on all windings on the motor (megohmmeter)
- Record frame and bearing temperatures (digital infrared thermometer)

- Record current readings on each phase of the motor when operating under normal load (clamp-on ammeter)
- Record voltage readings on each phase when operating under normal load (voltmeter)
- Record the nameplate information on the motor (serial number, model number, horsepower, etc.) as well as its location and usage (maintain records)

Figure 5.4 Motor Testing with a Megohmmeter. Source: www.aikencolon.com

A major part of proper maintenance is accurate record keeping on equipment one is assigned to maintain. A small effort towards accomplishing this could save a great deal of work in the end.

Inspections and tests on motors are required to detect problems before they become obvious or lead to a breakdown. Some of the tests are as simple as watching and listening to the motor. If an AC motor hums or buzzes, it may be under too heavy a load or it might also have loose core laminations. Vibration, squealing, dragging or scraping noises in any motor probably mean serious bearing problems or a rubbing rotor. Other motor problems may not be so obvious however. To find these types of problems takes instruments and careful record keeping.

One of the standard tests that can be performed on a motor is an **insulation breakdown test** with a megohmmeter. Unlike a standard ohmmeter that uses a small battery to drive current through the circuit to test resistance, a megohmmeter uses a high voltage equal to or greater than normal power line voltage. This allows it to measure very high resistances accurately. It also puts the motor insulation under a high voltage stress so that defects are more likely to show up. Using a megohmmeter is different from taking a reading with a standard ohmmeter. For one thing, the level of voltage involved is much greater.

Warning: Safety Precautions!

- Do not touch the leads tips or probes while applying megohmmeter voltage and make sure the voltage will not be applied to any solid-state equipment such as the VFD.
- The motor under test must be completely disconnected from the power line at either the contactor output or the motor junction box or both.

A good motor may show a reading of several hundred megohms or even infinity between the windings and the frame of the motor. A much lower reading however, does not mean there are definite problems. High temperatures and humidity will reduce the reading significantly. In addition, the insulation in some motors needs time to charge up like a capacitor. Some tests require the voltage being applied must remain for up to two minutes in order to obtain an accurate reading. If the reading keeps rising and is twice as high at two minutes as it was at one minute then the insulation is probably ok. If the reading levels off quickly at a fairly low level however, this is a sign that leakage current is flowing through or over the insulation. This current will probably cause further insulation breakdown during normal operation until a short develops and the motor fails. Megohmmeter readings are most useful when they are taken over the life of the motor at regular intervals under the same temperature and humidity conditions or corrected for humidity and temperature. The readings will normally decrease slowly as the motor ages. If a new reading is much lower than the one taken two months earlier, the motor should be watched carefully in the weeks or months ahead. If the readings continue to drop rapidly, it is time to replace the motor. Taking a megohmmeter reading is like charging a capacitor. If the megohmmeter being used for testing does not have a discharge switch, carefully discharge the winding under test by shorting the motor lead to the frame to allow any charge buildup to dissipate. A general rule is to allow the discharge lead to remain connected at least twice as long as the charge rate to ensure safe discharge. Sometimes the problem indicated by a megohmmeter is not poor insulation but rather moisture or humidity. Normally taking the time to dry out the motor housing will cause the readings to increase to normal.

Taking the frame temperature of a motor is also an important record to maintain. A good portable temperature probe (digital infrared thermometer) is an excellent instrument to add to a tool inventory. Whatever instrument is used, it is important to duplicate the conditions under which the temperatures are recorded to ensure a greater accuracy for comparison purposes. It is best to take the measurement after the motor has been doing its normal job for some time. An accurate comparison of temperatures will make it easy to spot a motor that is beginning to fail due to increase in heat buildup. Ideally, the best temperature points to record are the end bell housings where the bearings are located and mid-point on the motor frame.

Another measurement check is the voltage check on each of the power line phases feeding the motor. If the voltage on one or more of the phases is lower than normal for any reason the motor will overheat. Three-phase inductive motors are particularly susceptible to low voltage and will sometimes stall completely if the voltage drops as little as twenty percent.

Current readings are also useful. If the current in all three lines is high, the motor is overloaded. If the current in only one of the power lines is high with normal voltages, suspect an electrical problem in the motor.

Resistance readings will sometimes pinpoint electrical problems in the motor. Lock the motor out first and disconnect the power lines; occasionally a three-phase motor will have a neutral as well as the power lines connected. Be sure to disconnect this as well. Check the resistance between the motor frame and the motor leads using the highest scale on a digital or analog ohmmeter. On most simple ohmmeters anything but infinity is a sign of some kind of short to ground. Further testing may be required using a megohmmeter if a low reading is observed with a standard ohmmeter.

Observing the way in which the equipment is operating is also an indicator of the motor's condition. Vibration or sluggish operation may be an indication of a loss of motor torque. Belts may be hot or smoking. The motor may be cycling on and off due to internal overload protection cut-out.

All these tests and the routine maintenance and inspection procedures discussed here are intended to prevent motor failure. Maintenance is much easier than troubleshooting and repair. It is always worth taking the time to do maintenance procedures properly and to look closely for signs of problems. Periodic inspections and test readings that spot potential problems allow the mechanic to anticipate motor failure and avoid an unexpected breakdown.

Troubleshooting a Motor

Warning: Safety Precautions!

- Troubleshooting escalator drive motors requires working close to live or potentially live circuits. Only a qualified person, thoroughly trained in safe electrical practices, should work on this equipment.

Troubleshooting electric motors and their controls is a process involving several steps:

1. The first step is to **understand how the system works**. That means knowing what the system does as well as how each component works. A schematic diagram of the power circuit and a ladder diagram of the control circuit are usually essential. Often they are together on a single large systems diagram sheet or they are located within the same system maintenance manual. They show all the components of the motor control system and their relationship to each other. These are drawings that should be on hand before beginning the process of troubleshooting. If possible, study them in advance if you are not already familiar with the circuit. The maintenance logs and other work records for the system will also be helpful. They may provide important information, especially about recurring problems.

2. The second step is **investigating the symptoms**. This means trying to operate the system and observing how the system reacts. Also, be sure to talk to the operator who may have seen or heard something that indicates where the problem lies.

3. The third step is **listing the probable causes**. This will be easy if one has an understanding of how the systems work and has investigated them carefully. If there are many possibilities, it may be helpful to write down all the possible causes.

4. The fourth step is to **eliminate all but one of the possible causes**. By eliminating the parts of the system that are working correctly, the possibilities are narrowed down until the malfunctioning component is located. **Do not skip this step.** If the assumption is made that the problem has already been figured out and you start swapping out components trying for a quick fix, a lot of time will be wasted.

5. **Always test**. Discovering the root cause is the final step in troubleshooting. After all, fixing the problem will only have to be done over again if the cause of the problem is not corrected.

Troubleshooting the Entire Motor

Not all problems with motors and their controls require troubleshooting. Sometimes nothing more than an intermittent voltage fluctuation or an obviously jammed load has shut the system down. However, if the problem is not obvious, the same thing happens again; if the problem is not readily visible, tracking down the problem as quickly and systematically as possible is essential. When beginning troubleshooting, remember there are two basic situations: either the system is not working at all or it is not working as it should be. The way to proceed depends which of these situations is encountered.

If the system is not working at all, checking the protective devices, the fuses, breakers, overloads, phase detector, and ground fault detector will often isolate the problem to part of the system immediately. Usually starting with the overload is recommended, since this is easiest to check. If the overloads are tripped, the motor and the load should be checked for obvious problems. Other items such as brakes that are not released, a very hot environment, a blocked vent on the motor, a jammed load, stripped gears and broken belts may also be easy to spot.

If there is no obvious problem with the motor or the load, reset the overload and try to start the motor again. When performing this task, stay alert and be ready to act quickly. Whether or not the overloads trip again, a lot can be learned about what is wrong. Do not keep resetting the overloads while trying to solve the problem, as the motor will heat up faster than the overloads and could be damaged. How long it takes the overloads to trip again, if they do, may indicate where the problem lies. When an overload trips during or just after startup, it is usually a result of problems with the motor or the load. Listen carefully to the sound of the machinery and the motor as they start and watch for indications of dry bearings, bent shafts, and heavy loads. All these can trip overloads during startup.

Whether the overloads trip again or not, taking the time to use an ammeter and voltmeter to monitor line voltage and load current is essential. Also, check for phase loss or phase imbalance both of which will cause overloads to trip. A loss of as little as twenty percent of line voltage on one of the phases could result in a trip. A loss of ten percent of line voltage on a phase may not cause an overload to trip but it will shorten the life of the motor if left unresolved. A loss of phase is recognizable by a low humming coming from the motor and excessive current through the other two phases, will result in a tripped overload. If the motor does not run and the overloads are not tripped, the problem is most likely a blown power line fuse, a tripped breaker or ground fault protector. If this occurs, de-energize the system, lock it out properly, then check voltage upstream of the main disconnect to confirm proper AC supply and downstream to be sure the circuit is de-energized.

Breakers and most ground fault detectors have trip indicators but most fuses must be tested. Resistance measured across a good fuse will usually read zero (some time-delay fuses may read one or two ohms). Before re-energizing the system, it is necessary to first find the fault. If the fault is not located and the system is re-energized, it could mean sending high current directly back into a short or ground. Serious damage could result and the technician or others working with the technician could be injured. Many shorts and grounds occur in the motor and the power lines leading to it, but they can also occur inside the controller. Make a visual inspection of the controller. Damage from a short is usually easy to spot. Check for wiring continuity, as well as the soundness of both insulation and wiring. Loose or frayed wiring, even the odor of burned insulation may be obvious when the enclosure is first opened. If nothing obvious is found within the enclosure, the fault if probably downstream of the controller.

In most systems, faults in the motor windings can be detected by measuring resistance across all three lines as well as between each of the lines and ground. The easiest place to perform this test is downstream of the contactor. Resistance between any two lines should be the same from T1 to T2, from T2 to T3 and from T1to T3. If the resistance reading is zero for any of these readings, there is a definite short in the motor winding. Readings different from each other and unbalanced readings indicate faults that may blow fuses intermittently. Over time, the readings will diverge farther and farther until the motor eventually shorts out. Resistance readings from any of the lines to ground should be infinity. Anything less indicates a fault in the wiring to the motor or in the motor itself. Be sure to isolate the fault and fix it before re-energizing the system.

If the motor will not run and none of the protective devices are blown or tripped, the problem could be in the power circuit contacts. Taking resistance readings through the contactor from L1 to T1, from L2 to T2, and from L3 to T3 while manually operating the contactor each time will give an indication of whether or not the contacts are in good condition. Resistance readings should be zero ohms. Since these checks eliminate the power circuit and no faults are discovered, the problem almost certainly exists in the control circuit.

Some part of the control circuit is not working the way it should, even though voltage is present in the system. After the problem is narrowed down to the control circuit, remember that even the most complicated circuits are nothing more than combinations of simpler circuits.

Troubleshooting the control circuit

Troubleshooting the control circuit starts out just like troubleshooting the system as a whole. Either the system is not working at all or it is not working as it should. If nothing is working, the first step is to lock out the system and check the control circuit fuses. Replace any fuses that are blown but do not re-energize the system without determining where the fault occurred and correcting it. Often this can be done by determining when the fuse blew. For example if the system shut down when the operator attempted to start the escalator, a likely cause could be a shorted coil in the start-up contactor. Measuring the coil resistance on the contactor will determine whether it is good or defective. A resistance reading of zero indicates the coil is shorted and should be replaced. If resistance reading is infinity, then the coil is open and must be replaced. Interpreting any other reading requires knowing the proper resistance reading of the coil. This can often be determined by measuring the resistance of an identical known good coil for comparison. If the coil is bad, the readings will not match. When only a portion of the control system is not working, the problem is narrowed down to the components in that part of the circuit.

For example, if a problem exists within the safety string the system will not operate. On newer systems, the safety devices can be checked through the troubleshooting diagnostics on the PLC. The PLC will more than likely indicate which of the safety device or devices are keeping the system from starting up. Once the active safety device has been located, it is necessary to not only locate and reset the device but also determine what caused the device to be activated. Remember, fixing the problem will have to be done over again only if the cause of the problem is not corrected.

Voltage testing is also a good method for isolating a problem in a control line. A good method for testing voltage is to place one probe of a voltmeter just downstream of a load, just to the right (on the ladder diagram) of the coil or load device. The other lead is then placed on the hot side of the control line. Voltage readings are observed while moving the probe step-by-step through the circuit, observing the voltage at each step to see if it is normal. This is known as the series checking method.

The first time an incorrect reading is observed, the problem has been located. The voltage readings should usually be either full control voltage or zero depending upon whether the components in the line are active or inactive. Make note of any odd or stray voltage levels not consistent with the control circuit supply as these may be indications of an open circuit due to a fault or an inactive device in the control line. Lock out the system and verify the fault with an ohmmeter. In control lines containing numerous control devices, it is often easier to use the half split method. Each test eliminates half of the component in the control line until it is narrowed down to the fault.

Whichever method is used, the series method or the half split method, there are two important things to remember. The first thing is to make sure to test components in their operating state or condition. For example if testing downstream of a normally open pushbutton, a voltage reading will not exist unless the pushbutton is activated. Be especially careful of state or condition of components that operate automatically as pressure switches. Be sure to remove all jumpers when completing troubleshooting. The second important point to remember when troubleshooting is to operate the circuit. Observing what happens when the system is activated can often eliminate a large part of the circuit. For example, if the escalator operates in the up direction but fails to operate in the down direction a large part of the system has been verified to be working properly and troubleshooting has been narrowed down to one particular area of the control circuit.

Voltage testing is a reliable method of tracking down problems but watch out for back feed, voltage variations and wiring problem while testing. Voltage testing usually confirms that voltage is being transmitted from location to another in the circuit but not always. In a back feed situation, when a component has voltage on both sides of it, a voltage test will not determine if the component is working properly. Voltage testing is not sufficient when back feed occurs, instead lock out the system and perform a resistance continuity test on the device to determine its condition.

The second thing to look for is voltage variation. Voltage testing is more than just looking to see if voltage is present or not. It is not uncommon, especially in large systems that have been altered or modified over the years, for voltages to rise and fall as multiple components are switched in and out of the circuit. Some components, especially coils, may not operate reliably if voltages approach dropout levels. When low voltage levels are located, be suspicious of normally closed or usually closed contacts like stop buttons and seal-in or latching contacts. They may develop carbon buildup on contacts and high resistance after long use. Also, pay attention to contacts in the circuit which are opened under load during normal operation. They can wear out quickly.

The third thing to watch out for is wiring problems. These are common in motor control, so do not assume the faults found are always in switches, relays, coils and other devices. Each wire in the system should be thought of as a component just as likely to be faulty as anything else. In fact, broken wires, grounded wires, and even loose wires are often the source of problems. Ground faults frequently occur when insulation is damaged as wire is pulled through conduit. These grounds may not be noticeable at first but they can gradually worsen over time and begin blowing fuses.

Sometimes wiring is chewed on by animals, scraped by machinery, or it just wears out as the insulation breaks down with age. Never assume the wiring is okay when troubleshooting. When a coil does not pull in, one might assume it is faulty needs to be replaced. But the problem could be as simple as a loose wire or wire termination at the terminal strip on the device or on a wiring termination block. Watch for loose wiring and stray wire strands while troubleshooting motors and their control systems and when testing for voltage always try to eliminate the wiring as a possible cause of the problem.

These troubleshooting techniques can be applied to any control circuit large or small, simple or complex. The key is to always know the circuits well and always proceed logically. The most successful troubleshooting is done by people who understand the principles of motor control and who have a thorough knowledge of the actual motor control systems in their facility.

The extent of troubleshooting a three-phase motor is dependent upon the motor's application. If it is critical to return the unit to service, testing is usually limited to checking the voltage at the motor contactor in the drive unit. If the voltage is present and correct, the motor is assumed to be the problem. However, to actually verify the motor is at fault and eliminate the possibility of wiring fault, the unit will have to be removed from service and the motor junction box accessed. Once it has been verified that voltage is present on all three incoming phases at the junction box and the motor remains inoperable, the motor is usually replaced at this time so the unit can be restored to service.

Electrical troubleshooting of three-phase motors can be accomplished with a digital multimeter, a clamp-on ammeter, and a megohmmeter. To troubleshoot a three-phase drive motor, apply the following procedure:

- Using a voltmeter, measure the voltage at the motor terminals on the downstream (outgoing) side of the motor contactor. If the voltage is present and at the correct level on all three phases, the motor must be checked. If the voltage is not present on all three phases, the incoming power supply must be checked.
- If voltage is present but the motor is not operating, turn the handle of the safety switch or combination starter OFF. Lock out and tag the starting mechanism per company policy.
- Disconnect the motor from the load (gear drive coupling).
- After the load is disconnected, turn power ON to try restarting the motor. If the motor starts, check the load. Ensure the drive assembly is not frozen or jammed.
- If the motor does not start, turn it OFF and lock out the power.
- Access the drive motor. With an ohmmeter, check the motor windings for any opens or shorts. Remove the insulation from the power line terminals in the motor junction box. Use a voltmeter to ensure no electrical power is present on each of the terminations as the insulation is removed. Test between terminals and to the motor case (ground). Disconnect the motor leads from the incoming power lines. Take care to record the wire termination numbers or ensure the wiring labels are not removed. Once the motor leads have been accessed begin recording your resistance readings. Take a resistance reading of the T1-T2 coil, T2-T3 coil, and the T1-T3 coil. These coils must have a similar resistance reading. If the reading is zero, the coil is shorted. If the reading is infinity, the coil is opened. Since the coil winding is made of wire only, the resistance is low. However, there is always some resistance on a good coil winding. The larger the motor, the smaller the resistance reading.
- If the coil readings appear to be normal, reconnect the motor leads and power leads in the proper sequence.
- Use extreme caution when attempting to measure the incoming voltage between the three incoming power lines at the junction box. Be sure to follow company policy when restoring power to the unit for live circuit testing purposes. If power is present at the motor junction box following this test and the motor still fails to operate, motor replacement is required.
- Follow all local agency policies regarding restoring the unit to service

5-5 MOTOR OVERLOAD PROTECTION

The National Electric Code (NEC) defines Motor Overload Protection as that which is intended to protect motors, motor-control apparatus, and motor branch-circuit conductors against excessive heating due to motor overloads andfailure of the motor to start. Motor overload protection is also commonly referred to as “running protection.”

Motor overload protection is not intended to protect against motor branch-circuit short-circuit and ground faults. In a combination starter, this type of protection is provided by fuses, a circuit breaker, or a motor circuit protector (MCP). This protection is commonly referred to as “Short Circuit Protection” and is shown in the following schematic.

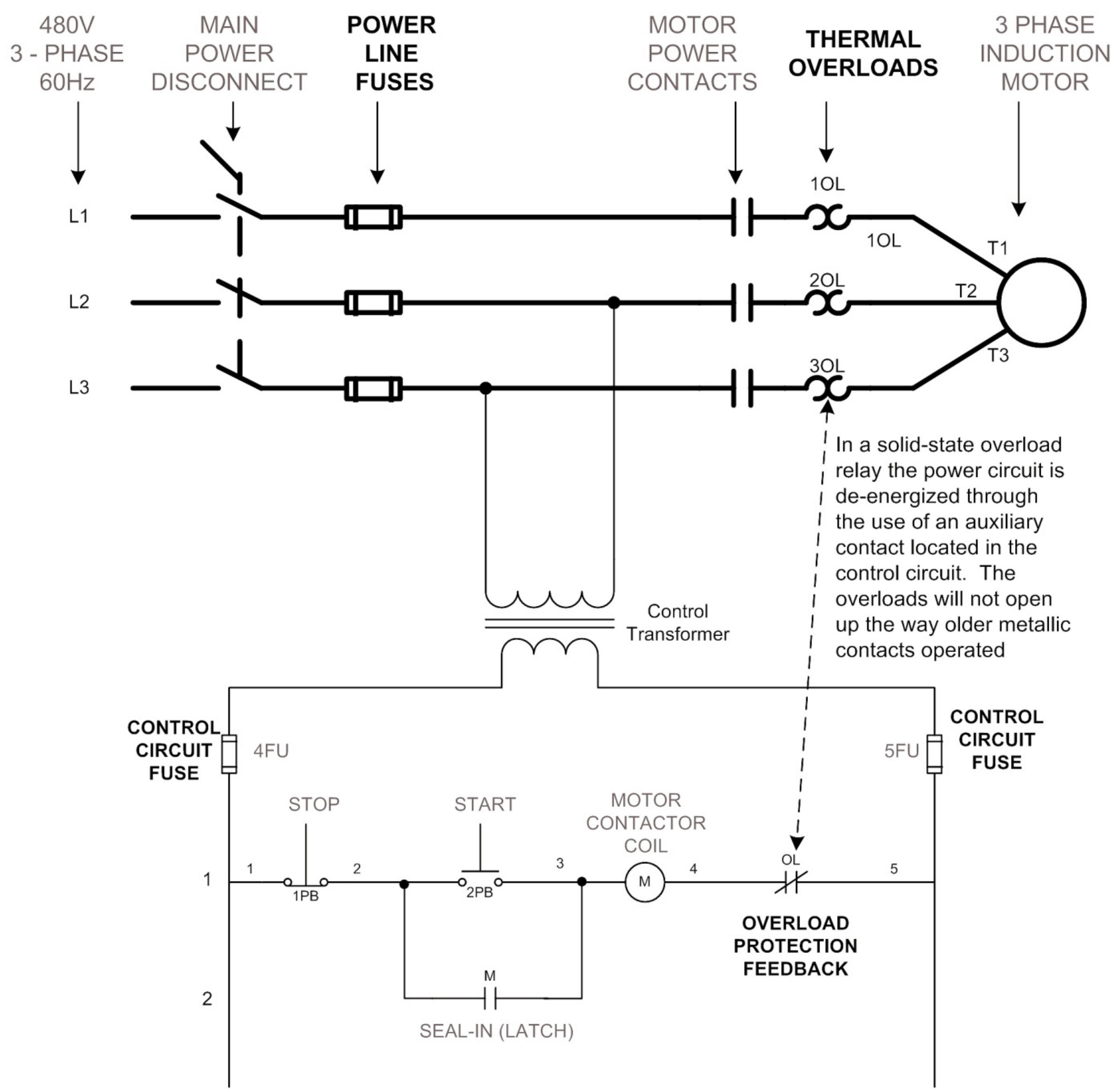


Figure 5.5 Motor Overload Circuit Protection

Overload protection for single and three-phase AC motors in the small (above 1 horsepower) and medium horsepower range is typically provided by one of two methods: **bi-metallic thermal overload relays{** TA \l "**bi-metallic thermal overload relays**" \s "bi-metallic thermal overload relays" \c 1 **}**, or **solid-state overload relays{** TA \l "**solid-state overload relays**" \s "solid-state overload relays" \c 1 **}**. Overload protection for large three-phase motors is sometimes provided by thermal overload relays which are connected to current transformers (CT's).

However, most new installations utilized microprocessor-based motor protective relays which can be programmed to provide both overload and short-circuit protection. These protective relays often also accept inputs from **resistance temperature devices (RTD's){** TA \l "**resistance temperature devices (RTD's)**" \s "resistance temperature devices (RTD's)" \c 1 **}** imbedded in the motor windings (usually two per phase). The relays are capable of displaying the winding and motor bearing temperatures and providing both alarm and trip capability.

5-6 DRIVE MOTOR REMOVAL AND REPLACEMENT

Motor Replacement

A replacement motor must produce the right horsepower and in an emergency a motor with higher horsepower might be substituted but it would operate at a part load. The **rated speed** of a replacement motor must be the same as that of the old motor in all cases.

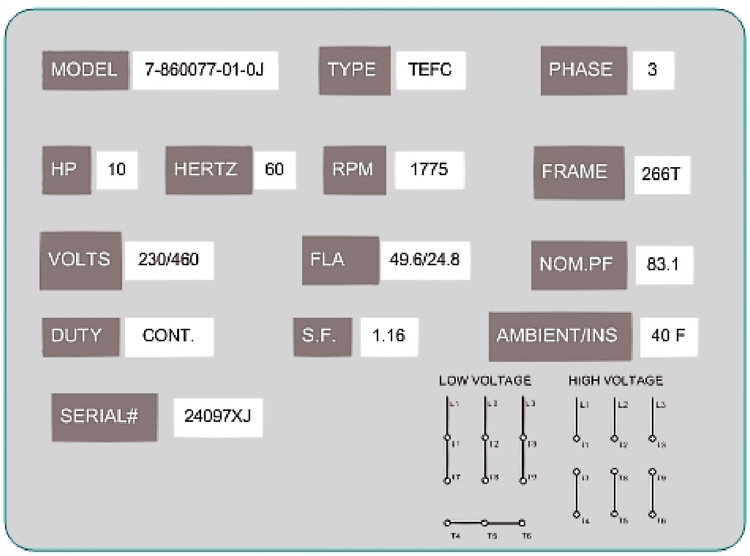


Figure 5.6 Motor Nameplate Example

The **service factor (SF){** TA \l "**service factor (SF)**" \s "service factor (SF)" \c 1 **}** rating should match or exceed the rating of the motor being replaced. SF is an output specification that corresponds to the continuous horsepower that is calculated by multiplying the specified horsepower times the **service factor (S.F.)** rating.

The **duty rating{** TA \l "**duty rating**" \s "duty rating" \c 1 **}** of a motor refers to whether the motor is meant for continuous operation or for intermittent operation.

The electrical input specifications include the supply voltage. Most transit escalator drive motors require a 480 VAC three-phase power supply.

A motor with input specifications of V 230/460 is a dual voltage motor. The actual circuit voltage at the motor should be within ten percent of the nameplate voltage or a motor stalling, otherwise an overload condition will occur.

A motor with an FLA of 49.6/24.8 means the motor's **full load amperes (FLA){** TA \l "**full load amperes (FLA)**" \s "full load amperes (FLA)" \c 1 **}** is the load current the motor will draw from each power line when producing its rated output power. The higher current applies when the motor is connected to the lower of the two supply voltages listed on the nameplate. The full load amperage determines the level of overload protection required for the motor.

LRA refers to the **locked rotor amperage** is**{** TA \l "locked rotor amperage" \s "locked rotor amperage" \c 1 **}** current that motor will draw under full load startup and stall. It can be from 2.5 to 10 time full load current.

The temperature rating of the motor is shown as an ambient reading for the installation location AMB 40^{o} C is the operating temperature rating of the motor described on the nameplate.

The insulation class of the motor is designated as INS.-B Duty. Any replacement motor must equal or exceed this rating.

A thermally protected motor type "M"means the motor thermostat must be reset manually.

Motor housings may have casings that are open, open drip-proof, open splash-proof, and totally enclosed. (Totally enclosed fan cooled, totally enclosed non-ventilated, totally enclosed air-over, totally enclosed explosion-proof.) This particular motor listed is a totally enclosed fan cooled unit.

Bearing types are often specified. Sleeve bearings usually require routine oiling or greasing.

NEMA (National Electrical Manufacturer's Association) has standardized the shaft and mounting dimensions of many motors and established frame numbers to ensure mounting compatibility between motors built by different manufacturers. The larger the frame number, the larger the motor.

1-phase motor types: shaded pole, induction split phase, repulsion/induction, capacitor start, capacitor run, universal, and synchronous.

When removing or installing a motor, be sure the power circuit is locked out. Proper grounding is very important for safety. Be sure to insulate the ends of any unused leads. Double check your connections and make the sure motor runs in the right direction before connecting it to a load that would be harmed by reverse rotation.

Go through the proper alignment procedure to prevent vibration and excessive loads on the motor bearings. Be sure the load puts no end thrust on the motor shaft and that the rotor will operate in the midpoint of its endplay. Motors must be bolted down to something solid. Both bearing and insulation failure are quicker in motors that vibrate or shake. Be sure to torque the mounting assembly to the required specifications

Proper maintenance includes keeping records on electrical motors. Record the line current and voltage to the motor both during startup and after it is running under normal load. Let the motor operate long enough to ensure breakers or overloads will not trip and that it is not overheating.

5-7 SUMMARY

Typically, transit systems use induction motors for the escalator drive systems. These induction motors do not contain brushes and offer robust capabilities. These motors have a limited number of internal components. Due to the simplicity of the design, induction motors suffer from fewer problems than other motors. To ensure that the drive motors remain in prime operating status, routine maintenance is required. This includes but is not limited to exterior and interior cleaning, and adequate lubrication. Failure to properly maintain the drive motor, can result in motor failure.

Escalator drive motors should be inspected and tested on a routine basis. A megohmmeter is a common tool used to test the drive motors. During inspection and testing, it is crucial that an accurate record be kept for each component of the drive motor. These inspections and tests can detect potential problems before they have a chance to fully develop. If a problem is detected, troubleshooting procedures should be followed to determine the underlying cause of the malfunction. Common troubleshooting steps include: troubleshooting the motor and troubleshooting the control circuit. If after troubleshooting, it is determined that the motor requires replacement, ensure that the new drive motor is rated for the same horsepower described within the OEM.

MODULE 6

Description of Operation

Outline

6-1. Overview
6-2. Schematic Diagrams
6-3. Line and Ladder Diagrams
6-4. Flow Charts
6-5. Block Diagrams
6-6. Pictorial Layout
6-7. Start-Up Sequence
6-8. Stop Sequence
6-9. Summary
6-10. Appendix

Purpose and Objectives

The purpose of this module is to provide the participants with a basic knowledge of the startup sequence of a transit escalator. Following the completion of this module, the participant should be able to complete the following objectives with an accuracy of 75% or greater:

- Describe what a Schematic Diagram is and its usage
- Describe what a Line or Ladder Diagram is and its usage
- Describe what a Block Diagram is and its usage
- Describe what a Pictorial Layout is and its usage
- Describe the Start-up Sequence of an escalator using a Schematic Diagram

Key Terms:

- Block Diagrams
- Flow Charts
- Line or Ladder Diagrams
- Pictorial Layout
- Schematic Diagram
  Start-Up Sequence

6-1 OVERVIEW

Escalators, regardless of the manufacturer type and model, contain two main electrical sections: Electrical Control, and Power.

The **electrical control** section provides the means for the start-up sequence, normal running operation, and the safety circuits of the escalator. The **power** section provides the electrical energy for the escalator's main drive motor. Visual aids are supplied by the manufacturer to assist the participant in understanding the start-up sequence as well as for diagnostic purposes are schematic diagrams, line or ladder diagrams, and flow charts. This module will focus on the start-up sequence of an escalator as well as the visual aids used in the process.

6-2 SCHEMATIC DIAGRAMS

A **schematic diagram** is a drawing which shows all circuit components in the form of electrical symbols, how they are wired together electrically without consideration of their actual physical relationships, and how they interact with each other to produce the desired end result. The main benefit of using schematic diagrams is they tell the whole story of what occurs and needs to occur electrically on an escalator for starting, running, and diagnostic purposes. Figure 6.1 is an example of a schematic diagram.

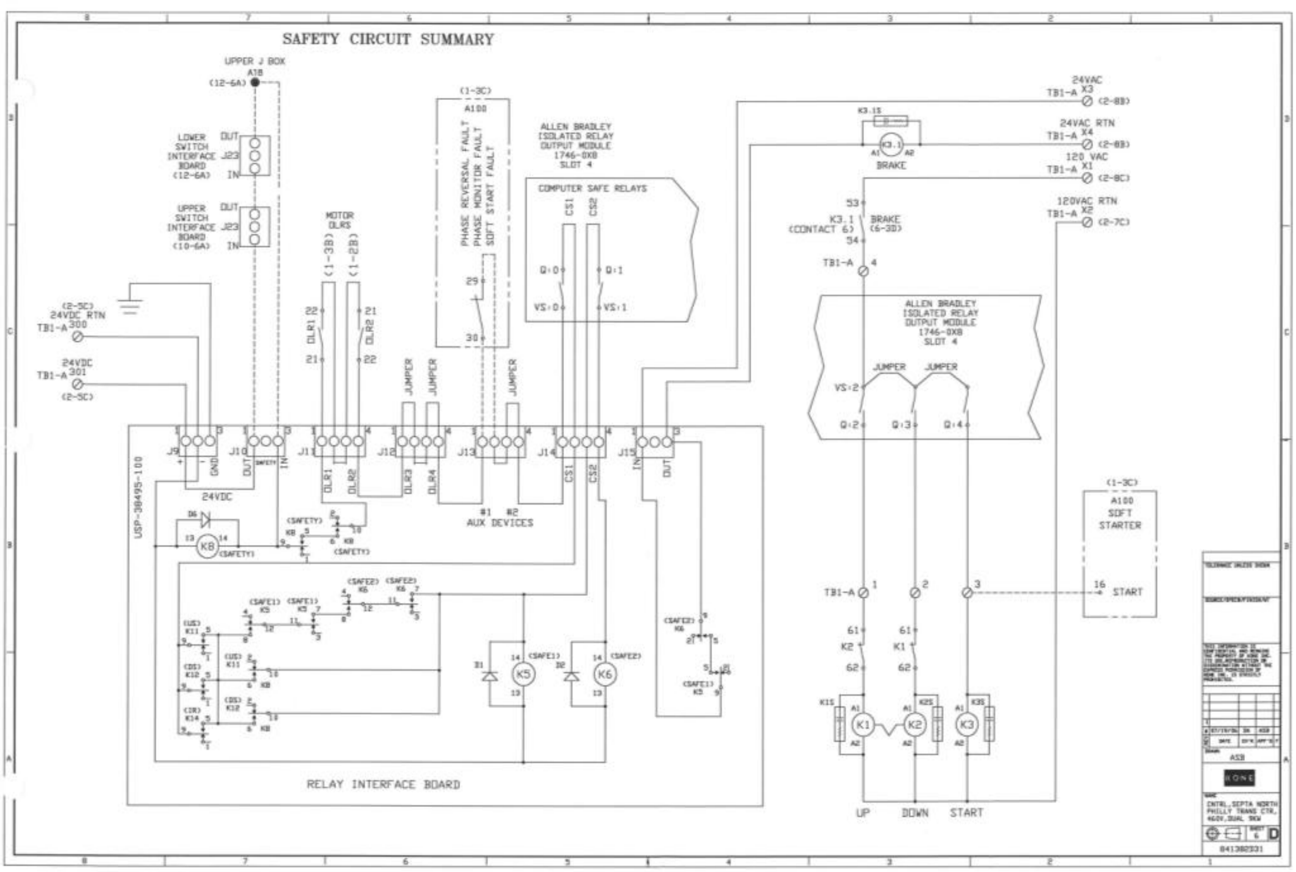


Figure 6.1 Schematic Diagram

6-3 LINE OR LADDER DIAGRAMS

An electrical **line diagram,** also referred to as a **ladder diagram,** uses a series of lines (rungs) and symbols that indicate the paths and components of a control circuit. Line diagrams are used to display the logic on a line-by-line basis and not the actual wiring of a circuit. When only one line is used, it is referred to as a single line diagram and is used mainly in power distribution systems. When two or more lines (rungs) are used, it is referred to as a ladder diagram because it resembles the rungs of a ladder used for climbing. Ladder diagrams are used mainly in control-type circuits. Figure 6.2 is an example of a ladder diagram.

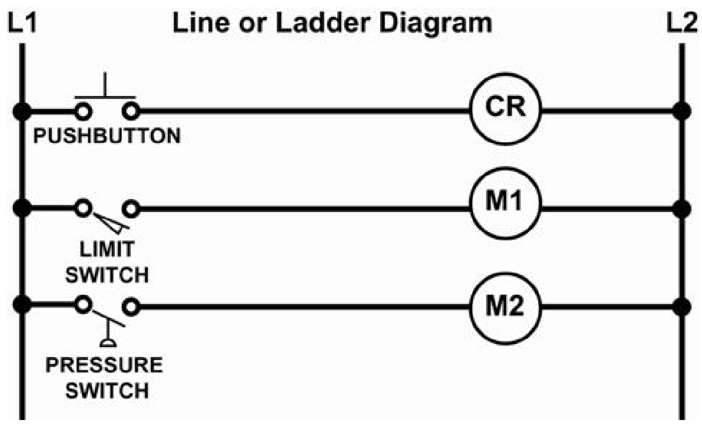


Figure 6.2 Line or Ladder Diagram

6-4 FLOW CHARTS

Flow charts are commonly used visual aids for troubleshooting an escalator. They consist of graphical shapes such as boxes, diamonds, and triangles that are connected by arrows and typically create two logical paths that can be followed when troubleshooting a problem. They are most useful when diagnosing complex networks of electrical and electronic circuits. Each step along a path asks a question requiring a “Yes” or “No” answer; depending on the answer given, will naturally “flow” to the next logical step to follow. Figure 6.3 is an example of a flow chart for troubleshooting an escalator that will not start. Following the flow chart, the first question asked is if the main power is turned on. If the answer is yes, simply follow the arrow to the next question that is, “Is there a safety device tripped?” Using a flow chart makes diagnosing problems much easier simply by answering the questions and following the flow. Each of the questions is set up starting with the most probable reason flowing down to less likely reasons.

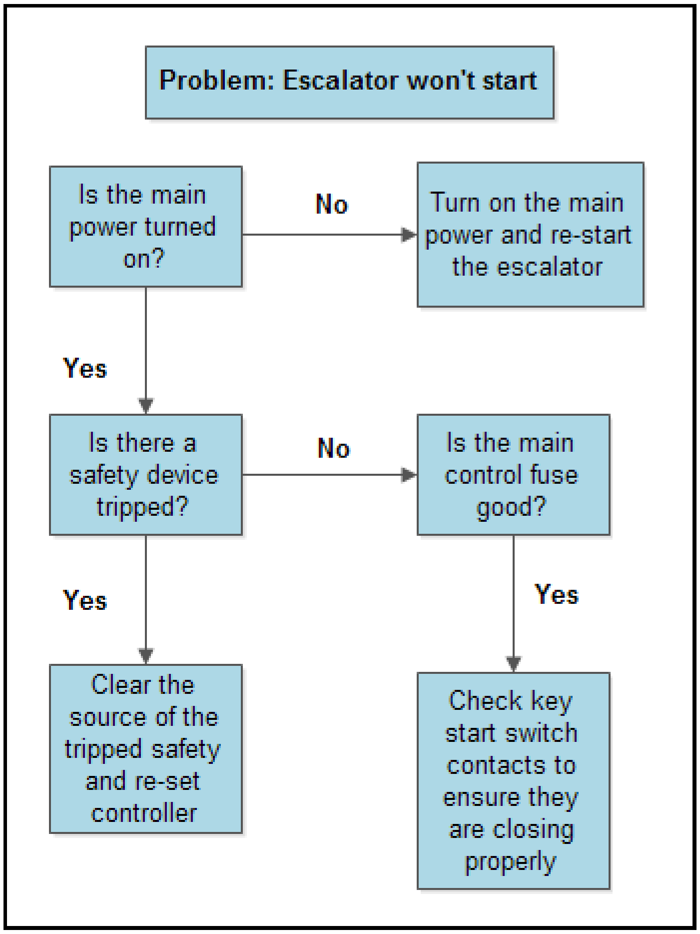


Figure 6.3 Flow Chart

6-5 BLOCK DIAGRAMS

A **block diagram** shows how of all the sub-systems located within an escalator are physically connected by means of conduits and other wire raceways. Their role is not to show the specific details of each system but to give a broader view of how the various systems are connected to another. Block diagrams are useful when troubleshooting a problem and there is a need to know how the individual systems are connected in relation to each other. This makes identifying and locating a suspected problem a great time saver. Figure 6.4 is an example of a Rough-In Block Diagram for a Kone Eco3000 Transit Escalator.

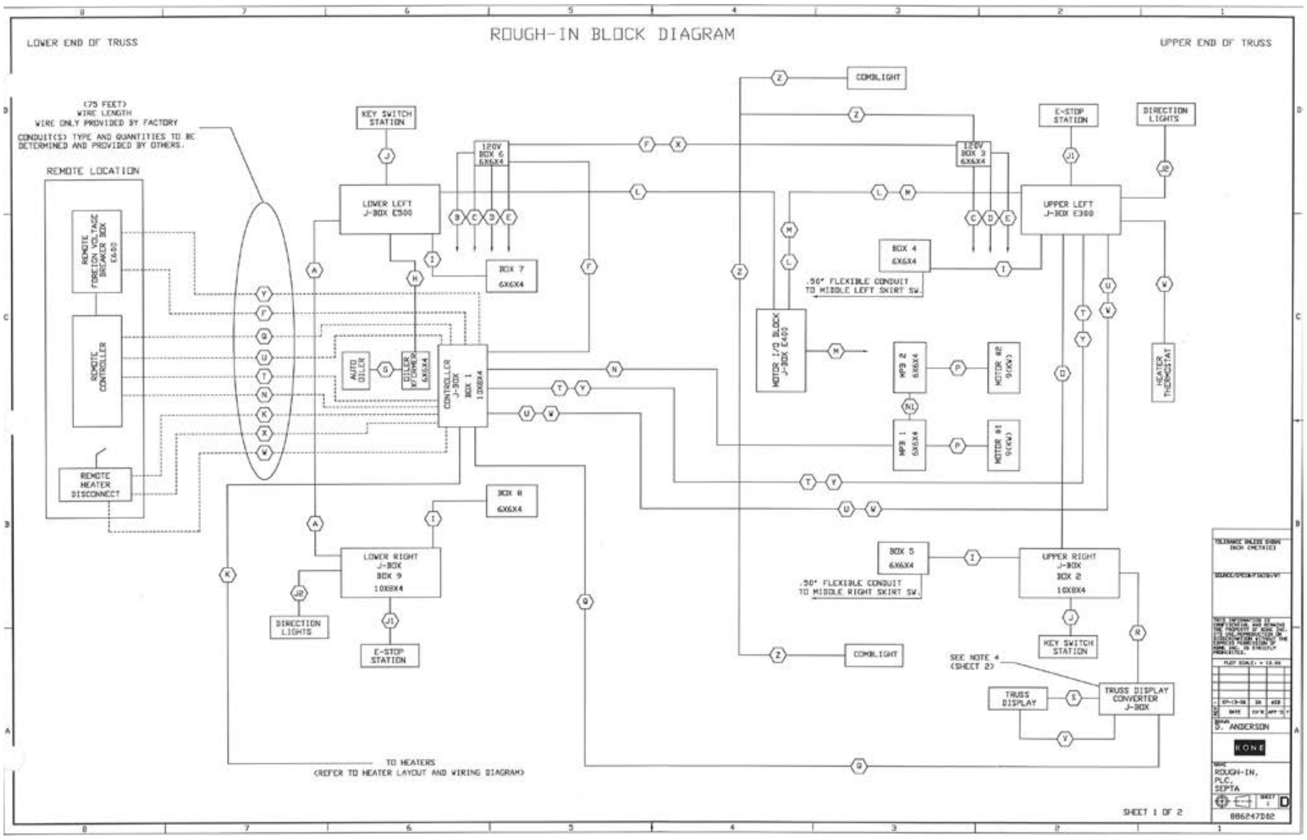


Figure 6.4 Block Diagrams

6-6 PICTORIAL LAYOUT

A **pictorial diagram** is a drawing that shows circuit components as they physically exist in real time. They display the actual location of circuit devices and components in their actual format. They are useful when a conceptual view of an actual layout is needed. Each component is labeled which makes it easier to locate and identify. Figure 6.5 is an example of a pictorial diagram.

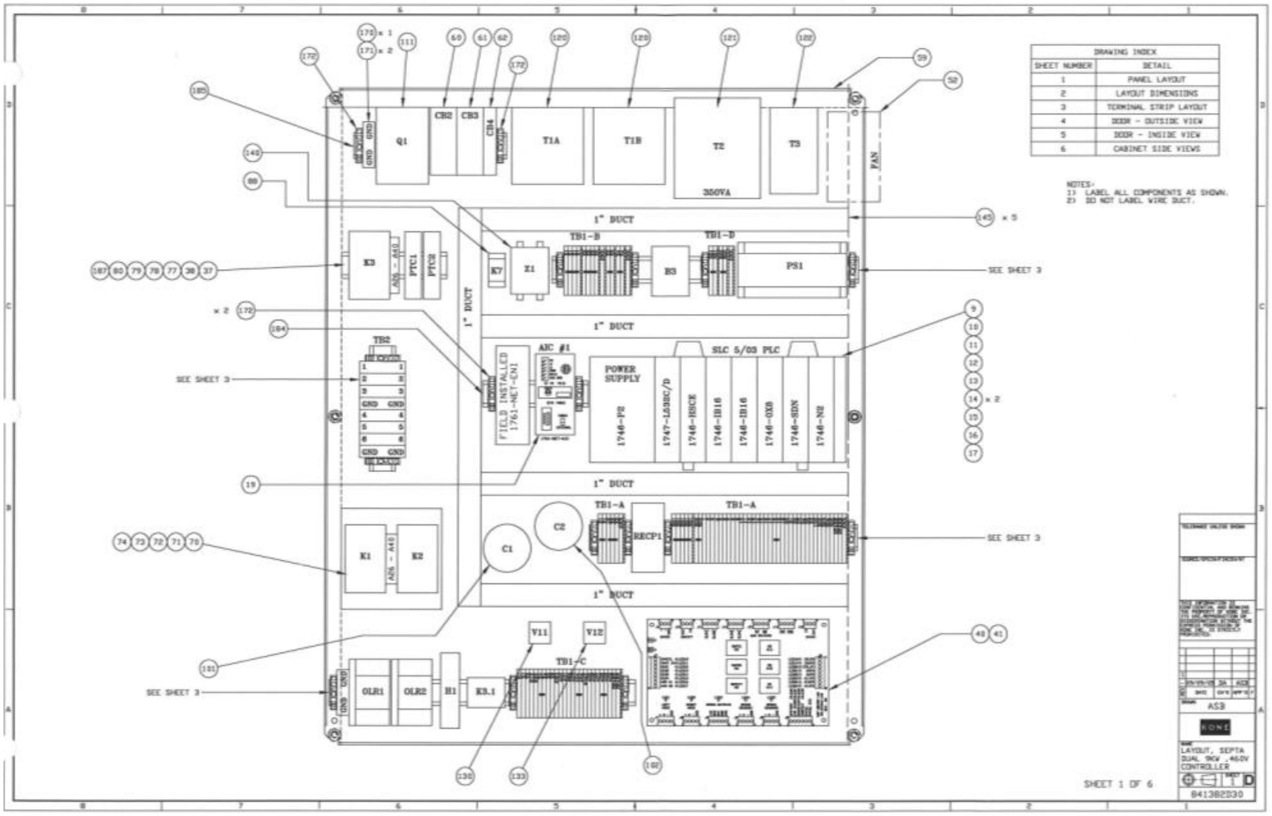


Figure 6.5 Pictorial Diagram

6-7 START-UP SEQUENCE

The logical sequence of events, both electrically and mechanically, that an escalator goes through from when the key is inserted and turned on until the escalator reaches a normal running mode, is known as the **Start Up Sequence** of Operation. All escalators, regardless of the manufacturer, go through a series of electrical and mechanical start-up steps prior to reaching their normal running operations. These steps do vary from manufacturer to manufacturer so it is important to check each escalator manual of the model installed for their Start-Up Sequence of Operation.

Below is a generic sequence for run operation – in both up and down direction, including bypass and inspection mode directions. Following this you will find a manufacturer specific example for a Kone Eco3000™. This manufacturer-specific example is included to give the participant a better grasp on real world application. Sequences for specific escalators at a given property should be supplied by the local transit authority and/or the OEM.

Generic Sequences for the “Up Direction”

Run

- Using the top or bottom escalator control key switches, turn a key switch to the “Up Start” position momentarily.

- The “Up Start” PLC input is turn, on and the PLC program start sequence is activated.
- **Note:** The following conditions must be met for the PLC program start sequence to occur.
    - Is the escalator in normal running mode, “Norm”. The PLC input called “Norm” must be on.
    - The safety circuit made, PLC “SAFE” input must be on.
    - Is the safety circuit power input on, PLC input “SWPR”?
    - Are all brake over-temp sensor inputs off (BT1 to BT6)?
    - Is the drive “Ready” PLC input on?

The following sequence of events should occur:

- The PLC drive contactor control output “DRC” is turned on, which energizes the DRC drive contactor, connecting the escalator motor(s) to the drive controller.
- The PLC “UPR” output is turned on, which commands the drive to turn on and get ready to run in the up direction.
- The drive relay output #2 is energized (providing a feedback signal to the PLC), turning on the “ON” input.
- The drive “ON” input tells the PLC that the drive is energized and ready to run the motor(s).
- The PLC brake output “BRAKE” is energized, which picks the “BR1” brake contactor, which in turn energizes the escalator brakes.
- The PLC “ONRLY” output is turned on which energizes the “ON” relay.
- Once energized, the brakes turn on the “BPI” inputs, which tell the PLC that the brakes are open.
- The PLC turns on the “HSPD” output which gives the motor drive controller a speed command.
- The drive controller ramps up the voltage and frequency output to the motor(s).
- The PLC monitors the step band speed, using the step band encoder and a high speed counter module.
- When the escalator step band has reached full speed (contract speed-5%), the bypass sequence is initiated.

Starting with the escalator power feed on, no faults present (observe fault display), and the status shown as “Not Running Ready to Run”

Drive Bypass

- During the acceleration period, the speed is monitored, and the acceleration process is timed.
- When the step band reaches the contract speed-5%, the drive is turned off by turning off the “HSPD” and the “UPR” outputs.
- Then the motor is disconnected from the drive by turning off the DRC output which de-energizes the “DRC” contactor.
- After an adjustable time period, the “UPO” output is energized, which picks the “DIR” contactor, which connects the motors directly to the line.

Low Speed Inspection

- Using the escalator maintenance run buttons, push the “UPB” up direction run button.
- The “UPB” PLC input is turned on and the PLC program start sequence is activated.
- **Note:** The following conditions must be met for the PLC program start sequence to occur.
    - Is the escalator in “Maint” running mode, “Norm”? The PLC input called “Norm” must be off.
    - Is the safety circuit made? PLC “Safe” input must be on.
    - Is the safety circuit power input on? PLC input “SPWR”.
    - Are all the brake over-temp sensor inputs off? (BT1 to BT6)
    - Is the drive “Ready” PLC input on?
- The following sequence of events should occur:
- The PLC drive contactor control output “DRC” is turned on, which energizes the DRC contactor, connecting the escalator motor(s) to the drive controller.
- The PLC “UPR” output is turned on, which commands the drive to turn on and get ready to run in the up direction.
- The drive relay output #2 is energized (providing a feedback signal to the PLC), turning on the “ON” input.

- The drive “ON” input tells the PLC that the drive is energized and ready to run the motor(s).
- The PLC brake output “BRAKE” is energized, which picks the “BR1” brake contactor, which in turn energizes the escalator brakes.
- The PLC “ONRLY” output is turned on which energizes the “ON” relay.
- Once energized, the brakes turn on the “BPI” inputs, which tell the PLC that the brakes are open.
- The PLC turns on the “ISPD” output which gives the motor drive controller a speed command.
- The drive controller ramps up the voltage and frequency output to the motor(s).
- The escalator step band will reach the speed set in the drive parameters.

Generic Sequences for the “Down Direction”

Run

- Using the top or bottom escalator control key switches, turn a key switch to the “Down Start” position momentarily.
- The “Down Start” PLC input is turned on, and the PLC program start sequence is activated.
- **Note:** The following conditions must be met for the PLC program start sequence to occur.
    - Is the escalator in normal running mode, “Norm”. The PLC input called “Norm” must be on.
    - Is the safety circuit made? PLC “SAFE” input must be on.
    - Is the safety circuit power input on, PLC input “SWPR”?
    - Are all brake over-temp sensor inputs off (BT1 to BT6)?
    - Is the drive “Ready” PLC input on?
- The following sequence of events should occur:
- The PLC drive contactor control output “DRC” is turned on, which energizes the DRC contactor, connecting the escalator motor(s) to the drive controller.
- The PLC “DNR” output is turned on, which commands the drive to turn on and get ready to run in the down direction.

- The drive relay output #2 is energized (providing a feedback signal to the PLC), turning on the “ON” input.
- The drive “ON” input tells the PLC that the drive is energized and ready to run the motor(s).
- The PLC brake output “BRAKE” is energized, which picks the “BR1” brake contactor, which in turn energizes the escalator brakes.
- The PLC “ONRLY” output is turned on which energizes the “ON” relay.
- Once energized, the brakes turn on the “BPI” inputs, which tell the PLC that the brakes are open.
- The PLC turns on the “HSPD” output which gives the motor drive controller a speed command.
- The drive controller ramps up the voltage and frequency output to the motor(s).
- The PLC monitors the step band speed, using the step band encoder and a high speed counter module.
- When the escalator step band has reached full speed (contract speed-5%), the bypass sequence is initiated.

Drive Bypass

- During the acceleration period, the speed is monitored, and the acceleration process is timed.
- When the step band reaches the contract speed-5%, the drive is turned off by turning off the “HSPD” and the “DNR” outputs.
- Then the motor is disconnected from the drive by turning off the DRC output which de-energizes the “DRC” contactor.
- After an adjustable time period, the “BYP” output is energized, which picks the “BYP” contactor, which connects the motors directly to the line.

Low Speed Inspection

- Using the escalator maintenance run buttons, push the “UDNB” down direction run button.
- The “DNB” PLC input is turned on, and the PLC program start sequence is activated.
- **Note:** The following conditions must be met for the PLC program start sequence to occur.

  - Is the escalator in “Maint” running mode, “Norm”? The PLC input called “Norm” must be off.
  - Is the safety circuit made? PLC “Safe” input must be on.
  - Is the safety circuit power input on? PLC input “SPWR”.
  - Are all the brake over-temp sensor inputs off? (BT1 to BT6)
  - Is the drive “Ready” PLC input on?

- The following sequence of events should occur:
- The PLC drive contactor control output “DRC” is turned on, which energizes the DRC contactor, connecting the escalator motor(s) to the drive controller.
- The PLC “DNR” output is turned on, which commands the drive to turn on and get ready to run in the down direction.
- The drive relay output #2 is energized (providing a feedback signal to the PLC), turning on the “ON” input.
- The drive “ON” input tells the PLC that the drive is energized and ready to run the motor(s).
- The PLC brake output “BRAKE” is energized, which picks the “BR1” brake contactor, which in turn energizes the escalator brakes.
- The PLC “ONRLY” output is turned on which energizes the “ON” relay.
- Once energized, the brakes turn on the “BPI” inputs, which tell the PLC that the brakes are open.
- The PLC turns on the “ISPD” output which gives the motor drive controller a speed command.
- The drive controller ramps up the voltage and frequency output to the motor(s).
- The escalator step band will reach the speed set in the drive parameters.

Manufacturer-Specific Example:

Normal Start Mode (Up or Down) For A Kone Eco3000™ Heavy Duty Escalator

Courtesy of Kone©

Note: In the following sequence, the participant will need to be able to reference the following materials, found in the Appendix:

A. Relay Coil and Contact Reference Chart
B. Schematic
C. Parts List

The following is the start-up sequence for a Kone Eco3000 Heavy Duty escalator:

1. Insert key in start switch.
2. Press and hold the start button.
3. Turn key toward the desired run direction and hold in that position (i.e., Up or Down).
4. The escalator will begin moving and the following events must take place before a holding circuit is achieved:
   - The escalator is running in the intended start direction
   - The escalator is running at least 90% of rated speed
   - The speed of the handrails are within the code allowed deviation from the speed of the step band,
   - No fault has occurred.

Once these conditions are verified, an alarm is sounded for 500 msec at which time return the key to the center position and remove.

The following actions performed by the PLC during start-up (Refer to the wiring diagrams and reference chart below):

- Energize Relay Interface Board Relay K5 via J14 CS1 and verify that K5 has energized.
- Energize Relay Interface Board Relay K6 via J14 CS2 and verify that K6 has energized.
- Energize relay K3. Verify that contactors have energized within 500mS.
- Verify that all brakes are released within 500 msec.
- Energize appropriate direction contactor K1 or K2. Verify that contactors have energized within 500 msec.
- Verify the speed of the handrails is within tolerance. (Ignore if disabled.)
- Verify that the Missing Step Device inputs indicate no steps missing. (Ignore if disabled.)
- Verify that the escalator is moving in the selected direction.
- Verify that the speed of the escalator is > 90% and < 115% within 10 seconds.
- Energize alarm relay for 500 msec when either of the ***Run Modes*** can be entered.
- The PLC will sound the alarm once for 500 msec to indicate that the start switch can be returned to center. If the start switch is released before the alarm sounds, then the no holding circuit will be achieved and the escalator will stop.

The escalator is now in normal run mode.

6-8 STOP SEQUENCE

A normal stop when running the escalator in normal running mode works as follows:

- When the top or bottom normal stop key switch is activated momentarily, the top normal stop input (duplex line board #3 in top junction box input #1) is turned on which initiates the stop sequence.
- The PLC receives this input thru the dupline[2] master module via its RS 232 serial port.
- The "BYP" or "UPO" out is turned off which disconnects the motor(s) from the line.
- The "Brake" output is turned off to drop the brake.
- The brake control unit then controls the escalator stop.
- The stopping distance is measured by the PLC and recorded in the memory.

Emergency Stop Sequence from High Speed in Normal Run Mode

- When the safety string is opened due to any switch or sensor trip condition, or when a fault has been triggered from the dupline system, or a missing step has been detected, the escalator will make an emergency stop.
- In normal run mode while running in drive bypass, the motor is disconnected from the line without delay.
- The brake relay "BR1" is de-energized without delay.
- The brake control unit stops the escalator within the prescribed distance.
- The stopping distance is measured and recorded by the PLC.

Emergency Stop Sequence before Reaching High Speed in Normal Run Mode

- When the safety string is opened due to any switch or sensor trip condition, or when a fault has been triggered from the dupline system, or a missing step has been detected, the escalator will make an emergency stop.
- In normal run mode while running, before the drive bypass occurs, the motor is disconnected from the motor drive controller without delay.
- The brake relay "BR1" is de-energized without delay.
- The brake control unit stops the escalator within the prescribed distance.
- The stopping distance is measured and recorded by the PLC.

[2] Dupline© is typically used as a remote I/O system, creating a link between field devices, such as sensors, contactors, valves, pushbuttons etc. and a central Monitoring Controller, which may be a PLC, PC or the Dupline® Controller. But Dupline® can also be used as a simple wire replacement system where signals are transmitted peer-to-peer without involving a controller or other intelligent unit.

6-9 SUMMARY

The operation of an escalator is illustrated in a number of ways that make it easier to understand. Some of these illustrations include:

- A schematic diagram is a drawing that shows all circuit components in the form of electrical symbols, how they are wired together electrically without consideration of their actual physical relationships, and how they interact with each other to produce the desired end result.

- An electrical line diagram, also referred to as a ladder diagram, uses a series of lines (rungs) and symbols that indicate the paths and components of a control circuit.

- A line diagram is used to display the logic on a line-by-line basis and not the actual wiring of a circuit.

- A flow chart is commonly used as a visual aid for troubleshooting an escalator. It consists of graphical shapes such as boxes, diamonds, and triangles that are connected by arrows and typically create two logical paths that can be followed when troubleshooting a problem.

- A block diagram shows how all of the sub-systems located within an escalator are physically connected by means of conduits and other wire raceways.

- A pictorial diagram is a drawing that shows circuit components as they physically exist in real time. They display the actual location of circuit devices and components in their actual format.

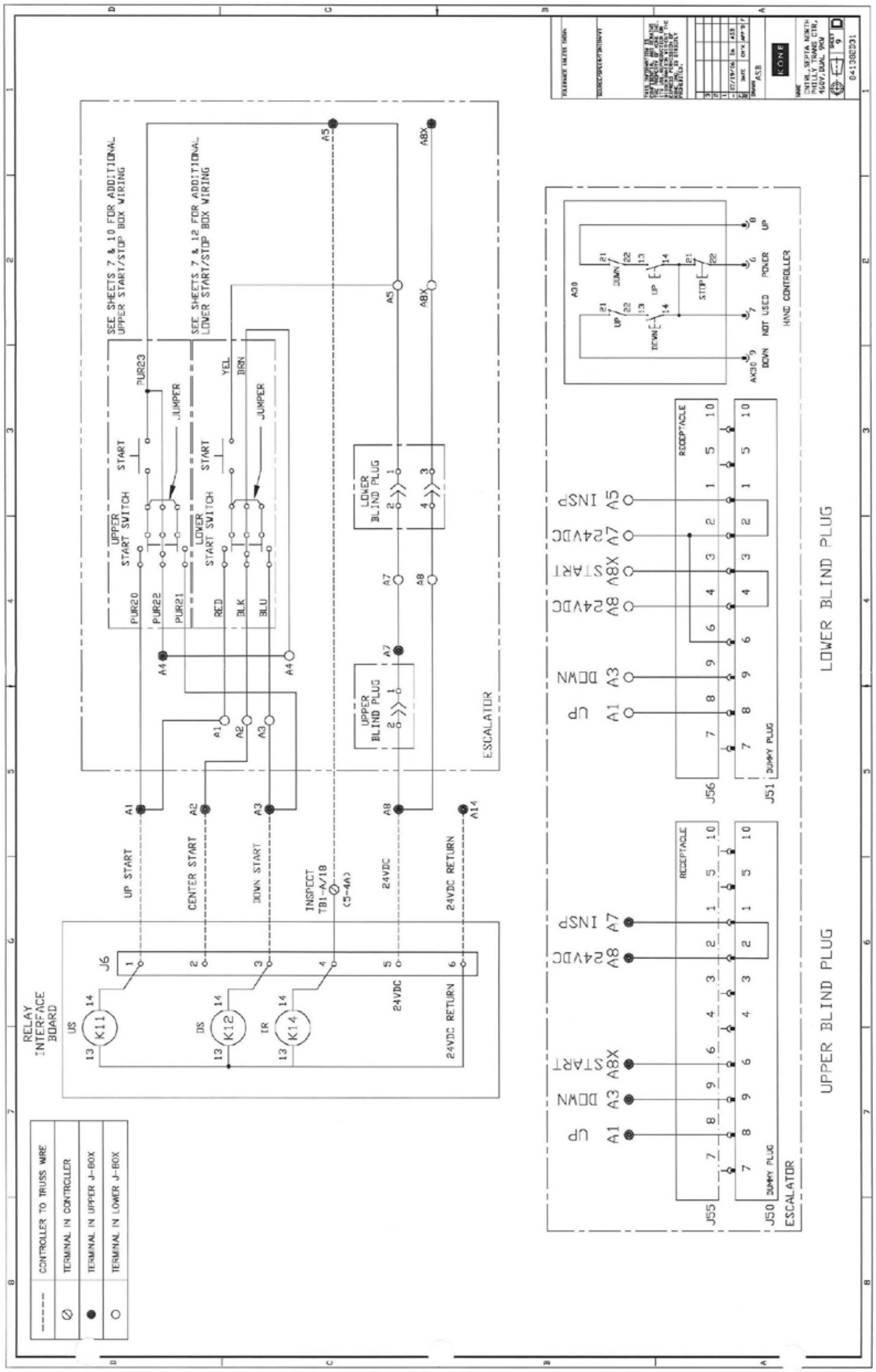
- The logical sequence of events, both electrical and mechanical, is the series of steps that an escalator goes through from when the key is inserted and turned on until the escalator reaches a normal running mode. This is known as the Start-Up Sequence of Operation. All escalators, regardless of the manufacturer, go through a series of electrical and mechanical start-up steps prior to reaching their normal running operation.

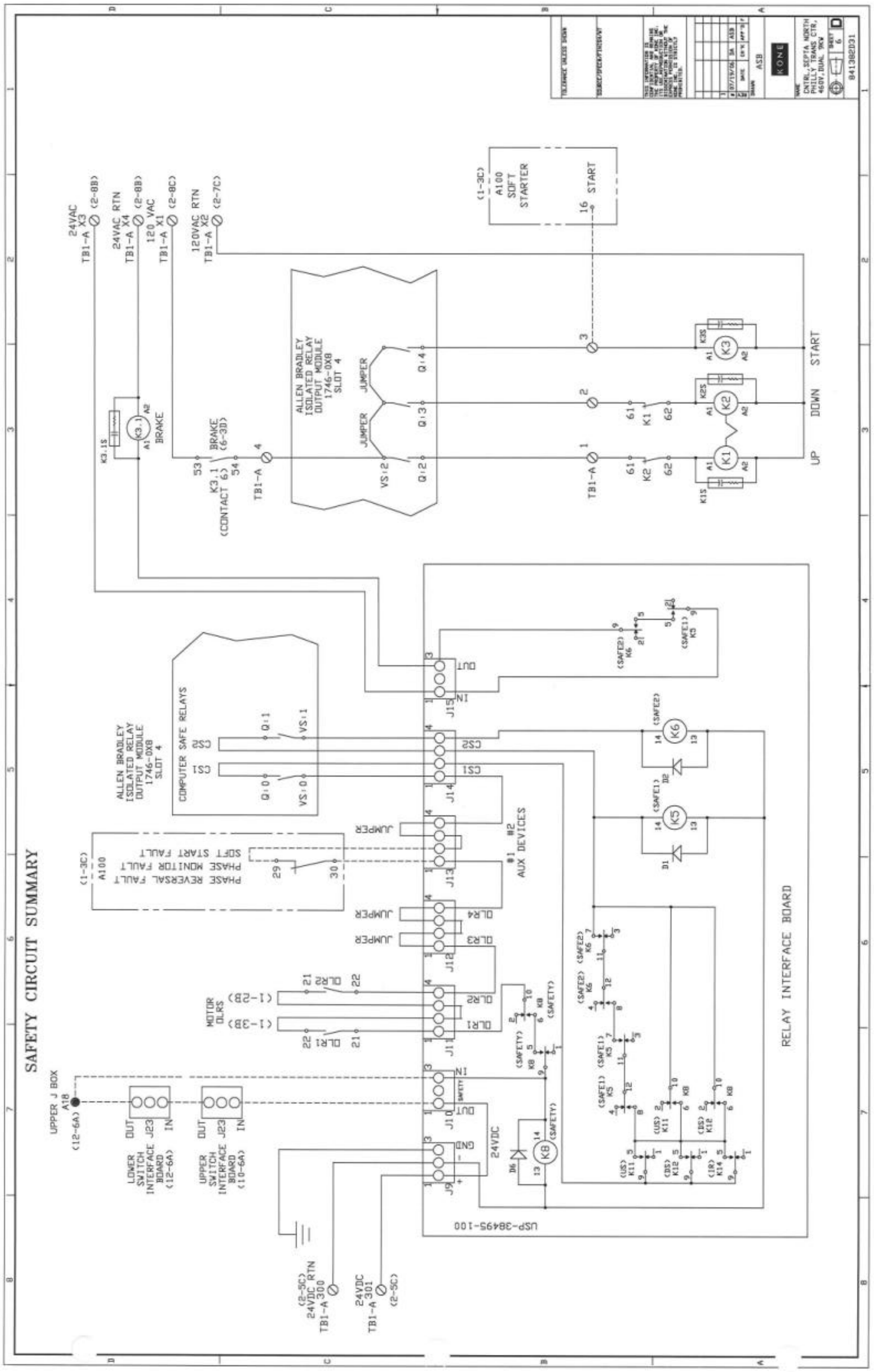
Appendix A - Example Reference Chart

RELAY COIL & CONTACT REFERENCE CHART

Relay	K1	K2	K3	K5 & K6
Coil	Sheet (6-4A)	Sheet (6-3A)	Sheet (6-3A)	Sheet (6-5B)
Function	RUN UP	RUN DOWN	START	SAFE RELAYS
Contact 1	N.O. (1-2B)	N.O. (1-2B)	N.O. (1-2D)	Sheet (6-4B)
Contact 2	N.O. (1-2B)	N.O. (1-2B)	N.O. (1-2D)	NOT USED
Contact 3	N.O. (1-2B)	N.O. (1-2B)	N.O. (1-2D)	(6-6B & 6-7B)
Contact 4	N.O. NOT USED	N.O. NOT USED	N.O. NOT USED	(6-6B & 6-7B)
Contact 5	N.O. (5-6B)	N.O. (5-6B)	N.O. (5-5B)	-
Contact 6	N.O. (6-3B)	N.O. (6-4B)	N.O. (1-4B)	-
Contact 7	N.O. NOT USED	N.O. NOT USED	N.O. (1-4B)	-
Contact 8	N.O. (1B-7C)	N.O. (1B-7C)	-	-
Contact 9	N.O. (6-6C)	N.O. (6-6C)	-	-
Contact 10	-	-	-	-

Appendix B - Safety Circuit Schematics




SAFETY CIRCUIT SUMMARY
RELAY INTERFACE BOARD
ALLEN BRADLEY ISOLATED RELAY OUTPUT MODULE 1746-OX8 SLOT 4
COMPUTER SAFE RELAYS
A100 SOFT STARTER
UP
DOWN
START
BRAKE
MOTOR OLRS
AUX DEVICES
UPPER J BOX
USP-38495-100

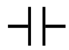
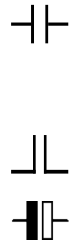
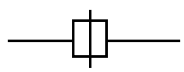
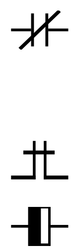
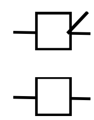
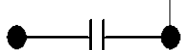
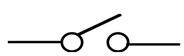
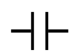
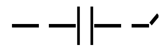
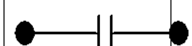
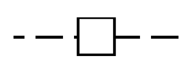
Appendix C - Parts List

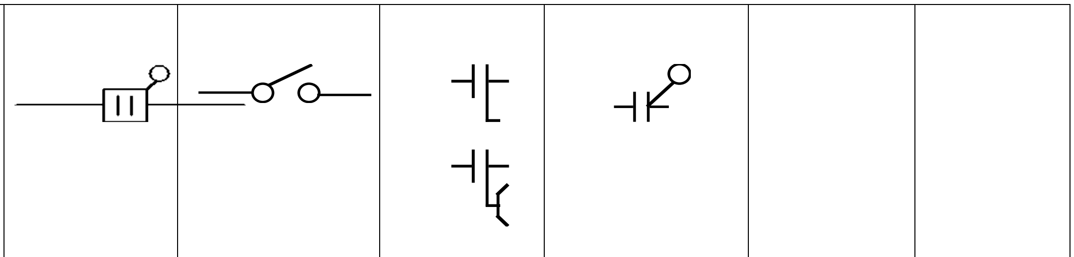
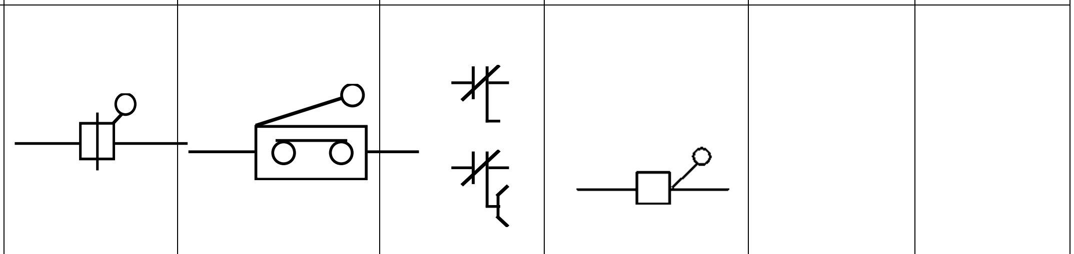
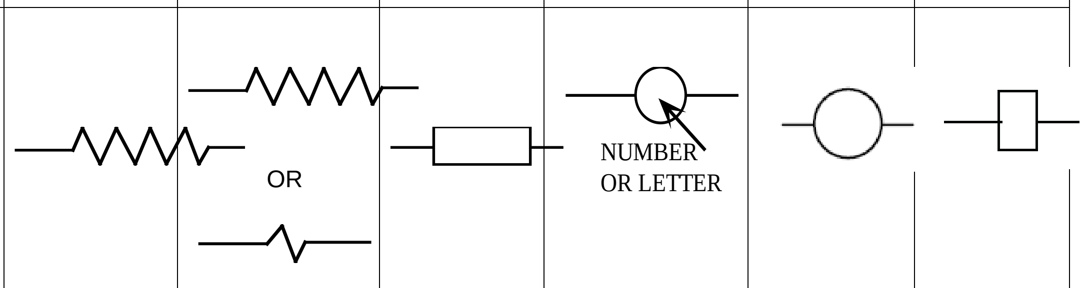
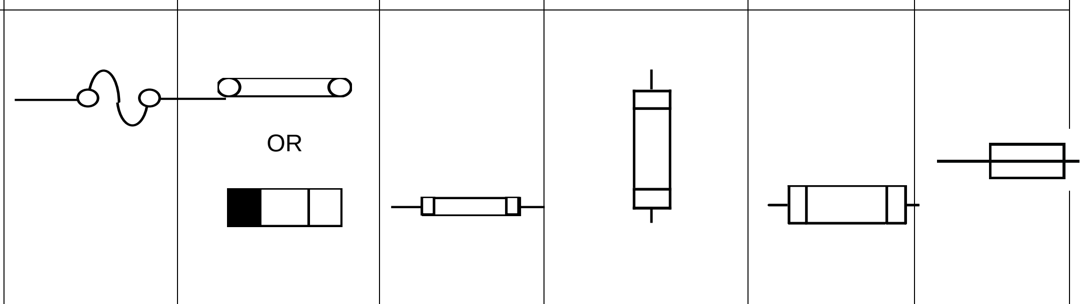
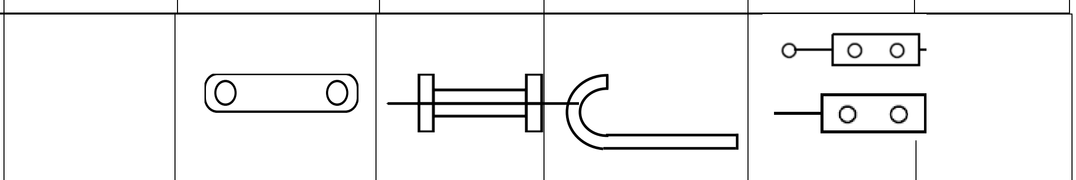
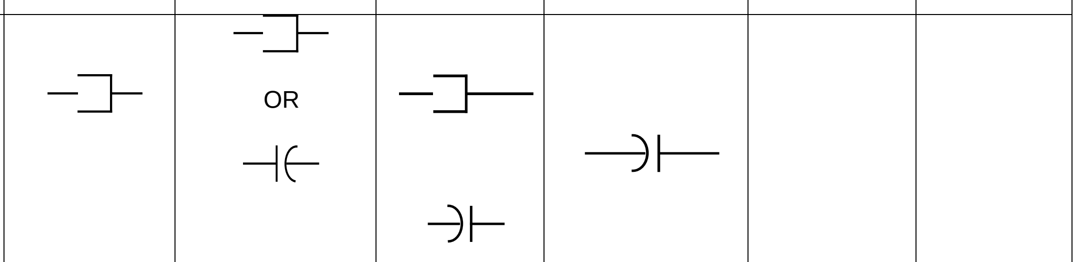
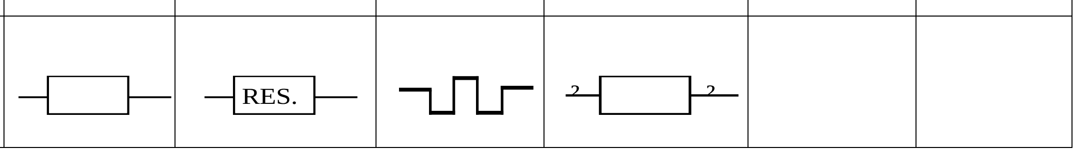
WO Title #	Title	Description
1	WD	Wiring Diagram, KM841382G03 GTRL, Dual 9KW, 460V
2	Assembly Drawing	Drawing, Assembly, KM841382G03 CTRL, Dual 9KW, 460V
9	PLC	Memory Module, 64K EEPROM, SLC 5/03
10	PLC	7 Slot Chassis
11	PLC	Power Supply
12	PLC	SLC500 Processor Unit
13	PLC	High Speed Counter Module
14	PLC	24VDC PLC Input Module
15	PLC	Isolated Relay Output Module
16	PLC	Device Net Scanner Module
17	PLC	Slot Filler
18	PLC	Panel View 100, Key, Color, RS232 (DH485)
19	AIC #1	Module, Interface Converter, DH485(RS485) to DH485(RS232)
30	Cable	Cable, DH485 (RS485) Connector, 10Ft Long
31	Cable	Cable, DH485 (RS232), 8 Pin Mini RND to Female 9 Pin D-Shell 6.5Ft Long
33	Adapter	Adapter, DB-9 Male to DB-9 Female Thin Null Modern Block Adapter
37	PTC1	PTC Relay, 24-240V DC/AC, 2 N.O. Contacts
38	PTC2	PTC Relay, 24-240V DC/AC, 2 N.O. Contacts
40	PC Board	PC Board, Relay Interface, (Mount using M-M stand offs)
41	Pad	Pad, Pink Foam, 5-9/16" x 9.0 x 3/8" thick, Each Corner notched 1/2" x 1/2"
45	Flash Card	32MB PCMCIA ATA Flash Card www.memoryx.net
48	PS1	Power Supply, 120VAC to 24VDC, 4AMP
51	B3	Thermostat, Dual Unit, reads in Fahrenheit (For Enclosure Heater and Fan)
52	M40	Fan Kit, Cooling. 115vac. 38CFM, IP55, Beige
53	M40B	Grill. Exhaust, w/Filter. IP55, Beige
54	H1	Heater, Panel, 120V. 30W
58	E102	Cabinet. Nema 4X. Stainless Steel, 36"Hx30"Wx12"D, Single Door
59	E102P	Sub panel, 34.20"x28.20"
60	CB2	Circuit Breaker, 2 pole, 1A
61	CB3	Circuit Breaker, 2 pole, 2A
62	CB4	Circuit Breaker, 1 pole, 1A
70	K1&K2	Contactors,Rev,32A, 120vac Coil, 1-NO & 1-NC Aux Each
71	K1A	Auxiliary Contact, 2 N.O., 2 N.C.
72	K1S	Quencharc Suppressor, R-C, 125vac, 1000hm., 5MFD. 1/2W
73	K2A	Auxiliary Contact, 2 N.O., 2 N.C.
74	K2S	Quencharc Suppressor, R-C, 125vac, 1000hm., 5MFD. 1/2W
77	K3	Contactor, Non-Reversing, 32A, 120vac Coil, 1-NO & 1-NC Aux
78	K3A1	Auxiliary Contact. 1 N.O. & 1 N.C.

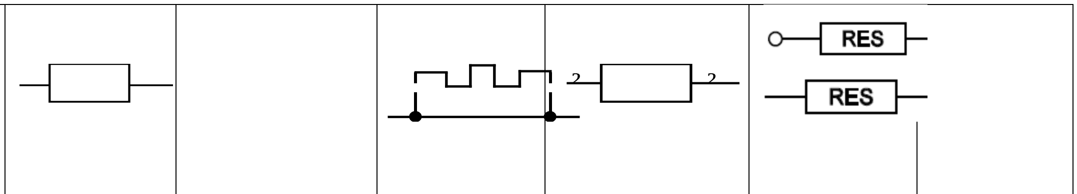
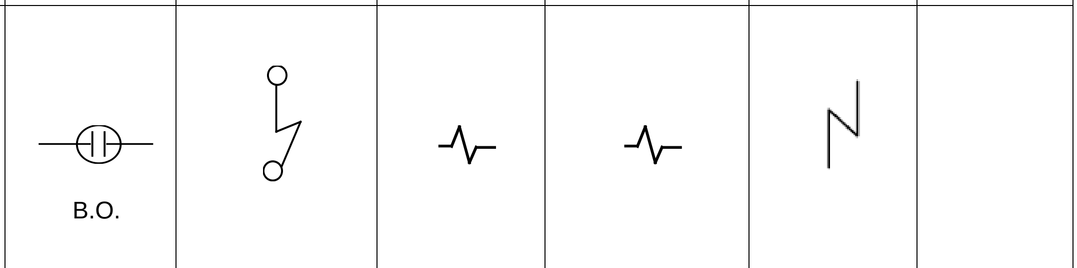
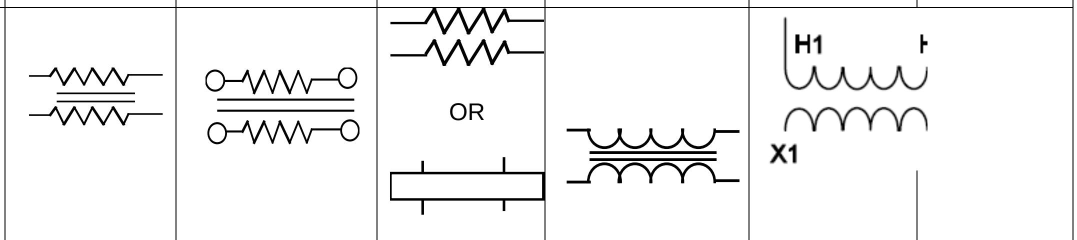
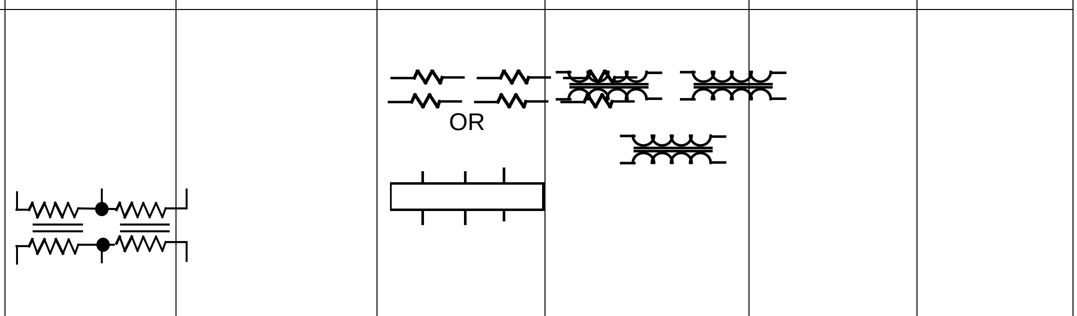
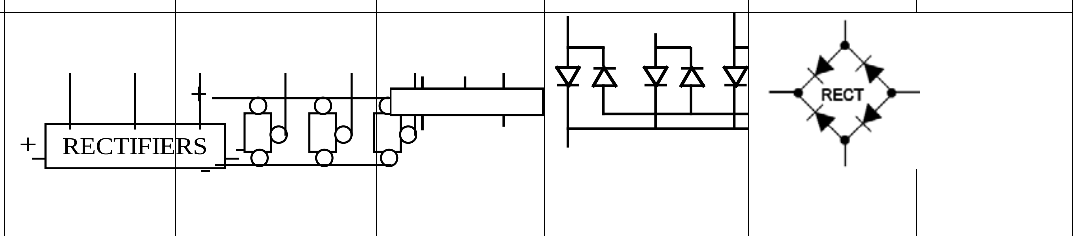
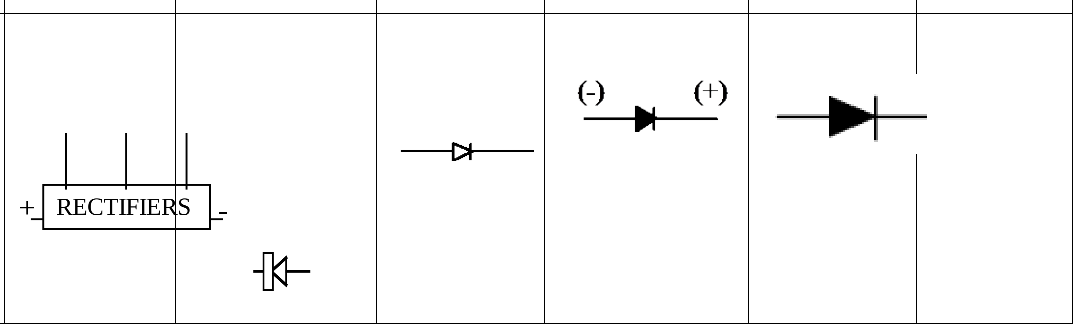
WO Title #	Title	Description
79	K3A3	Pneumatic Timing Module, Off Delay. 1 N.C. & 1 N.O.
80	K3S	Quencharc Suppressor, R-C. 125vac, 1000hm.,5MFD, 1/2W
83	K3.1	Relay, 10 amp, 24vac coil, 4- N.O. Contacts
84	K3.1A	Auxiliary Contact, 1 N.O & 1 N.C.
85	K3.1S	Quencharc Suppressor, R-C, 125vac, 1000hm,.5MFD, 1/2W
88	K7	Relay, 15 amp, 120vac coil, DPDT, Flange Top Mount
	Alternate Vendor	Relay, 15 amp, 120vac coil, DPDT, Flange Top Mount
90	OLR1	Manual Motor Starter/Protector, 16-20Amp, 1 N.O. & 1 N.C. Aux Contact
91	OLR2	Manual Motor Starter/Protector, 16-20Amp, 1 N.O. & 1 N.C. Aux Contact
101	C1	Capacitor, 2700uf, 350VDC, Screw Terminal, W/Mallory Mount VR10A
102	C2	Capacitor, 2700uf, 350VDC, Screw Terminal, W/Mallory Mount VR10A
103	D6	Diode, General Purpose, 1N5408, 3A, 1000V PIV
104	D7	Diode, General Purpose, 1N5408, 3A, 1000V PIV
105	D8	Diode, General Purpose, 1N5408, 3A, 1000V PIV
106	D9	Diode, General Purpose, 1N4007, 1A, 1000V PIV
107	R7	Resistor, 4.7K Ohm, 5W, Wire Wound
108	R8	Resistor, 10 Ohm, 10W, Wire Wound, 5%
110	Q1	Operating Handle with defeater re/yellow
111	Q1	Non-Fused Disconnect Switch 100 Amp with shields
112	Q1	Operating Shaft 18 inc
120	T1A & T1B	Transformer, 460V to 208VAC, 150VA, W/Finger Safe Kit
121	T2	Transformer, 460V to 120VAC, 350VA, W/Finger Safe Kit
122	T3	Transformer, 120V to @24VAC, Class2, 75VA
130	V11	Full Wave Bridge
133	V12	Full Wave Bridge
140	Z1	Line Filter, 120VAC
145	1' Wire Duct	Duct, 1" Wire, W/Cover, Qty=Length in inches
148	RECEP1	Receptacle, Dual Utility Outlet, 125V 15A
150	TB1-*	Terminal Block, 2 Pole
151	TB1-*	Terminal Block, 3 Pole
152	TB1-*	Jumper, 2 Pole
153	TB1-*	Jumper, 3 Pole
154	TB1-*	Jumper, 4 Pole
155	TB1-*	Jumper, 5 Pole
156	TB1-*	Jumper, 6 Pole
157	TB1-*	Ground Block, 2 Pole, Green/Yellow
158	TB1-*	Ground Block, 3 Pole, Green/Yellow
159	TB1-*	End Plate
160	TB1-*	Label, Blank, Vertical, DEK 5
161	TB1-*	End Bracket
165	TB2-* & TB3-*	Terminal Block, 2 Pole, 600v, 140A
166	TB2-* & TB3-*	Ground Block, 2 Pole, Green/Yellow, 16mm
167	TB2-* & TB3-*	End Plate, Terminal Block

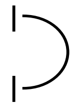
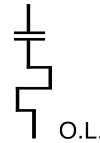
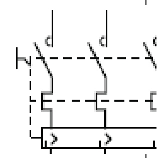
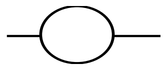
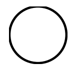
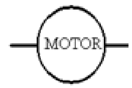
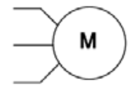
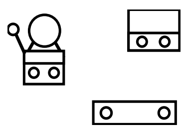
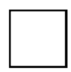
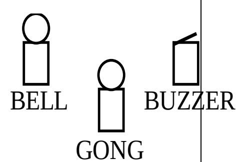
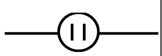
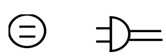
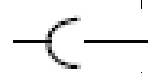
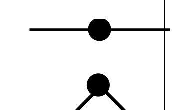
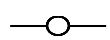
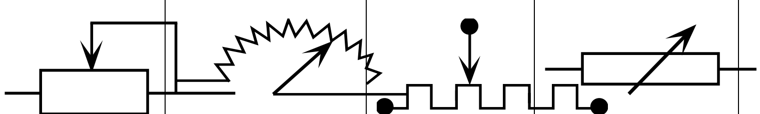
WO Title #	Title	Description
168	TB2-* & TB3-*	Label, Blank, Horizontal, RC1010
169	TB2-* & TB3-*	End Bracket, Series EW 35
170	Extra Parts (CB's)	Ground Block, 2 Pole, Green/yellow, 16mm
171	Extra Parts (CB's)	Label, Blank, Horizontal, RC1010
172	Extra Parts (End Bracket)	End Bracket
180	DIN RAIL (TB1-A)	DIN RAIL, 35mm, Length = 1" x QTY
181	DIN RAIL (TB1-B)	DIN RAIL, 35mm, Length = 1" x QTY
182	DIN RAIL (TB1-C)	DIN RAIL, 35mm, Length = 1" x QTY
183	DIN RAIL (TB2)	DIN RAIL, 35mm, Length = 1" x QTY
184	DIN RAIL (AIC #1)	DIN RAIL, 35mm, Length = 1" x QTY
185	DIN RAIL (CB's)	DIN RAIL, 35mm, Length = 1" x QTY
187	DIN RAIL (K3)	DIN RAIL, 35mm, Length = 1" x QTY
189	DIN RAIL (K1&K2)	DIN RAIL, 35mm, Length = 1" x QTY
200	Door Appliqués	Envelope, Adhesive backed, 10" x 12"
201	Door Appliqués	Label, Motor Overload Setting
202	Door Appliqués	Label, Logo, Self Adhesive
203	Door Appliqués	Nameplate, Adhesive Backed, SEPTA-, 155mm x 250mm
204	Door Appliqués	Nameplate, Inspections & Tests
205	Door Appliqués	Nameplate, CSA Cap Voltage Warning

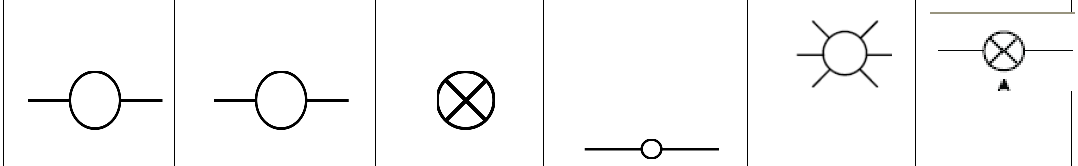
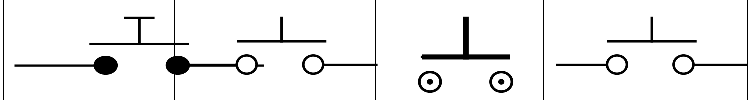
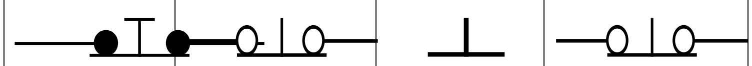
Appendix D – Electrical Symbols

NAME	GENERAL	MONTGOMERY/ KONE/O&K	OTIS	WESTINGHOUSE	NEMA	EIC
NORMALLY OPEN CONTACT *(SWITCH MOUNTED ON PANEL)*				CONTACTOR  RELAY		
NORMALLY CLOSED CONTACT *(SWITCH MOUNTED ON PANEL)*				CONTACTOR  RELAY		
NORMALLY OPEN CONTACT *(SWITCH NOT MOUNTED ON PANEL)*						
NORMALLY CLOSED CONTACT *(SWITCH NOT MOUNTED ON PANEL)*						

NORMALLY OPEN MECHANICALLY OPERATED SWITCH	
NORMALLY CLOSED MECHANICALLY OPERATED SWITCH	
COIL	
FUSE	
SHUNT	
CONDENSER	
CONSTANT RESISTANCE	

RESISTOR (OPTIONAL)	
BLOWOUT COIL	
TRANSFORMER (SINGLE PHASE)	
TRANSFORMER (POLYPHASE)	
RECTIFIER (POLYPHASE)	
RECTIFIER (SINGLE PHASE)	

CIRCUIT BREAKER				 O.L.		
MOTOR				 MOTOR	 Three-phase induction	
BELL-BUZZER GONG				 BELL GONG BUZZER		
PLUG AND RECEPTACLE						
TERMINAL STUD						
VARIABLE RESISTOR OR POTENTIOMETER						

INDICATOR LIGHT	
SINGLE MAKING BUTTON	
SINGLE BREAKING BUTTON	
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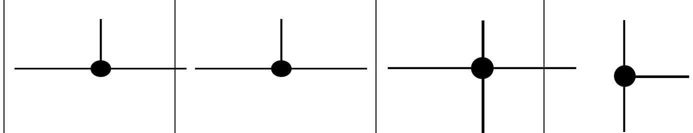
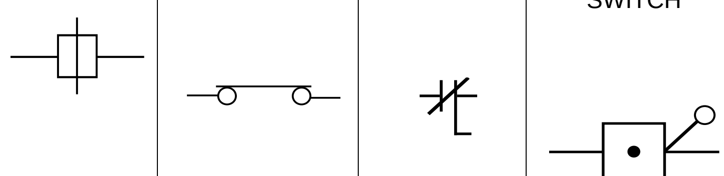
WIRE TAP	
FIELD CONNECTION BETWEEN TERMINALS ON TWO PIECES OF FACTORY WIRED EQUIPMENT	
SAFETY OPERATED SWITCH	

THREE-PHASE DISCONNECT