ELECTRICAL SAFETY REQUIREMENTS FOR IRRIGATION SYSTEMS[1]

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INTRODUCTION

Electrical safety is especially important for irrigation systems. Pumps and other equipment operate in a wet or damp environment. This environment increases the chances of equipment failure if the working parts become damp or wet. Personnel working around or with irrigation equipment often are wet or damp so their susceptibility to electric shock is greater than it would be if they and the environment were dry.

Electrical safety concerns in irrigation are not new. Electric motors have been used to drive irrigation pumps for many years. The National Electrical Code (NEC) has always had electrical safety requirements for motors. These requirements have been followed by many electricians and installers. In the last 25 years, the application of electrical equipment in irrigation has expanded to include more pumps, more controls, and more equipment (such as center pivot machines and chemigation equipment). In addition, the breadth and detail of the NEC increased so it became more difficult to find specifics related to the electrical rules for all of the irrigation equipment.

The need for specific and concise documents for electrical equipment used in irrigation led to the development of electrical standards for irrigation. The Irrigation Association (IA); the ASAE; The Society for Engineering in Agricultural Food and Biological Systems; representatives of the center-pivot/lateral move industry; the U. S. Department of Agricultural, Agricultural Research Service; and Rural Electric power suppliers have all been involved in the development of electrical standards for irrigation.

The first electrical standard developed was "Wiring and Equipment for Electrically Driven or Controlled Irrigation Machines." This standard applies to all wiring and equipment that is on an irrigation machine and is basically the responsibility of the manufacturer but also includes the installer. The installer needs to maintain the integrity and design provided by the manufacturer. This

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standard was first adopted by ASAE in June of 1973 as Standard No. S362. Since then the standard has been slightly revised twice and was adopted by the American National Standards Institute (ANSI) in 1988. It is currently listed as "ANSI/ASAE S362.2 Wiring and Equipment for Electrically Driven or Controlled Irrigation Machines." Through the efforts of IA and ASAE, representatives to the International Standards Organization (ISO), the standard, with some revisions, is now an international standard. The present document is designated 1SO-12374.

Recognizing that electrical inspectors needed rules and guidelines for irrigation machines, a technical subcommittee of the National Electrical Code Committee developed a new article which first appeared in the 1975 edition of the NEC. Article 675 in the NEC is entitled "Electrically Driven or Controlled Irrigation Machines." This article has many parallels to ASAE S362, although there are more specific requirements for cable and for branch circuits. Again, this NEC article applies only to irrigation machines so other sections of the NEC would apply to pump motors, controls, etc.

The second industry-developed electrical standard was ASAE S397, "Electrical Service and Equipment for Irrigation." This standard was developed to apply to all irrigation equipment and provides guidelines for equipment selection, protection, and grounding. The standard has minimal information on control circuits. The standard was first drafted in 1976 and was adopted by ASAE as a tentative standard in 1978 and revised to a full standard in December 1985. It is now listed as ANSI/ASAE S397.2.

Standard S397 was intended to bring to focus the main electrical requirements for complete irrigation systems. As such, it contains references to many sections of the NEC and also to the Canadian Electrical Code. There are unique circuits for each source of three-phase electric power that have been identified for irrigation service. The circuits show the location of grounding circuits, disconnects, fuses, lightning arrestors, power factor correction capacitors, etc.

As chairman and recording secretary for all three committees, which developed ANSI/ASAE S362, NEC article 675 and ANSI/ASAE S397, I was privileged to assemble and record the best efforts of many experts in the fields of electrical wiring, electrical inspection, electrical equipment, power supply, and irrigation and electrical research. These standards reflect the combined input of many fine individuals, companies, and organizations. This paper is dedicated to those individuals, companies, and organizations as I present my recommendations for use of those standards.

There are four major factors that affect the electrical safety of irrigation systems. These factors are: (1) proper equipment selection, (2) electrical protective devices, (3) grounding, and (4) installation. Proper installation maintains the protection obtained by implementation of factors 1, 2, and 3. Each of these factors is discussed in some detail.

PROPER EQUIPMENT SELECTION

Irrigation equipment operates in a wet, often corrosive environment. The enclosures for electrical equipment should always meet at least a NEMA 3R rating (National Electrical Manufacturers Association). This 3R means the equipment is made for outdoor conditions and is rainproof. For rainproof or waterproof ratings, some water may get in an enclosure but the equipment is mounted such that it should still function. Most "pump panels" are of NEMA 3R construction. Pump panels are defined as an enclosure containing a disconnect, short-circuit protection (fuse or circuit breaker), a motor controller, and control equipment.

Many irrigation applications beyond the pump panel require watertight or raintight enclosures for the electrical equipment. Watertight or raintight enclosures are designed to keep water from entering the electrical enclosure. Most watertight enclosures found today are made of fiberglass or plastic derivatives with gasketed and latched covers. When combined with nonmetallic conduit (rigid or flexible) or cable with appropriate fittings, the electrical system is both watertight and corrosion resistant. Keeping electrical equipment dry and free of corrosion reduces the chance of failure so the safety also is improved.

The equipment also must be properly sized in order to serve the intended load. Figure 1 is a schematic of an irrigation installation from the transformer to the motor loads. This general schematic is similar to Figures 1 - 7 in ASAE S397. However, in Figure 1, the circuit components are referenced to a specific section of the NEC. All of the NEC requirements are shown for selecting equipment with adequate rating, sizing conductors, and sizing protective devices. This figure shows a three-phase installation. When the equipment meets the NEC minimums, the first safety requirements have been met.

ELECTRICAL PROTECTIVE DEVICES

The recommended circuit location of short-circuit and overcurrent protective devices is shown in Figure 1 for service from a wye-transformer service. For other services, such as delta and open delta power supply, see Figure 2 in this paper and Figures 2 - 7 in ASAE S397.

Short-Circuit Protection

Every motor circuit must be protected by a properly sized short-circuit device. Short-circuit protection provides quick interruption of large currents, i.e., currents larger than the starting current of the motor. The short-circuit protection is provided by fuses or circuit breakers. Where a choice is available, fuses are recommended over circuit breakers. Because of infrequent operation, circuit breakers may be adversely affected by dust and moisture so that they lose their ability to interrupt the circuit. In some localities, replacement fuses are more readily available than replacement circuit breakers. Dual element fuses should be selected as they can be sized at 150 percent or more of the motor rating and will withstand the motor starting current. The number and location of short-circuit devices are shown in Figure 1 for a three-phase wye circuit. It is important to note that only two fuses are used in a three-phase system when the supply service has a grounded phase conductor (see Figure 2 which is similar to Figures 3, 4, and 7 in ASAE Standard S397.2). Because the grounded phase conductor also carries current, a fuse in that conductor may be opened by a short circuit. In such a case, some of the system remains at line voltage even though the motor has stopped—a very dangerous condition.

For multimotored irrigation machines (center pivots, lateral moves, etc.) the NEC permits several motors on one circuit to be protected by one short-circuit device. However, there are limits. All motors must be 2 hp or less, and no motor can require more than 6 amperes (A) of running current. The short-circuit protection device on such a branch circuit cannot exceed 30 A at 600 volts (V) or less. In addition, each motor shall have individual overcurrent protection, and the taps from the branch circuit to any motor cannot exceed 25 ft in length.

Overcurrent Protection

All motors require a higher current for starting than for normal operation at rated load and speed. To avoid opening the short-circuit protective devices every time the motor starts, the short-circuit devices must be rated at considerably higher current capacity than the full load current. Overcurrent protection, or motor overload protection, on the other hand, must be capable of detecting relatively small overcurrent over a more extended period of time. Thus, most overload protection is provided by a thermal element device selected for a specific value of motor current. When the current exceeds the preset limit, enough heating of the element occurs to activate a switch which opens the motor control circuit. The circuit can be reset manually or automatically. Automatic resetting may cause the motor to again overload and may damage the equipment or start the equipment unexpectedly resulting in a safety hazard. If the overload device has to be reset manually, the need for service or repair is noted. Therefore, manual reset overload devices should be selected except for very few special applications.

Overcurrent protection can be provided by dual element fuses sized at 125 percent of the full-load current of the motor to be protected. For large motors where fuses are costly, it is better to size the fuses for short-circuit protection (usually 150% of the motor hp rating) and let the thermal overcurrent device in the controller provide the overcurrent protection.

The thermal overload device can be part of motor controller (external as in Figure 1), or the device can be inside the motor housing (internal). Internal overload protection devices are common in small motors. Multimotored irrigation machines generally have internal overload protection on each motor. Main pump motor controllers almost always have external overload protection.

Ambient Temperature Compensation

Irrigation motor controllers operate over a wide range of temperatures. Ambient compensated overload elements should be specified to protect the irrigation pump motors. If ambient compensation is not specified, then the standard rating of 40°C thermal elements may be provided. This standard rating means that the overload device will trip at the selected overcurrent when the ambient temperature is 40°C. During hot days, temperatures exceeding 60°C have been measured within outdoor pump panels. Typical responses of ambient compensated overload devices compared to standard overload devices are shown in Figure 3. For ambient temperatures above 40°C, the ambient compensated elements will not trip unless the motor overcurrent exceeds the motor rating by 15 percent. For ambient temperatures above 40°C, the ambient compensated elements will not trip unless the motor overcurrent exceeds the motor rating by 15 percent. The standard requirement for overcurrent protection is 115 percent. However, at 60°C, the non-compensated heaters may "trip" at 90 percent of the normal motor current. When temperatures are less than 40°C, the ambient compensated device will only permit a little more than its standard overcurrent while the noncompensated device may allow 110-125 percent of standard 115 percent overload. This could be 125 to 150 percent the motor rating. Ambient compensation has not been common in the past because applications of the same equipment were in industrial processes where nearly constant operating temperatures were found. In recent years, some manufacturers of irrigation pump panels started providing ambient compensated relays as standard equipment.

Lightning Protection

There is a high probability of lightning damage to electrical irrigation equipment. Lightning or surge arrestors can provide protection from the damaging voltages and currents of nearby lightning and are recommended. The arrestors are installed on the power supply or "line" side of the electrical connections. If disconnects and switches are open, then equipment is not protected from "load side" surges. In practice it may be advisable to also install arrestors on the "load side" to protect from lightning surges that may enter from the irrigation equipment. The basic rule for installing lightning or surge arrestors is to place the first one on the line-side where power is received.

Other arrestors can be placed on either line-side or load-side of equipment depending on the perceived direction of power surges from lightning. Figure 2 shows some suggested locations for lightning arrestors.

Phase Failure

In 3-phase applications, occasionally one phase of the electric supply fails. This failure may be from electrical failure in the irrigation installation or from failure in the power supply system. When this occurs, the irrigation pump motors will continue to run on the remaining two phases. The current is greatly increased in the remaining phases but not enough to operate a short-circuit device. Therefore, motor overload protection must function to protect the motor. In these instances, heat damage to motor windings often occurs before the thermal overload elements have responded, because the overload elements are designed with a delay to prevent nuisance tripping. Protective devices, known as phase-failure relays, can be installed to sense the loss of a phase and open the motor control circuit before motor damage occurs.

Ground-fault Circuit Interrupters

Ground-fault circuit interrupters (GFCI's) are required in many non-irrigation electrical applications. GFCI's open the electrical supply in the event of stray current returning by way of the earth rather than through the electrical circuit. In the wet irrigation environment and with long electric lines to remote motors, there is usually leakage to earth exceeding the standard trip range of GFCI's. Therefore, because of frequent tripping, GFCI's are not currently recommended for use in irrigation installations. The only irrigation application currently recommended for GFCI's is for a 120-volt convenience outlet provided for operation of electrical tools and accessories.

GROUNDING

Electrical systems and circuits are usually connected to "ground." Ground by definition is "a conducting connection whether intentional or accidental between an electrical circuit or equipment and the earth or to some conducting body that serves in place of the earth." Intentional ground examples would be the ground connection at a transformer/meter service or at the electrical service to a pumping plant or building. Accidental ground examples would be an ungrounded circuit conductor contacting a grounded surface by an insulation failure or a broken conductor or connection. These accidental or unplanned faults are often called "ground faults."

In discussing the connection of electrical systems or equipment to ground the terms "grounded" and "grounding" need to be understood. A grounded circuit conductor is an intentionally grounded circuit conductor that carries current during normal operation of electrical systems and equipment. The term "grounded" is past-tense meaning the action has already taken place. Therefore when conductors and equipment are grounded to earth, the system is grounded. A grounding circuit conductor is also an intentionally grounded circuit conductor, but its main function is to carry current during fault conditions. Grounding is a present and ongoing function. Grounding should be continuously present waiting to conduct fault current should the occasion arise.

Grounding is especially important for safety reasons. Proper grounding will limit the risk of: (1) injury to personnel and (2) damage to equipment. Grounding will limit the potential (voltage) difference between equipment and earth and will provide a low impedance path for fault current so enough current can flow to open an overcurrent device (fuse, circuit breaker, or fault detector). For general discussions, grounding can be divided into categories of electrical system grounding and equipment grounding.

Sometimes the term "bonding" is confused with grounding. Bonding is a way of making sure that no open circuits or high resistance circuits occur in the grounding path. Bonding screws, bonding jumpers, welds, and clamps are used to make certain the grounding circuits remain intact to carry enough fault current to open the overcurrent protective device. Therefore, grounding circuits should not have any switches, fuses, etc. in the circuit, and the number of connections should be minimized.

ELECTRICAL SYSTEM GROUNDING

Most rural electrical distribution systems provide electrical service with one circuit conductor that is intentionally grounded in order to limit the potential to earth. This grounded circuit conductor is often called a "neutral" but is more correctly a "grounded circuit conductor." The grounded circuit conductor carries current during normal operation of 120-V loads and will carry any current imbalance in three-phase services. In corner-grounded three-phase motor circuits, the grounded conductor carries the same current as the "hot" conductors. The grounded conductor must be identified by white or gray insulation or markings.

At the service entrance or first service disconnect of an irrigation installation, the "grounded" conductor is again connected to earth by a grounding electrode conductor attached to a grounding electrode. The grounding electrode conductor and grounded conductor are "bonded" together by a jumper or connected at a bus bar in the service panel. These bonding and grounding connections are shown in Figures 1 and 2.

A ground rod driven at least 2.4 m (8 ft) into the earth is commonly used as a grounding electrode. Concrete-encased electrodes, metal buildings where effectively grounded, and ground rings also are acceptable as a grounding electrode system.

EQUIPMENT GROUNDING

The grounding and bonding of noncurrent carrying metallic equipment is equipment grounding. This includes motor housings, controllers, metal boxes, frames, and enclosures for pumps, switches outlets, timers, thermostats, etc. Metallic conduct is not recommended for use in irrigation facilities because of the corrosive environment. A copper equipment grounding conductor must be used for equipment grounding on irrigation machines as specified in NEC Section 675-13. Therefore, an equipment grounding conductor must be included in each cable, cord, or conduit on irrigation machines. I recommend the same grounding methods on all irrigation equipment. If a metal conduit corrodes or the conduit connection comes loose, an equipment grounding conductor maintains the integrity of the grounding circuit. Nonmetallic conduit is more corrosion resistant and is recommended for all irrigation installations.

In addition, NEC Sections 250-51 and 250-91 (c), note that the earth shall not be used as the sole equipment grounding conductor. Therefore, an equipment grounding conductor is needed for every piece of equipment. A ground rod alone is optional but not adequate. The bonding together of grounded and grounding conductors provides the best grounding path.

The grounded and grounding conductors must be kept separate at all points beyond the first service disconnect to assure that the grounding conductor is not current-carrying during normal operation [NEC 250-23 (a)]. Interconnections are often found in irrigation installations. These should be corrected to maintain the grounding safety.

INSTALLATION

Switches and controls should be mounted at a height to permit servicing without kneeling or climbing. Handles for disconnecting switches must not be higher than 6.5 ft or lower than 3 ft above the ground or operator platform. In addition, all switches must be permanently labeled as to their function or use.

A suggested layout of an irrigation control center is shown in Figure 4. Suggested labels for disconnects and recommended mounting heights are shown. The required working clearance in front of the equipment and required burial depth of conductors are detailed. A metal frame is an alternative to the wood frame shown as long as all equipment is securely supported, and the metal frame is grounded. All splices and common grounding can be done in the gutter to keep space in other equipment for control devices.

The installer should be familiar with the need for proper location of equipment and the need to maintain the integrity of enclosures, the continuity of grounds, and properly sized short-circuit and overcurrent protection.

If power factor correction capacitors are installed, the current through the thermal overcurrent devices in a pump panel will be reduced. The rating of the overcurrent devices must be reduced according to the "installed running current" through the device. Figure 5 shows the proper connection of a power factor correction capacitor and some control circuits. Note that the control circuits are fused.

The installer is the final "key link" in properly installing the equipment that the designer and manufacturer has supplied. He/she must be sure that all electrical safety codes have been met.

SUMMARY

The purpose and scope of electrical standards for irrigation have been reviewed and the standards identified. Additional guidelines for equipment selection, size and placement of protective devices, proper grounding, and installation have been discussed. Following these electrical requirements will result in a longer lasting, safer installation. Reprints of the Electrical Standards are available either from the Irrigation Association or from ASAE.

CITED STANDARDS

ANSI/ASAE S362 "Wiring and Equipment for Electrically Driven or Controlled Irrigation Machines." American Society of Agricultural Engineers, 2950 Niles Road, St. Joseph, MI, 49085.

ANSI/ASAE S397 "Electrical Service and Equipment for Irrigation." American Society of Agricultural Engineers, 2950 Niles Road, St. Joseph, MI, 49085.

NFPA 70, 1993 National Electrical Code. National Fire Protection Association, Batterymarch Park, Quincy, MA, 02269.

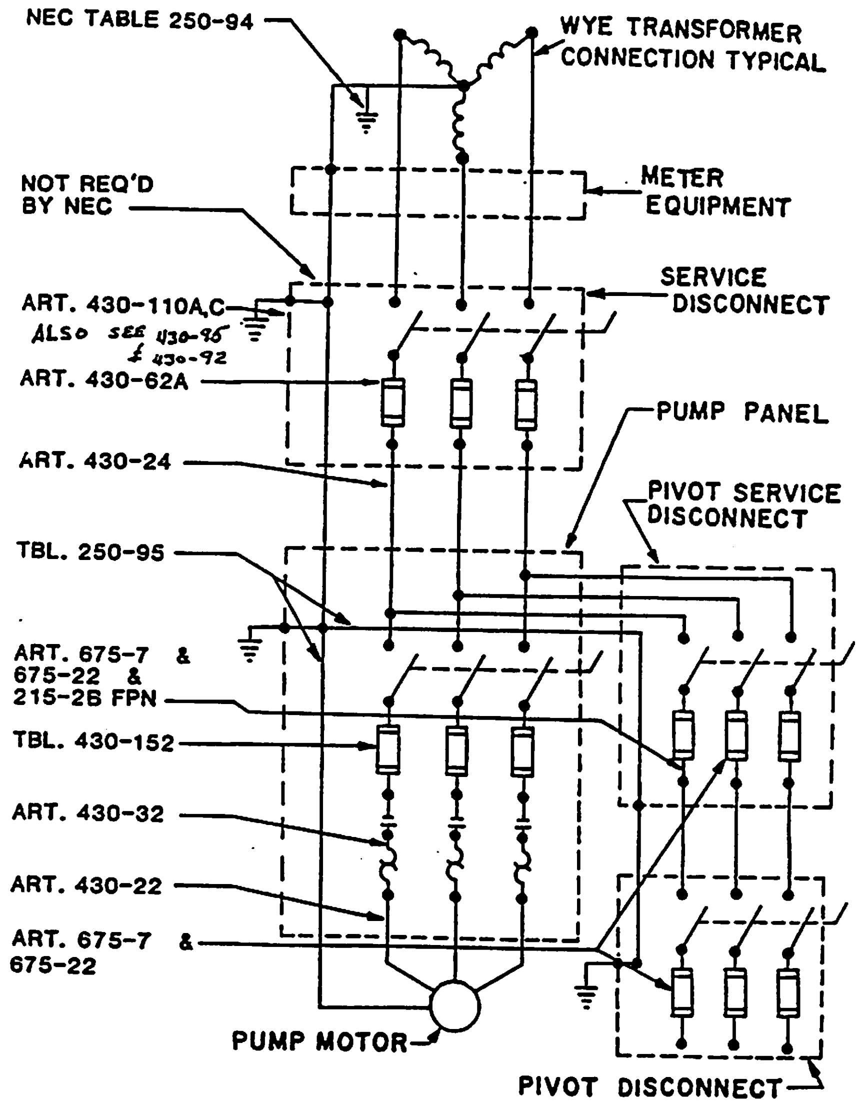

FIGURE 1. Schematic of circuits for an irrigation installation with reference to National Electrical Code (NEC) sections for selection and protection of equipment.

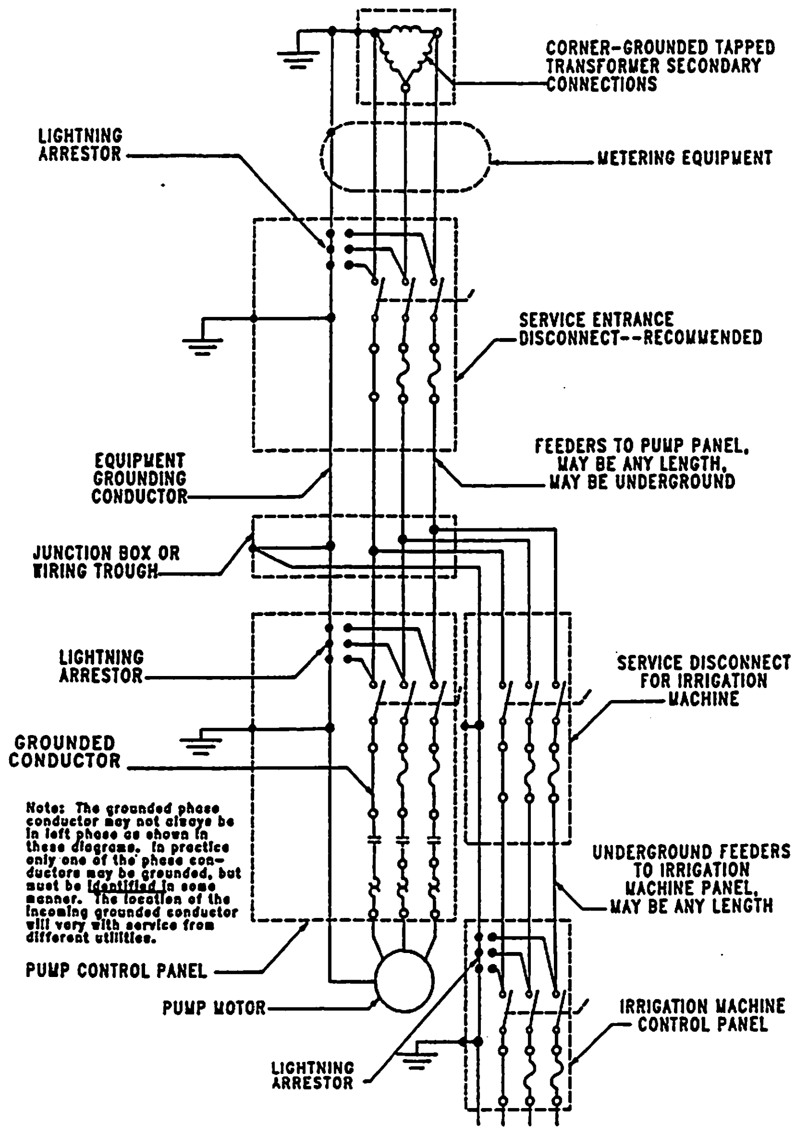

FIGURE 2. Schematic of a corner-grounded supply system for an irrigation installation showing the grounding and fusing for this type of supply.

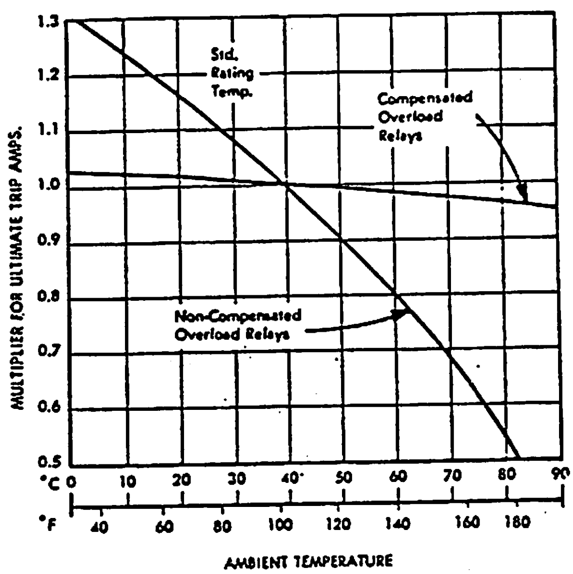

FIGURE 3. Ambient temperature effect on trip amps of ambient and non-ambient compensated overload relays.

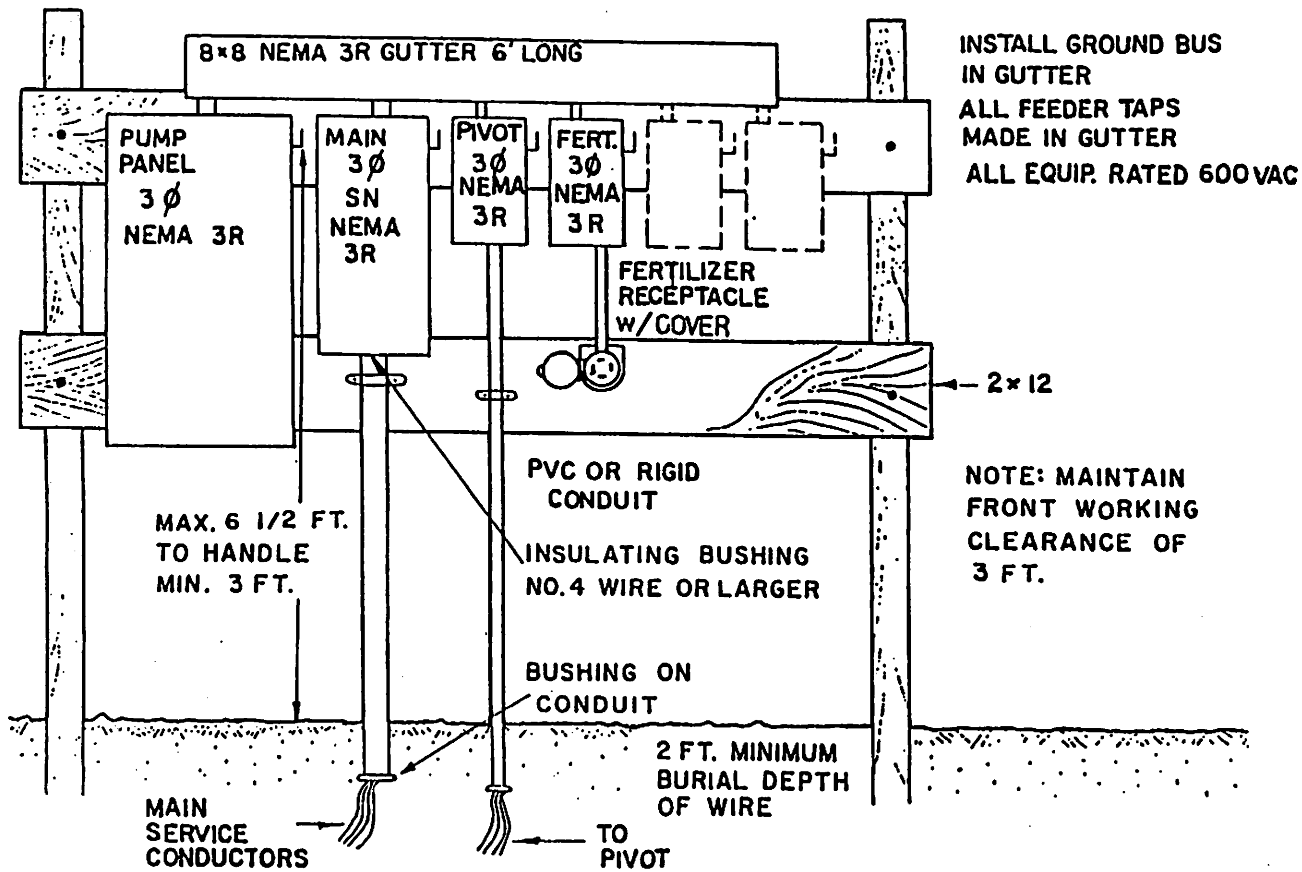

FIGURE 4. Recommended layout of an irrigation installation with notes about clearances and other electrical code requirements.

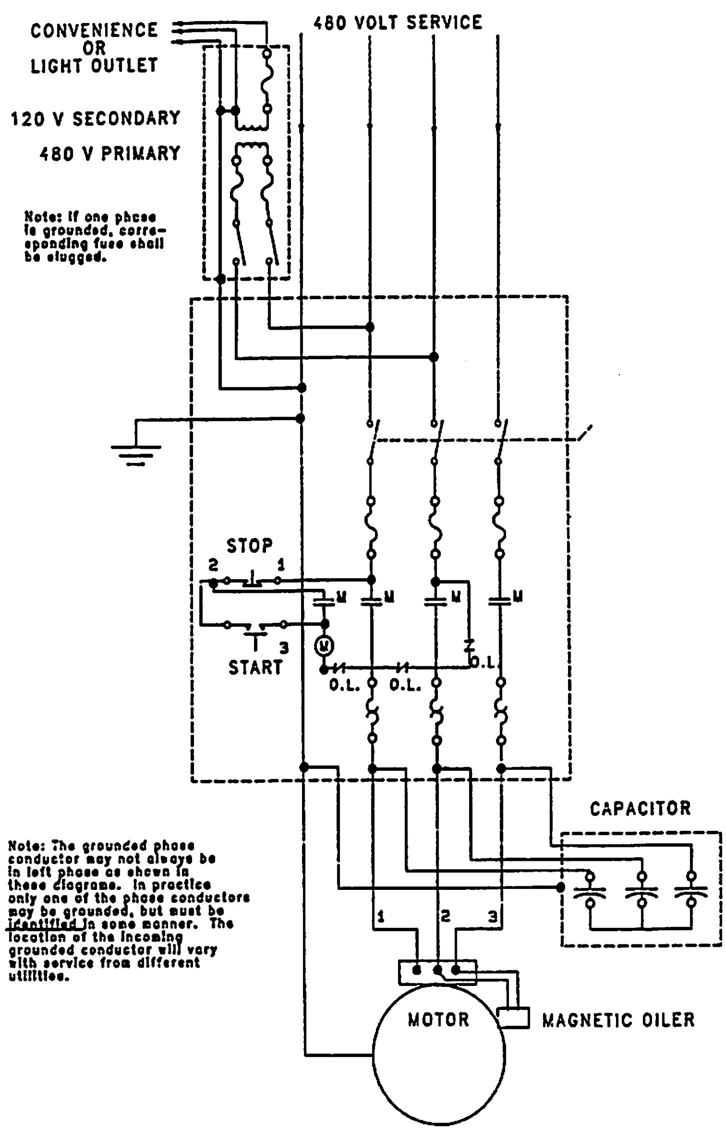

FIGURE 5. **Schematic showing proper connection of power factor correction capacitors and control circuits.**