Design, Selection and Installation of Electrical Wiring and Equipment

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ABSTRACT

Electrical equipment and wiring methods appropriate for the environments found in milking centers are discussed. Proper grounding of systems and equipment and selection of overcurrent devices to facilitate fail-safe electrical systems are presented. Methods to limit voltage drop to 5% from the facility power source to the end-use equipment are offered. There are recommendations for location of equipment and wiring and additional safety switches for protection of equipment and facilitating service. Since many recommendations are general, there are suggested references for further details on wiring and equipment selection.

INTRODUCTION

Proper design, selection, and installation of electrical systems for milking centers are crucial to using electricity safely and efficiently. Inferior wiring and equipment cause hazardous conditions for humans and livestock, and often result in higher insurance premiums, increased maintenance costs and greater risk of fire. The mere fact that an electrical system "works" doesn't mean it's safe or will fail safe.

The standard for electrical work in the United States is the *National Electrical Code*[7] (NEC, National Fire Protection Association 1996). The NEC is a standard for selection and safe installation of equipment and materials. Article 547 in the NEC provides specific requirements for wiring in milking center facilities, or any damp, corrosive environment.

Additional requirements are found in other sections of the NEC. Practices which supplement the requirements of the NEC, reduce maintenance, describe alternatives, and permit expansion, are described in other handbooks (Midwest Plan Service, 1992; National Food and Energy Council, 1993b) and publications (Bodman and Stetson, 1991; Stetson, et al., 1989; National Food and Energy Council, 1993a.)

Milking parlor equipment is washed regularly with chemicals creating a wet and corrosive atmosphere. Corrosive gases, moisture, and dust hasten deterioration of electrical components. Some milking centers have been wired using practices and materials that cannot withstand these conditions. Some have electrical systems which have deteriorated to the point of danger. Wiring methods and materials that minimize this deterioration and maintain electrical safety and equipment function in dairy facilities are described.

ELECTRICAL SERVICE, SINGLE PHASE OR THREE PHASE

With larger dairy complexes and proportionate increases in electrical loads, 120/240 volt (V) single-phase (1^{N}) service may be inadequate or unsuited. When electrical loads in a building exceed 400 amps, or motors of 10 hp and larger will be used, the option of three-phase (3^{N}) electrical service should be investigated.

The advantages of a 3^{N} electric service are reduced costs for wiring and equipment such as motors and controllers, ability to start and operate larger motors, reduced voltage drop and availability of higher system voltages. The disadvantages are the costs to extend 3^{N} over long distances, billing rates that may be more expensive, and availability of local electrical contractors that are familiar with 3^{N} systems.

The local utility must be consulted to determine the availability and cost of 3^{N} power. Once the need, availability, and costs for 3^{N} power have been determined, the next step is to select the appropriate secondary system voltage and configuration. The three most common 3^{N} voltages and configurations are: A) The 120/208 V WYE system serves 3^{N} loads and allows balancing 120 V loads among the three-phases. Care is needed in selecting both 3^{N} and 1^{N} motors that will operate on 208 V, and derating any 240 V heating elements. B) The 120/240 volt DELTA system will operate all 240 V motor loads and 120 V 1^{N} loads, but care is required to avoid connecting 120 V loads to the high voltage or "wild" phase of the system. Proper balancing of the loads is more difficult with this supply. C) The 277/480 volt WYE system offers reduced conductor and motor controller sizes and costs. For a required horsepower rating, the motors are physically smaller. However, dry type transformers are required to operate 120 V loads. This voltage can also be a safety issue with individuals unaccustomed to working with 277 or 480 V.

Determining the most appropriate electrical service to the dairy complex must be a joint effort between the dairyman, power supplier, equipment suppliers, and electrical contractor. Coordination is essential to provide a safe, workable electrical system whether it results in a single phase or three phase supply.

ELECTRICAL SUPPLY SYSTEM

The electrical supply system of a milking center consists of service conductors from the power supply source to the service equipment in the milking center. Service conductors

and service equipment must be large enough to provide electrical capacity for present and future needs. Conductors should be sized to limit voltage drop to 2% or less. The total voltage drop from the meter to any operating equipment should not exceed 5%. Therefore, if each designed segment (service, feeders and branch circuits) is 2% or less the total voltage drop will be near 5%. Use tables in the Agricultural Wiring Handbook (AWH, National Food and Energy Council 1993) for sizing service conductors based on electrical load and distance. Voltage drop exceeding 5% causes dimming of lights, a shortened life of motors, controllers and other equipment. It is also a source of stray voltage.

A minimum sized milking center will require a 100 ampere (A) electrical supply and distribution panel. Supplies and equipment of 200 and 400 A are often needed. When sufficient capacity for a milking center cannot be provided with a single distribution panel, a common practice is to install multiple panels. A main disconnecting means is recommended. This enhances safety in case of an emergency. Each distribution panel is then wired as a subpanel using 4-conductor service. Interconnection of the grounding and neutral conductors at subpanels increases the risk of stray voltage and is a violation of the (NEC 250-23(a) and 250-61). Wiring diagrams for main panels and sub panels showing separation of grounding and neutral (grounded) conductors are in Figure 36 of the Farm Buildings Wiring Handbook (FBWH, Midwest Plan Service, 1992).

Service conductors should enter service equipment through the side or bottom. This keeps condensation in the conduit from dripping onto the panelboard. Use electrician's putty to seal the conduit at each end to minimize the migration--and condensation--of moisture. Numerous corrosion problems have been observed when service conduit enters the top of a service panel and condensation drips onto electrical contacts. In many of these types of installations circuit breakers have corroded and become non-functional. Conduit sealant will help - but side or bottom entry is a better choice.

Locate the service equipment on an interior partition or on the surface of a well insulated exterior wall in the utility room or office. Never recess any panel or electrical box into an outside wall. Inadequate insulation behind the enclosure results in condensation and corrosion.

Provide at least 3 ft of open, accessible work space in front of service equipment and distribution panels from the floor to the ceiling. The door or cover must be capable of being opened a full 90 degrees (NEC 110-16). Where possible, place distribution panels near the larger electrical loads. This will minimize requirements for long runs of larger, more expensive conductors and reduce voltage drop. If the distribution panel must be located in a room subject to frequent washdown, use a moisture-tight nonmetallic enclosure (NEMA 4 or 4X). If the panel is installed in the equipment room be sure that other equipment does not infringe on the 3-foot space needed for safely servicing the panelboard.

Each disconnecting device (e.g., switch, circuit breaker, etc.) must be clearly labeled to indicate its purpose. Select a distribution panel or subpanel with sufficient space for the needed circuits. Each circuit should be protected by a circuit breaker sized to the conductor or circuit load. Fused distribution panelboards are not common, but fused

disconnects for services, feeders and branch circuits are common. Rejection-type holders for cartridge fuses are designed to match the voltage of the fuse to the voltages of the supply and provide short-circuit and overcurrent protection. Edison-base fuse holders used for secondary protection must be adapted to accept type S fuses. This prevents installation of a larger current-rated fuse when a fuse blows. Supplementary protection such as for a fan motor in a SSN fixture should be an Edison-base to allow closing of the cover.

Lightning Surge Arrestors

Equip all service equipment with a lightning arrestor (sometimes called surge arrestor). Mount the arrestor on the exterior of the panel being protected. Provide additional surge or transient voltage protection for sensitive equipment such as computers that control feeders or milkers and other data recorders associated with milk production, breeding, etc. The main arrestor protects the additional surge protector from high voltage spikes.

Grounding

A grounding electrode is required at every service entrance. Rods of 8 ft length (minimum) are commonly used, but the NEC (250-81) does allow other methods. Resistance from the grounding electrode to surrounding soil must be 25 ohms or less (NEC 250-84). If more than one rod must be used to get 25 ohms or less, additional rods should be spaced at least twice the length of the ground rods (e.g., two 8 ft rods should be at least 16 ft apart) and interconnected with a copper conductor and ground rod clamps approved for direct burial.

The grounded service conductor (neutral) is connected to a properly sized grounding electrode conductor to the grounding electrode (NEC 250-53 and Table 250-94) to provide system grounding. (Note: With a 4-wire service, the grounding electrode conductor is attached to the grounding bus not the neutral bus.) The grounding electrode conductor to the grounding electrode must be protected from physical damage and must be continuous. Only nonreversible splices are permitted. Grounded conductors carry current during the normal operation of 115 V equipment. They must have white or gray identification. They also carry fault current from the service equipment to the service transformer because of the bonding to the grounding in the distribution panel (in a single-phase three-wire service.

Grounding conductors should carry current *only* under fault conditions and are commonly referred to as the "grounding" wire. NEC Table 250-95 specifies required grounding conductor size based on circuit overcurrent protection rating. The NEC requires that grounding conductors be bare or be identified with green or green with yellow stripe insulation or marking. All new wiring in dairy complexes must include a copper equipment grounding conductor (NEC 547-8(c)). Equipment such as motors or electrically-heated waterers must be grounded by means of this equipment grounding conductor. Installing a ground rod at such equipment as a substitute for an equipment grounding conductor is not permitted (NEC 250-51), but a ground rod may be installed as a supplement to the grounding conductor. However, the "extra" grounding can result in

undesirable ground current at the waterer. The grounded and grounding conductors are only permitted to be interconnected at the service equipment (NEC 250-23). The FBWH has many circuit diagrams showing the proper connection and separation of the grounded (neutral) and grounding conductors.

To minimize danger from electrical faults, the NEC requires all metallic equipment, e.g. metallic water lines, milklines, gates, flooring materials or grates--including building components, within 8 ft of the floor or soil surface, to be bonded together and to the electrical grounding system. Bonding can be achieved through the branch circuit equipment grounding conductor or other appropriate grounding conductors.

The NEC requires an equipotential plane in agricultural facilities. This practice has been recommended for dairy facility designs for several years. Such an installation reduces the problems of stray voltages in the animal confinement areas and should prevent electrocutions in the event of equipment ground faults. Details of constructing equipotential planes are found in ASAE Engineering Practice EP473 AEquipotential Plane in Animal Containment Areas@ and in ASAE EP342 ASafety for Electrically Heated Livestock Waterers@.

Circuits

Milking centers will require both general purpose and special equipment circuits. General purpose circuits include lights and duplex convenience outlets. Special equipment circuits include those for vacuum pumps, refrigeration units, ventilation fans, heaters, fixed equipment, appliances over 1,500 W, motors exceeding 1/3 hp, and other special purpose outlets such as milk transfer pumps and portable or fixed high pressure washers.

A general purpose circuit should allow 1.5 A per fixture or convenience outlet. Use the actual load value to size circuits that supply such loads as heat lamps, floodlights, and water heaters. Branch circuit conductors with only one motor should be sized for 125% of the motor full load current rating. The motor currents listed in AWH Tables 8 and 9 or NEC Tables 430-147, 430-148 and 430-149 should be used. If more than one motor will be on a circuit, rate the largest motor at 125%, and add the others at 100% of full load current rating. The 1996 NEC changes values for the Design E (energy efficient motors).

Long runs of undersized conductors result in wasted energy and reduced performance of lights and electrical equipment. Each branch and feeder circuit should be sized so voltage drop does not exceed 2%. Size all conductors based on length of run as well as connected load. Relationships between current, circuit length, voltage drop, and conductor size are in detailed Tables in the AWH.

Standby Power

Standby generators reduce the risk of loss and inconvenience associated with power outages. A double throw transfer switch is required at the main farm service entrance or at the milking center so the standby power source is always isolated from incoming power lines. This keeps generated power from feeding back over the supply lines, and eliminates generator damage when utility power is restored.

Precise sizing of a standby power unit can be difficult. For a partial-load system, use the sum of the starting wattage of the largest motor (a Table for motor starting wattages is in Section 33 FBWH), plus the running wattage of all other motors, nameplate wattage of essential equipment, and wattage of essential lights. Especially with a partial-load system, develop a procedure and identify circuits to be used with the standby generator. Post instructions or procedures near the generator. For additional details on the safe use and operation of standby power units, see Section 33 of FBWH, Section 22 of AWH, ASAE EP364, and Benson and Stetson, 1990.

WIRING MATERIALS AND METHODS

Some of the wiring materials required for milking centers may be available only from wholesale electrical supply houses. Use switches and receptacles of specification grade - not those found in many stores. Materials and equipment should bear a label indicating they are listed by Underwriters' Laboratories (UL), or by some other recognized testing agency, e.g., Electrical Testing Laboratories (ETL), Factory Mutual, etc. A suggested list of equipment is included following the references.

All interior wiring should be attached to *interior surfaces* of the building and not concealed within wall cavities, ceilings, or attic spaces. In insulated buildings, surface mounting eliminates the need to make holes in the continuous vapor barrier, thus reducing the migration of moisture into wall or ceiling cavities and attics with resulting condensation. Surface mounting also reduces the risk of rodent damage and facilitates inspection and repair.

Cable and Conduit

Cable is often used rather than conduit, except where subject to physical damage or where multiple circuits are needed. Type UF cable is required (NEC 547-4) because it is moisture resistant and allows use of watertight connectors and fittings at box connections. Do not use Type NM or NM-B cable as these cables are not rated for damp or wet locations.

Rigid nonmetallic conduit offers an effective complement or alternative to Type UF cable, especially where wiring is subject to frequent washdown, physical damage or where conduit may facilitate use of multiconductor circuits. Single conductors rather than cable are used in conduit. Select conductors with a Type W designation such as THWN. Use schedule 40 conduit for general use. Use schedule 80 and other protective methods in areas subject to physical abuse by animals or equipment.

Allow for thermal expansion and contraction in each conduit run. Install at least one 6-in expansion joint per 50 ft of conduit. Expansion couplings (1-in expansion) are available for expansion at boxes or panel boards. Attachment of the conduit must allow movement as temperatures change. Install conduit to minimize entry of dust, water and vapor into enclosures. Where conduit will be simultaneously exposed to different temperatures, such as where it passes through the outside wall of a heated building or between two different rooms, the inside of the conduit must be sealed using electrician's duct sealer. Silicone or similar caulking should not be used as a substitute for duct seal.

Color coding requirements must be followed (NEC 210-5). Except where they are part of a cable assembly, all conductors of No. 6 AWG or smaller must have the correctly colored insulation (NEC 310-12). Phase conductors may be any color except green, gray or white. In a center-tapped DELTA 3-phase supply system, the high voltage phase must be in the center lug of 3-phase equipment and be orange or labeled with orange tape (NEC 215-8).

Use flexible wiring methods for fans and other equipment subject to vibration. Liquidtight, flexible, *nonmetallic* conduit wired with stranded conductors is recommended. Liquidtight flexible metal conduit should not be used as the metal inner core corrodes. Flexible cords with water-and-dust proof strain-relief fittings are also appropriate. Select cords with a wet rating, such as SJW, SJTEW, STW, SOW, SEW.

Electrical nonmetallic-tubing (ENT) is not recommended in dairy complexes because of temperature limitations and snap-on fittings are not watertight. In addition the corrugations of ENT make it difficult to sanitize. Rigid metal conduit is not recommended (except to provide required mechanical protection in very special areas). Use rigid nonmetallic conduit for best corrosion resistance and protect it with posts, beams, etc. rather than use rigid metal conduit.

Boxes and Fixtures

Molded plastic boxes and gasketed covers are necessary on all boxes to protect wire splices, switches, receptacles, and other electrical apparatus from exposure to moisture, corrosive gases and dust. Plastic boxes with pre-punched knockouts are not designed for use in buildings in a dairy complex (NEC 547-4(a)). They are designed for residential and some commercial uses. Metal boxes and fixtures corrode and lead to electrical system failure. Do not use brown Bakelite[7] fixtures as they are not watertight. Cast aluminum boxes in milking center interiors are not recommended, even though they are rated corrosion resistant. Experience has shown cast aluminum boxes deteriorate and delaminate when exposed to the vapors of milking system cleaning chemicals.

Receptacles should be in molded plastic boxes with spring-loaded gasketed covers. Outdoor receptacles in use for extended periods should have a special cover so the outlet is weatherproof when in use (NEC 410-57(b)). Switches must also be protected from moisture, either by means of spring-loaded covers, moisture-tight switch levers, or flexible moisture-tight covers. These covers will accommodate general use switches.

All connections should be water-and-dust-tight. Nonmetallic cable-to-box connectors are available with tapered hub, threads and a neoprene, rubber, or plastic bushing or grommet sized and shaped to fit a range of sizes of cables or cords.

Mount receptacles, switches and thermostats where they will be protected from animals. A rule of thumb is to place boxes and controls at least twice animal height, or at least 4 ft above the floor unless extra protection is provided. Provide 6 to 8 in of wire at each box to facilitate making connections and servicing switches, outlets and other devices.

Lighting

Lighting must be planned to minimize shadows, especially around the cows' udders in the milking parlor. In general, multiple lower wattage fixtures are preferable to fewer higher wattage fixtures, despite higher costs. Incandescent, fluorescent and quartz lights are commonly used in milking parlors. High pressure sodium, quartz and metal halide fixtures are used in high areas or outside areas. Each has different properties of light output, color, and maintenance which might make it more suitable for special tasks. All light fixtures subject to condensation or water cleansing must be watertight and made of corrosion resistant materials (NEC 547-7(c)). Many of the globed, plastic incandescent light fixtures presently sold are only listed as waterproof. Light fixtures in outdoor areas or in some high buildings may only need to resist dust, moisture and corrosion (NEC 547-7(a)).

A heat-resistant globe is required for incandescent lights to cover the light bulb. Temperatures in boxes above some globed fixtures exceed 90EC. Neither Type THHN/THWN conductors nor the conductors in Type UF cable meet these temperature requirements. Some new incandescent globed fixtures are designed to allow wiring with 60EC rated conductors and are rated watertight. Make certain the conductors meet the fixture specifications for temperature rating. Globe-type fixtures with fluorescent bulbs are being used in some installations.

Fluorescent fixtures cost more than incandescent but produce three to four times more light per watt. Lamp life ranges from 7,500 h for short-use cycles to 20,000 h for long-use cycles. Standard fluorescent units do not perform well below 60EC but can be ordered with special ballasts to allow starting under cold conditions. Fluorescent lights are also sensitive to relative humidity higher than 65%. Fixtures with fiberglass enclosures and polycarbonate (Lexan^{7}) covers have been found most serviceable. Fluorescent light fixtures made of ABS plastic and fitted with acrylic diffusers have not provided satisfactory service. Type UF cable and THHN/THWN conductors can be wired into fluorescent fixtures if the conductors are kept away from the ballast.

Quartz lights provide a high intensity light and are more efficient than incandescent lights. Bulb replacement costs are high but bulb life is long (20,000 h or more). Sharp shadowing can be a problem without careful planning. One common application is for cleaning and inspection of bulk milk tanks. Mount the lamps so if a bulb breaks the glass does not fall into the bulk tank. Use PAR type lamps so the outside reflector contains any internal rupture of filaments and shields. Low-bay high-pressure sodium or metal halide fixtures are used in some milking centers. Careful fixture placement is needed to reduce shadowing. Metal halide provides white light and excellent color rendition. Bulbs with good color rendition can be obtained for the high-pressure sodium lamps.

Switching Lights

Multiple fixtures are needed in milking centers to provide adequate lighting and minimize shadows. To reduce neutral current, and stray voltage problems, use a 230 V, 2-pole switch and energize half of the lights from each side of the switch and from each side (phase) of the service.

MOTORS AND CONTROLLERS

Fans, Pumps, Washers, Etc.

Because of dust and corrosion, use only totally-enclosed motors. Open motors are more prone to early failure and more apt to cause fire. All motors should be Farm Duty rated.

With fractional horsepower motors, or when more than one fan is included on a branch circuit, secondary overcurrent and short-circuit protection is necessary. A fused switch or properly sized circuit breaker installed in a corrosion resistant box, and located within 5 to 10 ft of each fan, is recommended for safety during cleaning and maintenance. (The NEC requires a disconnect to be within sight of and within 50 ft of the motor.) Fused switches and special circuit breakers are available to meet both individual fan overcurrent and switching requirements. Size the device at 150% (125% for motors without thermal protection) of the motor full load current rating. For fusing, use a time delay fuse or rejection-type cartridge fuses (also time delay).

Most fans, motors, heaters, and mounted high-pressure washers, should be permanently wired. Try to avoid cord and plug connections. Plugs require receptacle covers to be open continuously, allowing moisture and corrosive gases to enter the wiring system. Permanent wiring maintains the integrity of the watertight electrical system. As an alternative use waterproof plug and receptacle cord assemblies.

Simultaneous operation of multiple 115 V motors to dispense feed can cause appreciable neutral current flow. The voltage drop caused by the neutral current can cause a voltage on grounded equipment within the cow environment. To prevent such problems, use: (a) all 230 V motors or (b) 230 V 2-pole switches with half the 115 V motors controlled by each side of the switch and from each side (phase) of the service.

Several manufacturers use 115 V starting coils in controllers which operate 230 V motors. To comply with NEC requirements regarding separation of grounds and neutrals, these motors and controllers must be served with four conductors. Many installers incorrectly use 3-conductor cables or cords for control panels for milk pumps and milking system components. When internal components such as pulsators, milk pump control circuitry, air injectors, etc. are operated on 115 V, and the grounding and grounded circuits are again connected, the result is current flow over the grounding conductor. An example of a properly wired 4-wire circuit is found in Figure 29 of the FBWH. Use only horsepower-rated contactors to control large motors such as vacuum pumps. Use 230 V milk pump motors to reduce the risk of voltages developing on the grounding system and within the cow environment.

High Pressure Washers

High pressure washers should be hard-wired into junction or switch boxes and should be ground fault circuit interrupter (GFCI) protected. On portable units a GFCI is required as part of the service cord. Even with GFCI protection, an equipment grounding conductor must be part of the wiring system to the washer.

Crowd Gates and Electric Fence Chargers

The electric fence chargers, or equivalent type controller, used on crowd gates must be properly grounded. The grounding terminal should be attached to a separate grounding electrode (rod) located as far as practical from the electrical service ground. A minimum separation distance of 25 ft is recommended. Do not connect the charger output grounding terminal to water lines, stalls, metal pipes or any part of the electrical system grounding network. Electric fence controllers used to energize pasture and lot fences should be located at least 10 ft away from the parlor (or any building), mounted with a disconnect in a weatherproof shelter or enclosure. Installing electric fence controllers inside a building increases the risk of lightning damage and fire.

INSPECTION

Some power suppliers require an inspection before electrical service will be provided. Some insurance companies require inspections, while others offer reduced premium rates for buildings that are inspected and verified as meeting NEC requirements. If inspection is not required, the use of available inspection services is encouraged.

SUMMARY

Appropriate electrical wiring practices are often overlooked when remodeling or constructing dairy facilities. The wet and corrosive conditions in these buildings necessitate particular practices and materials to increase the life of the electrical system and to reduce the likelihood of loss of property, animals, and income, or personal injury caused by electrical failures. Use equipment wiring and installation methods which will assure that the equipment fails safely. Equipment will fail. Provide fail-safe wiring.

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