RECLAMATION
Managing Water in the West

Design Standards No. 4

Electrical Infrastructure – Plants and Switchyards

Chapter 3: Plant Machine-Voltage Equipment
Phase 4 Final

U.S. Department of the Interior
Bureau of Reclamation

December 2015

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Design Standards Signature Sheet

Design Standards No. 4

Electrical Infrastructure–Plants and Switchyards

DS-4(3)-13: Phase 4 Final
December 2015

Chapter 3: Plant Machine-Voltage Equipment

Foreword

Purpose

The Bureau of Reclamation (Reclamation) design standards present technical requirements and processes to enable design professionals to prepare design documents and reports necessary to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. Compliance with these design standards assists in the development and improvement of Reclamation facilities in a way that protects the public's health, safety, and welfare; recognizes needs of all stakeholders; and achieves lasting value and functionality necessary for Reclamation facilities. Responsible designers accomplish this goal through compliance with these design standards and all other applicable technical codes, as well as incorporation of the stakeholders' vision and values, that are then reflected in the constructed facilities.

Application of Design Standards

Reclamation design activities, whether performed by Reclamation or by a non-Reclamation entity, must be performed in accordance with established Reclamation design criteria and standards, and approved national design standards, if applicable. Exceptions to this requirement shall be in accordance with provisions of *Reclamation Manual Policy*, Performing Design and Construction Activities, FAC P03.

In addition to these design standards, designers shall integrate sound engineering judgment, applicable national codes and design standards, site-specific technical considerations, and project-specific considerations to ensure suitable designs are produced that protect the public's investment and safety. Designers shall use the most current edition of national codes and design standards consistent with Reclamation design standards. Reclamation design standards may include exceptions to requirements of national codes and design standards.

Proposed Revisions

Reclamation designers should inform the Technical Service Center, via Reclamation's Design Standards Web site notification procedure, of any recommended updates or changes to Reclamation design standards to meet current and/or improved design practices.

Chapter Signature Sheet
Bureau of Reclamation
Technical Service Center

Design Standards No. 4

Electrical Infrastructure – Plants and Switchyards

Chapter 3: Plant Machine-Voltage Equipment

DS-4(3)-13[1]: Phase 4 Final
December 2015

Chapter 3: Plant Machine-Voltage Equipment is a chapter within Design Standards No. 4 that was substantially rewritten. This chapter contains considerations for the following items associated with hydroelectric power, pumping plants, and pump-generating plants:

- Switchgear
- Electrical bus
- Mechanical interlocks
- High- and medium-voltage breakers
- Disconnect switches
- High-voltage cables
- Fault withstand of electrical equipment

[1] DS-04(3)-13 refers to Design Standards No. 4, chapter 3, revision 13.

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Chapter 3

Plant Machine-Voltage Equipment

3.1 Introduction

3.1.1 Purpose

The purpose *of Design Standards No. 4 – Electrical Infrastructure, Plants and Switchyards*, Chapter 3, "Plant Machine-Voltage Equipment" (DS 4-3) is to briefly explain important concepts pertaining to the electrical infrastructure design of power system equipment for Bureau of Reclamation (Reclamation) hydroelectric powerplants and pumping (electrically operated) and pump-generating plants. This chapter is not intended to be a complete handbook of electrical engineering. Topics that are not discussed in this chapter are listed below, along with recommended references for obtaining that information.

3.1.2 Scope

Reclamation electrical infrastructure designs at plants include various types of plant facilities, with the power equipment arranged therein. These designs are discussed in a general way in this chapter. Topics in this chapter include all major power system equipment located in or at plants, except as follows:

- For discussion of items common to all Reclamation electrical infrastructure, such as basic methods, equipment designations, required drawings, and low-voltage cable and conduit systems, see DS 4 - chapter 1.
- For rotating machinery and ancillary equipment, see DS 4 - chapter 2.
- For power and distribution transformers, see DS 4 - chapter 4.
- For switchyard design, layout, and associated power equipment, see DS 4 - chapter 5.
- For control and station service equipment and systems, including instrument transformers, see DS 4 - chapter 6.
- For electrical grounding information, see DS 4 - chapter 9.

This version of DS 4-3 completely replaces all previous versions. However, for historical purposes, the 1984 version of this chapter is included on the Technical Service Center (TSC) design standards archive Web page: http://www.usbr.gov/tsc/techreferences/designstandards-datacollectionguides/designstandards.html.

3.1.3 Concepts and Definitions

The following concepts and definitions may be of particular interest to Reclamation electrical designers. Refer to the various industry standards (referenced below) for any terms and definitions that are not listed.

Equipment designation: A coordinated system of identifying letters and/or numbers used for Reclamation electrical power equipment identification.

Generator step-up unit (GSU): A unit power transformer used for stepping up the generator machine-voltage to transmission voltage.

Generating unit: The combined system of the generator (stator-rotor), shaft, turbine, and wicket gates.

Metal-enclosed bus: A grouping of rigid bars (aluminum or copper), either insulated or uninsulated, supported by insulators in a metal enclosure that is at earth potential.

Powerplant: A hydrofacility designed to generate electricity; hence, a hydroelectric facility.

Pumping plant: A facility with electrically driven pumping units. Pumping plants that are hydraulically driven are not discussed in this chapter.

Pump-generator plant: A facility with units that can be operated as generators or pumps (motors). These units are provided with phase reversal switches that usually interchange the A and C phases to reverse the unit rotation. This allows the unit to have both generation and pumping capabilities.

Power equipment/systems: Equipment and systems intended for the transmission, transformation, and switching of electrical energy.

Power frequency: All Reclamation alternating-current (AC) electrical systems operate at 60 cycles per second, or hertz (Hz), which is referred to as the power frequency. Thus, all equipment must be specified to operate at this frequency.

Switch operating number: The coordinated system of identifying numbers for Reclamation power switching equipment. Refer to DS 4 - chapter 1 for procedures on developing the numbers. Briefly, the numbers indicate the following:

- **First number.–**Sequential circuit number up to two digits
- **Second number.–**Circuit voltage range
- **Last number.–**Even number indicates an interrupting device; odd number indicates disconnecting device; zero (0) indicates ground switch

Unit: Unit refers to a rotating machine (generator or motor). An adjective that describes the purpose of certain machine-supporting equipment, such as 'unit' switchgear, 'unit' transformer, etc.

Voltages: Various types of voltages are described below:

- **High voltage (HV).–**Typically refers to a specific voltage class of power equipment in the range of 69 kilovolts (kV) to 230 kV.
- **Machine voltage.–**Equipment that is rated at the same voltage as the generator or pump unit (machine).
- **Medium voltage (MV).–**A specific voltage class of power equipment in the range of 2.4 kV to 46 kV; some entities include 69 kV in this range.
- **Low voltage (LV).–**Voltage levels below 1,000 volts (V).

3.1.4 Units of Weights and Measurements

Policy on use of weights and measurements for electrical infrastructure generally adheres to Reclamation policy (U.S. Customary Units [USC]), except as follows:

- **Celsius temperature scale.—**Electrical machines and associated power equipment are designed and specified based on the Celsius temperature scale. This is the standard for gage manufacturers and industry standards.
- **Dimensions and weights.—**The International System of Units (SI) (millimeter [mm], centimeter [cm], meter [m], kilogram [kg]) should be placed in parentheses next to USC units on electrical equipment drawings used in specifications. This is the industry standard for electrical power equipment manufacturers. Note: design clearances are rounded up to the

nearest deca millimeter (for example, 8 feet 6 inches becomes 2,600 mm, instead of 2,591 mm).

3.1.5 Codes, Standards, and References

Reclamation electrical infrastructure designs and specifications for plant power equipment predominantly follow the requirements and guidelines of the following industry/professional standards, including any amendments, as well as applicable Reclamation (e.g., Reclamation's latest version of *Safety and Health Standards* [RSHS], *Facility Instructions, Standards, and Techniques* [FIST], *Power Equipment Bulletins* [PEB]) and Federal codes and standards:

- American National Standards Institute (ANSI)
- Association of Edison Illuminating Companies (AEIC)
- ASTM International (ASTM)
- Institute of Electrical and Electronics Engineers (IEEE®)
- InterNational Electrical Testing Association (NETA)
- National Electrical Manufacturer's Association (NEMA)
- National Fire Protection Association (NFPA)
- Underwriter's Laboratory (UL)
- International Electrotechnical Commission (IEC)

Existing facility systems or apparatus should be brought up to relevant code standards at the time of refurbishment, change out, or for a compelling safety issue.

Two companion reference books for electrical power systems are *the Standard Handbook for Electrical Engineers*, published by McGraw-Hill Book Company, and *Electric Power Engineering: Reference and Applications Handbook*, by C.J. Agrawal.

Reclamation Guide Form Specifications for Equipment include design and construction requirements that are/may not be discussed in this design standards chapter; thus, for more information, consult TSC Engineering and Laboratory Services Division, Specifications Group. Guide form specifications are not available to the general public.

Reclamation Standard Drawings is referenced in this chapter. Internal Reclamation users should obtain copies from the latest electronic, online drawings management system. All others should contact Reclamation's Regional Public Affairs Office.

3.2 Layout and General Considerations

3.2.1 Layout, Arrangement, and Location of Equipment

The layout, arrangement, and location of power system equipment in plants are based on many factors including the power system design (based on the facility switching diagram); structural considerations, site conditions (e.g., environmental, physical space); and the client's requirements. These elements, combined together, determine the number of units, bus type, switchgear, transformers, etc. Some components may be located outdoors, such as the unit switchgear and station service distribution transformers. Power transformers are typically located outdoors.

See DS 4 - chapter 1 for further discussion regarding power system design, layout, and arrangement of plant power system equipment.

3.2.2 Arc-Flash Considerations

The hazards associated with switching and interrupting equipment failure must be considered in the design and location of this equipment. Various methods of managing arc-flash can be found in FIST 5-14, Arc Flash Hazard Program, but primarily involve relaying, remote operation with rack-in/rack-out circuit breakers, arc-flash resistant switchgear, and/or locating equipment in dedicated rooms or outdoors. The electrical plant designer(s) should consult with the TSC power systems engineer(s) and the purchasing office to determine which method or methods will be used. Note: Any switchgear specified to be arc resistant shall be in accordance with IEEE® C37.20.7. The designer and owner should consider and dictate the arc-resistant type in the specifications.

The location of personnel during operations and racking of switches, breakers, and motor starters/contactors shall be considered during design:

- **Switches.—**If required, switches can be specified as a motor operated switch or be provided with a remote operation device.

- **Breakers and motor starters/contactors.—**The installation should allow for operation of these devices outside of the arc flash boundary. This can be accomplished by providing remote closing and tripping capabilities from a control room or by using a remote pendant device. The remote controls should be located outside the arc flash boundary.

- **Breaker racking.—**For rack in/out breakers, remote racking devices should be provided to allow the operator to be outside the arc flash boundary during this process.

- Motor control centers (MCC).—If required, 480V MCC buckets can be provided with means to withdraw the buckets from a remote location.

3.2.3 Clearances

Electrical clearances shall be maintained for outdoor equipment with exposed components above 1,000 V (i.e., bushings, insulators). Refer to DS 4 - chapter 5 for the requirements. The same requirements also exist for any indoor, exposed, live components, including metal-enclosed cabinets and switchgear.

Clearances for personnel and working space shall be maintained. This includes space considerations to properly gain access and to remove components from equipment such as drawout breakers. These regulations are specified by the Government standards (RSHS, Occupational Safety and Health Administration [OSHA]), and by industry standards (National Electrical Safety Code [NESC®]), and they are further discussed in DS 4 - chapter 5.

3.2.4 Equipment Identification

All power equipment (except metal-enclosed bus) shall receive unique equipment identification designations. In addition, power-switching equipment receives switch-operating numbers. Refer to DS 4 - chapter 1 for detailed descriptions and procedures.

3.2.5 Equipment Recommendations

The TSC power systems engineers should develop ratings for power equipment and protective relay recommendations, including instrument transformers. These recommendations will vary, depending on the powerplant and its location within the bulk electric system.

3.2.6 Factory Testing and Inspections

All power equipment should be factory tested by the manufacturer. These may include design and production/routine tests. Factory design tests on identical equipment are allowed to meet the design test requirements; however, if factory design tests are not available, are outdated, or the equipment is not identical, the contract should require actual design tests.

Factory inspections and test witnessing by Reclamation staff are generally required for major electrical equipment. Early in the design process, discussions should be held between the TSC and the owner regarding factory inspections and test witnessing. On multiple unit contracts, consult with the client regarding the number of inspection trips that are required for each type of equipment.

3.2.7 Field Acceptance Testing

Field acceptance testing of electrical power equipment typically follows the procedures and tests outlined in FIST manuals, IEEE® standards, and NETA acceptance testing specifications (ATS) (an ANSI approved standard). The Engineer of Record is responsible for determining which tests should be performed for each piece of equipment based on design standards, project specific requirements, and engineering judgment.

3.2.8 Hazardous Materials

The following hazardous materials may exist in/on power equipment in older installations and shall be properly identified and addressed in any construction contract. Consult the TSC Materials and Corrosion Laboratory or regional safety office for requirements:

- Polychlorinated biphenyl (PCB)—transformer and circuit breaker oil, including bushings, and possibly surrounding soil
- Lead and other heavy metals (RCRA 8) in paint/coatings
- Asbestos conduit (with trade name ‘Transite’), and asbestos in switchgear circuit breakers, wire insulation, and cable tray liners
- Sulfur hexafluoride (SF_6) gas toxic byproducts (circuit breakers, switches, and connecting bus)

3.2.9 Power Service

For small to medium sized pumping plants, incoming power is provided by a unit substation with high-voltage switching and step-down transformer. Smaller facilities are generally powered by a pole-mounted transformer (e.g., 300-kilovolt amperes [kVA] or less), which is generally provided by the utility. The unit substation can be located in the plant, switchyard, on a plant deck, or adjacent to an outdoor-type motor control board to form a continuous lineup. If it is located separately from the motor control board, the connection to the motor control equipment (MCE) may be either bus or insulated cable. See DS 4 - chapter 5 for more detailed discussion of unit substations.

For large pumping plants and all power and pump-generator plants, incoming/ outgoing power is provided by power transformers located either on the plant deck or in a switchyard.

3.2.10 Seismic Performance

For seismic performance requirements, see DS 9 - chapter 13. Electrical equipment discussed in this chapter requires seismic considerations including metal-enclosed bus and switchgear.

In addition, IEEE® 693, provides guidance on seismic design for transformers and other electrical equipment within plant structures, as well as within switchyards.

3.2.11 Service Conditions

Designer(s) specifying power equipment should be familiar with the industry rated service conditions for each piece of equipment, as stated in the referenced industry standards. The industry refers to these as the ‘usual’ and ‘unusual’ service conditions. These conditions typically include ambient temperatures, altitude, and atmospheric conditions (humidity, pollution, salt, etc.). The first two items are of primary concern because many installations are considered ‘unusual’ service conditions (e.g., either at higher elevations or in hot climates or locations). Therefore, the designer(s) must review the industry standard’s service conditions for each piece of equipment for details. See the list of applicable standards at the end of this chapter.

Any ‘unusual’ equipment service conditions shall be clearly stated in any equipment specifications. Unusual conditions would be any condition that is more extreme than the industry standard ‘usual’ conditions. It is also suggested that equipment manufacturers be consulted prior to issuing any specifications dictating ‘unusual’ conditions.

Note that most equipment standards consider earthquake occurrence as an ‘unusual’ service condition; thus, as stated in the discussion above regarding seismic performance, every equipment specification shall include the site seismic qualification level.

3.2.12 Finishes

All housing surfaces shall be painted, except stainless steel. External and internal surfaces are coated with at least one coat of corrosion resisting paint. Most manufacturers prefer the color ANSI gray No. 61 for exterior surfaces and white for interior surfaces. Other special colors may be requested depending on any specific décor that may be required for the installation.

3.2.13 Terminations

Never make solid conductor connections from bus bar/tube to another solid piece of equipment. The designer(s) shall allow for temperature expansion, contraction for materials used, and vibrations caused by equipment such as breakers, motors, and generators. Therefore, flexible or slip connectors must be used when making a connection to terminals on switchgear, generator, motor, transformer, etc. If flexible or slip connectors are not used, there is potential for damaging or destroying equipment such as bushings, bus, etc. Bus manufacturers typically design the bus with expansion and contraction joint, as necessary, depending on length, number of bends, or transitions in the bus. Ampacity of any flex connecter should not be less than the rated continuous current of the bus conductor.

3.3. Machine-Voltage Bus

3.3.1 General

Machine-voltage bus may consist of:

- An assembly of flexible insulated power cables, referred to as generator or motor leads, including their supporting structures, end connections, and terminations.

- An assembly of rigid conductors with associated connections, joints, and insulating supports within an overall grounded nonferrous metal enclosure, referred to as metal-enclosed bus, of which there are four construction types. The assembly may include noninsulated, flexible, braided links.

- A system that is a combination of the above two types (i.e., flexible insulated conductors rigidly mounted and supported within a metal enclosure), referred to as a cable bus.

3.3.2 Rigid Bus Description, Selection, and Application

3.3.2.1 General

A rigid bus should be classified according to current-carrying capacity as a heavy current-carrying capacity bus with a rating of 3,000 amperes (A) or more, or light and medium current-carrying capacity bus with ratings of less than 3,000 A. Rigid bus conductors may be either of copper or aluminum.

In outdoor or high humidity installations, rigid bus should be specified with space heaters. The heaters help prevent condensation buildup in the housing.

Rigid bus is further classified as to type of construction, which is discussed below.

3.3.2.2 Nonsegregated-Phase Bus

A nonsegregated-phase bus is a rigid bus assembly with phase conductors supported inside a common nonferrous metal enclosure without barriers between the phases. This bus is typically provided with prefabricated lengths and manufactured fittings for corners and turns. The enclosure is typically provided with removable covers.

This bus is available for either indoor or outdoor installation. The construction is intended specifically for use with metal-clad switchgear. The bus typically has momentary current, insulation, and temperature rise ratings equal to the associated metal-clad switchgear equipment. The bus structure may be conveniently terminated with a housing throat for connection to flanges on either power transformers or generators. The housing construction is mechanically coordinated with that of metal-clad switchgear to ensure convenient connection to this type of equipment. The nonsegregated-phase bus is available at voltage ratings from 600 V to 38 kV and current ratings from 600 A to approximately 5,000 A. However, at current ratings 4,000 A and above, the nonsegregated-phase bus loses the advantages of being coordinated mechanically and electrically with the associated switchgear.

3.3.2.3 Segregated-Phase Bus

A segregated-phase bus is a rigid bus assembly with phase conductors supported inside a common nonferrous metal enclosure. They are segregated by metal barriers between phases and are generally preferred for use in medium-voltage (MV) systems with continuous current ratings greater than 3,000 A. This type of bus is also used in large generating and pumping plants to connect a static exciter to its associated machine terminals.

3.3.2.4 Isolated-Phase Bus

An isolated-phase bus is a rigid bus assembly that has each phase conductor supported and enclosed by an individual nonferrous metal housing separated from adjacent conductor housings by an air space. An isolated-phase bus may be either self-cooled or provided with forced-cooled provisions, which circulate air through the bus and an associated heat exchanger. This type of bus may be custom built where it is necessary to make modifications to an existing bus at older plants.

The isolated-phase bus is designed for use on circuits with an importance that requires the utmost in reliability and complete freedom from any elements that might result in phase-to-phase faults. The isolated-phase bus is available in maximum voltage ratings of 15.5, 27, and 38 kV, with continuous current ratings up to 24,000 A; however, higher currents may be achievable. The use of an isolated-phase type bus should be considered for current ratings greater than 4,000 A.

At large current ratings, when the size required for self-cooled designs becomes too large to be economical, forced-air cooling is available to reduce dimensions and weights to reasonable limits. Moving air is channeled down the bus between the housing and the conductor, and the accumulated heat is removed by air-to-water heat exchangers. The size of housings and conductors for an isolated-phase bus is largely determined by the current rating, the maximum allowable temperature rise, and the prevailing ambient temperatures; therefore, it is not practical to establish current ratings that would necessitate a change from self-cooled to forced-cooled bus.

The modern isolated-phase bus is provided with cylindrical aluminum housing over each phase and is electrically continuous, welded construction. Older installations may include ‘noncontinuous’ enclosures which are flanged and bolted. This design is no longer used. Refer to various industry and manufacturer’s information for further information.

All conductors are of high-conductivity aluminum or copper positioned in the center of the housing. The conductor is supported inside the metal enclosure with disc or post insulators. Generally, low-current bus ratings use single-channel conductors. Cylindrical conductors are used for the higher current ratings. It is important to note that copper conductors cannot be welded in the field; therefore, the metal enclosure must come in bolted sections. For outdoor installations, additional maintenance will be required on bolted sections of bus enclosures.

3.3.2.5 Busway

A busway is a type of nonsegregated-phase bus consisting of sectionalized, prefabricated bus bars that are rated 600 V or less. Its main use is in small pumping plants as a power connection between the transformer and the MCC.

3.3.3 Cable Bus Description, Selection, and Application

3.3.3.1 General

A cable bus is a power cable bus assembly that has insulated power cables arranged and spaced with a support block assembly within a common metal bus housing enclosure to provide the desired bus ampacity. Power cable conductors can consist of one conductor per phase up to six conductors per phase, with all cables separated and spaced equally apart with nonmagnetic support blocks. The cable blocks and support brackets are located every several feet along the cable bus length to provide support and the required short-circuit strength. The cable bus assembly does not have a barrier between the phases.

Cable bus conductors are insulated power cables that may be either copper or aluminum. See other sections in this chapter for a more detailed discussion on medium-voltage power cables.

3.3.3.2 Bus Construction

A cable bus typically is provided in off-the-shelf sizes for different desired circuit ampacities and can be configured so that continuous lengths of cables can be installed in the field from source to load. The enclosures come with prefabricated lengths and fittings for corners and turns, and they can be modified in the field to match up with installed equipment. The enclosure is typically fabricated with extruded aluminum side members and formed top aluminum covers that are removable.

3.3.3.3 Classification and Standard Ratings

A cable bus is classified according to voltage level and current-carrying capacity. Typical voltage ratings are 600 V, 5 kV, 15 kV, and 35 kV. Continuous current ratings are from 400 A to 8,000 A.

3.3.3.4 Types

The cable bus is available for either indoor or outdoor installation and typically has louvered side members for ventilation. It should be noted that nonventilated cable bus designs could be supplied, but the current-carrying capacity of this design is approximately 60 percent of the capacity of the same cables in a standard ventilated design. The construction is intended specifically for use with metal-clad switchgear, and the bus has momentary current, insulation, and temperature rise ratings that are equal to the associated metal-clad switchgear equipment. The bus enclosure may be conveniently terminated with a housing throat for connection to flanges on power transformers, generators, or motors with the insulated cable continuing inside of equipment for final termination. The housing construction should be mechanically coordinated with that of metal-clad switchgear to ensure appropriate connection to this type of equipment.

3.3.3.5 Use Considerations

Rigid bus typically starts at 1,200 A or above; therefore, it may be advantageous to consider cable bus at the lower current ratings, between 400 to 800 A, due to ease of construction and cost effectiveness over rigid bus. These low current applications of cable bus may be for motors, small generators, or transformers.

At current levels of 2,000 A or above, the cable bus should have multiple parallels (three or more per phase) that require special interface considerations at the terminating equipment.

In general, once bus ampacities exceed 1,200 A, then nonsegregated, segregated, or isolated-phase bus should be considered over cable bus.

The cable bus has more flexibility during installation because field adjustments can easily be made onsite versus rigid bus that needs to be manufactured with exact dimensions.

3.3.4 Miscellaneous Considerations

3.3.4.1 Inductive Heating Considerations

To prevent undue heating of magnetic structural members, which are situated near heavy current rigid bus, it is necessary to take special precautions at these locations. Bus structures that have a single housing for all three conductors provide their own shielding if the housing material is of high conductivity and sufficiently thick. In these cases, additional shielding is not required. Bus structures having individual housings for each conductor may create a magnetic condition that could easily cause undesirable temperature rise in the nearby magnetic steel members. For many years, this condition was remedied by providing various shielding devices near isolated-phase bus at those points where excessive heating would occur. If a large area was to be shielded (e.g., an area of reinforcing concrete rods), it was common practice either to use adequate areas of high-conductivity sheet metal or to arrange a grid that could be considered as a secondary circuit with respect to the main bus. The material used for such a circuit must be highly conductive. Steel members of the bus structure running perpendicular to the direction of the main conductors were protected by loops or rings of high-conductivity material surrounding them. These loops were continuous electrically and of low resistance, located on the steel to be protected, and located immediately below each conductor. In operation, each ring acts as a short-circuited secondary of a transformer, where the primary is the bus itself. By the demagnetizing effect of the current induced in the rings, the flux density in the steel is reduced to a value corresponding to low temperature rise. Beams or columns running parallel with the conductors should be protected by high conductivity sheets of ample thickness or by grids of high-conductivity material similar to those referred to as protective means for reinforcing bars.

The significant improvement in bus design was made by developing electrically continuous housings that are arranged so that the magnetic field, external to the bus, is reduced to 5 or 10 percent of its original values. In this type of bus design, the enclosures are welded together to form a completely welded installation that provides water and dust tightness, permits bus pressurization to prevent unwanted condensation, and is easy to install. The principle used to minimize the magnetic field surrounding the isolated-phase bus by electrically continuous enclosures is not new. The principle is based on well-established physical laws. With a given current flowing in one direction in a conductor, and in the opposite direction in its enclosing sheath, no flux external to the sheath or enclosure will result. Because the isolated-phase bus with completely welded enclosures restricts the access to the conductors and the insulators, its acceptance has been somewhat contingent upon an essentially maintenance-free bus design. Many years of operating experience throughout the industry have shown that bus insulator failures are almost nonexistent. Using modern welding techniques, it is now practical to fabricate maintenance-free welded electrical joints in aluminum conductors, made either in the factory or in the field, to eliminate all bolted electrical joints so that the powerplant designer(s) can now confidently specify isolated-phase bus with completely welded housings.

3.3.4.2 Structures

The bus manufacturer typically determines support structure location; however, the TSC Civil/Structural (C/S) engineers should be consulted for best locations and any other issues, such as building joints and safety.

3.3.5 Ratings, Specifications, and Standards

3.3.5.1 Ratings

Equipment recommendations for machine-voltage bus should be provided by the TSC power systems engineer(s) and follow the applicable IEEE® preferred ratings. The designer(s) should refer to industry standard IEEE® C37.23 for a discussion of the various required ratings and their importance.

3.3.5.2 Specifications

The TSC electrical designer(s) have developed guide form specifications for various types of bus (previously discussed) and they are presently titled as follows:

- 15-Kilovolt Non-Segregated-Phase Bus
- 600-V Busway
- Isolated-Phase Bus
- Generator Cable Bus

3.3.5.3 Contracting Considerations

When a generator voltage bus with rigid conductors is required, it is common practice to contract for the complete structure, including conductors, mountings, external supports, enclosures, and taps. The designer may also consider in the same contract the replacement of housings for potential transformers, surge arresters, capacitors, grounding switches, disconnecting switches, and any other accessory electrical equipment connected to the bus. Guide specifications are written on a performance basis and shall require the contractor to provide equipment that will carry the required rated current within specified temperature limits, as well as short-circuit current withstand ratings. The manufacturer is to provide shielding, as necessary, to keep the temperature rise of magnetic materials near the bus from exceeding specified limits; and the limits must be specified. Bus layout shall be coordinated with other equipment that the bus will be connected to, in order to provide convenient and rapid assembly of the equipment at the jobsite. The contractor may be required to furnish the services of an erecting engineer to supervise the installation of the bus and associated equipment.

3.3.5.4 Standards

The following standard should be consulted and followed in the course of working on metal-enclosed bus:

- IEEE® C37.23, Standard for Metal Enclosed Bus

For cable bus, in addition to IEEE® C37.23, all the cable standards discussed elsewhere in this chapter also apply, in addition to the particular requirements in the National Electrical Code (NEC) and the applicable requirements of NEMA VE 1, Metal Cable Tray Systems, and NEMA VE 2, Cable Tray Installation Guidelines.

For busways, presently, there are three standards of interest:

- NEMA BU 1.1, Instructions for Handling, Installation, Operation, and Maintenance of Busways Rated 600 Volts or Less
- NEMA BU 1.2, Application Information for Busway Rated 600 V or Less
- UL 857, Busways

3.4 Machine-Voltage Switchgear

3.4.1 General

Switching and short-circuit protection for machines and associated bus is provided by machine-voltage switchgear. The switchgear consists of metal-enclosed structures containing power circuit breakers or motor controllers, disconnecting switches, grounding switches, instrument transformers, bus, and associated connections in a compact assembly. This type of switchgear occupies a minimum amount of space and provides maximum safety, accessibility, convenience, and interchangeability. This type of equipment is also provided in different styles, as follows:

- Metal-clad switchgear uses withdrawal-type circuit breakers.
- Station-type switchgear uses stationary, nonwithdrawal type circuit breakers.
- MCE switchgear uses motor controllers for MV motors (2,300 V to 7,200 V).
- MCC use motor controllers for LV motors (600 V or less).

Metal-clad switchgear and station-type switchgear are used at powerplants, large pumping plants (motors above 7,200 V), and pump-generator plants. At small or medium-sized pumping plants (motors at 7,200 V or less), the induction motors are started and protected by ‘motor controllers.’ The switches and bus mentioned as part of switchgear are discussed in detail in other sections below. Instrument transformers may also be in the switchgear and are used for control, protection, and/or metering, are discussed in DS 4 - chapter 6.

Switchgear may also be used outdoors, particularly in switchyards. Refer to DS 4 - chapter 5 for discussions related to outdoor yard installations.

3.4.2 Metal-Clad Switchgear

This switchgear includes removable or withdrawal-type circuit breakers and associated equipment; however, this gear typically does not use disconnect switches for isolation of circuit breakers or bus. If they are provided, they usually are for station service feeders or other local services. The circuit breaker may be designed to be installed and withdrawn in several methods. The most common methods are: (1) simple rack-in and connection, and (2) a slightly more complicated version is racked in and lifted inside the gear for connection to the bus. The gear is provided with a mechanism to transition the unit between the ‘connected’ and ‘disconnected’ positions within the gear; then, once in the 'disconnected' position, the unit may be rolled out of the switchgear cubicle for maintenance and moved around via use of a pallet jack, manufacturer provided truck, or other means of moving the breaker.

The breakers are equipped with self-aligning and self-coupling primary bus contacts and secondary disconnects. Today, the type of breaker used is a vacuum interrupting type; however, in the past, air-blast units were used, and a few may still exist at some Reclamation plants.

Primary bus conductors and connections in metal-clad switchgear are covered with appropriate insulating material. Mechanical interlocks are provided to ensure a proper and safe operating sequence of circuit-interrupting devices, isolating devices (disconnecting switches), and any ground switches on the bus. Typical mechanical interlocks use the key interlock system (i.e., Kirk Key or similar system), which sequences the operation of the breakers, disconnect switches, and ground switches. Typically, the sequences ensure that the breakers are opened first, the disconnect switches are opened second, and, once the system is deenergized, the ground switch can be closed. The mechanical interlocking scheme shall be designed properly to ensure that the ground switch cannot be closed if the system is energized (e.g., breakers and disconnects closed, unit running, transformer energized from the high side). Additionally, the mechanical interlocking scheme shall also be designed to ensure that the disconnect switches (typically no-load disconnect) cannot be opened when the circuit is energized. Metal-clad switchgear may be arranged with a terminating compartment for connection to insulated cables or to metal-enclosed bus (typically nonsegregated-phase bus for metal-clad switchgear), available for both indoor and outdoor installation. Voltage ratings and insulation levels for metal-clad switchgear should meet the requirements of IEEE® C37.20.2. The associated breakers are in accordance with IEEE C37.04. If the breakers are for generator use, IEEE® C37.013 also applies.

The standard ratings range is typically from 4.76 kV to 38 kV, with continuous current ratings of 1,200, 2,000, 3,000, and 4,000 A.

In addition to its use as machine-voltage unit switchgear, it may also be used as part of a medium-voltage, station-service distribution system for the facility. See DS 4 - chapter 6 for that particular application.

3.4.3 Station-Type Switchgear

Existing switchgear of this type typically includes compressed air circuit breakers that are mounted in a fixed position in sheet metal enclosures, which are included with the associated equipment, as stated above. The circuit breakers in this gear are maintained in place and must be designed with a certain amount of working space inside the gear, around the units. The air supply system consists of a motor, compressor, motor starter, air storage tanks, accessory control, and safety protective equipment. The air supply system is assembled on a frame and separately mounted near the circuit breaker. The air supply unit is also connected to the station compressed air system as an emergency air supply.

This type of gear, using air-blast breakers, is applied in higher current applications that are typically outside the range of metal-clad vacuum breakers. However, this type of breaker is no longer manufactured. Vacuum breaker ratings are steadily increasing to fill this range; however, at the higher currents, especially interrupting currents that are greater than 80 kA, SF_6 gas breakers can be used to replace this equipment or can be provided in a new installation.

The purpose of the disconnecting switches, group-operated, is to provide isolation from the source and/or load or line voltage during breaker maintenance. A grounding switch may also be provided to ground the metal-enclosed bus that is connected to the switchgear. If ground or disconnect switches are specified, then a mechanical interlock system must be provided to avoid misoperation, which can create an arc flash hazard (see Section 3.4.2, “Metal-Clad Switchgear,” for mechanical interlock discussion).

This type of equipment is commonly used for connection to isolated-phase bus. The switchgear terminals are equipped with suitable adapters to accommodate connection to the isolated-phase bus.

Note that no exact industry standard exists for this type of switchgear; however, parts of other standards, such as IEEE® C37.04, C37.013 (for generator breakers), and C37.20.2, would apply to these breakers and gear. Insulated bus should be required to meet IEEE® C37.20.2.

3.4.4 Motor Control Switchgear

3.4.4.1 General

Motor control switchgear performs the functions of starting, stopping, and protecting pump motors. Manual, remote, or automatic control may be provided, depending on the design of the installation and whether full-time operator control is required. This equipment may also house meters and relays; however, refer to DS 4 - chapter 6 for further discussion of the particulars of pump unit motor control and protection, as well as associated meters and relays.

3.4.4.2 Selection

Motor controls will range from small, single unit LV plants to medium size, multi-unit, 480-, 2,400-, 4,160-, or 6,900 V installations. Individual controllers for LV plants consist of a combination molded-case circuit breaker and motor contactor. Individual controllers at medium-voltage plants have fuses and vacuum contactors. Large, medium-voltage pumping plants at voltages above 6,900 V use metal-clad or station-class switchgear to start and stop motors.

3.4.4.3 Enclosures

Motor controls are installed in prefabricated sheet metal enclosures. MCCs are used for LV controllers. MCEs are used for medium-voltage controllers. The enclosures contain compartments for the incoming power feeder and for controlling each motor. MCEs have separate compartments for the motor contactor and the LV motor controls. Control circuits are provided for each controller. Power for the control circuits is obtained from a fused, control-circuit transformer.

MCC enclosures can be either NEMA 250 Type 1 or Type 12 for indoor installations. Outdoor MCCs consist of a NEMA Type 12 enclosure mounted inside a weatherproof enclosure. MCE enclosures can be either ungasketed or gasketed for indoor installations. Outdoor MCEs consist of a gasketed enclosure mounted inside a weatherproof enclosure.

3.4.4.4 Surge Protection

Unlike generators, where the surge protection equipment is located in its own enclosure, surge protective equipment for pumping units in small and medium-size plants is usually connected to the control equipment bus immediately after the main incoming disconnect device. It consists of surge arresters and capacitors wye-connected to ground, one to each phase. This equipment shall be designed to help prevent harmful lightning surges and switching surges from damaging the motor insulation. For very large motor installations, each motor will have its own surge protective equipment connected to the motor terminals.

3.4.5 Ratings, Specifications, Testing, and Standards

3.4.5.1 Ratings

Equipment recommendations for machine-voltage switchgear should be provided by the TSC power systems engineer(s) and follow the applicable IEEE® preferred ratings. Equipment recommendations for motor controllers should be provided by the TSC power systems engineer(s) and follow the applicable NEMA preferred ratings. However, the plant electrical designer(s) should be aware of the information in the following subsections.

3.4.5.1.1 Continuous Current Rating

Continuous current ratings should be specified by the TSC power systems engineer(s).

3.4.5.1.2 Short-Circuit Rating

The short time and interrupting current ratings of a circuit breaker are based on short-circuit currents. These short-circuit ratings are based on system characteristics and on how quickly the breaker opens. They shall be determined in accordance with the standards. During low frequency starts, breaker interrupting capability is reduced by the square root of (f/60). For example, at 30 Hz, the interrupting capability is reduced to 70.7 percent. Therefore, it is critical that the TSC power system engineer(s) are alerted to any low frequency starting requirements, whether normal or emergency. Please note that short-circuit currents are provided in symmetrical, as well as asymmetrical, ratings. It is critical to ensure that the specifications provide the short-circuit requirements with a symmetrical and/or asymmetrical rating.

3.4.5.1.3 Capacitive Current Switching

Special consideration shall be given to installations where the circuit breakers are required to interrupt capacitive currents, even though the capacitive current is of small magnitude. These cases may arise in the switching of shunt capacitors; in the switching of long, unloaded cable circuits; or in the switching of unloaded transmission lines. When circuit breakers are required for this type of switching operation, it is important that the interrupting requirements of the circuit breaker be defined fully in the specifications. The interrupting problems that accompany these switching operations are the result of high switching surge voltages associated with interrupting capacitive currents.

3.4.5.1.4 Generator Circuit Breakers

Generator circuit breakers must be specified with out-of-phase switching and transient recovery voltage requirements.

3.4.5.2 Specifications

The TSC electrical designer(s) have developed guide form specifications for this equipment, which are presently titled as follows:

- Medium-Voltage Metal-Clad Switchgear
- Medium-Voltage Motor Controllers
- 600-Volt Motor Control Center

The TSC presently does not have a guide form specifications for station-type switchgear, although the guide specification for Medium-Voltage Metal-Clad Switchgear could be edited for this type of equipment.

Note that when machine-voltage switchgear is required, it is Reclamation practice to contract for the complete structure, including bus and associated mountings, external supports, enclosures and taps, housings for potential transformers, surge arresters, capacitors, the unit switchgear, and any other electrical equipment connected to the bus and switchgear. Specifications are written on a performance basis and require the contractor to furnish equipment that will carry the required current within specified temperature limits, and to provide shielding, as necessary, to keep the temperature rise of magnetic materials near the bus from exceeding specified limits. Equipment layout shall be coordinated with other equipment that it will be connected to, in order to provide convenient and rapid assembly of the equipment at the jobsite. In addition, equipment shall be rated to withstand all forces encountered under normal operating conditions and during short circuits. The contractor may be required to furnish the services of an erecting engineer to supervise the installation of the bus and associated equipment.

3.4.5.2.1 Current Transformers

Note that for current transformers (CT) applied in switchgear, manufacturers are not able to provide the complete range of ratings as listed in the IEEE® C57.13 standards. Therefore, always check the equipment recommendations with the TSC power systems engineer(s) to ensure that the proper size is being specified for application in switchgear. At a minimum, the single-ratio CTs shall have a relaying accuracy class rating in accordance with IEEE® C37.20.2 for either a C or T classification. A rating of C indicates that the CT accuracy is calculated before construction. A rating of T indicates that the CT accuracy is obtained by factory testing.

3.4.5.2.2 Personal Protective Grounding Provisions

The nature of enclosed switchgear makes it difficult for operation and maintenance staff to apply personal protective grounding leads. To overcome this, ball studs should be specified for installation on outgoing terminal pads and at other locations as determined by the designer. See figure 3.4.5.2.2-1 for example installation.

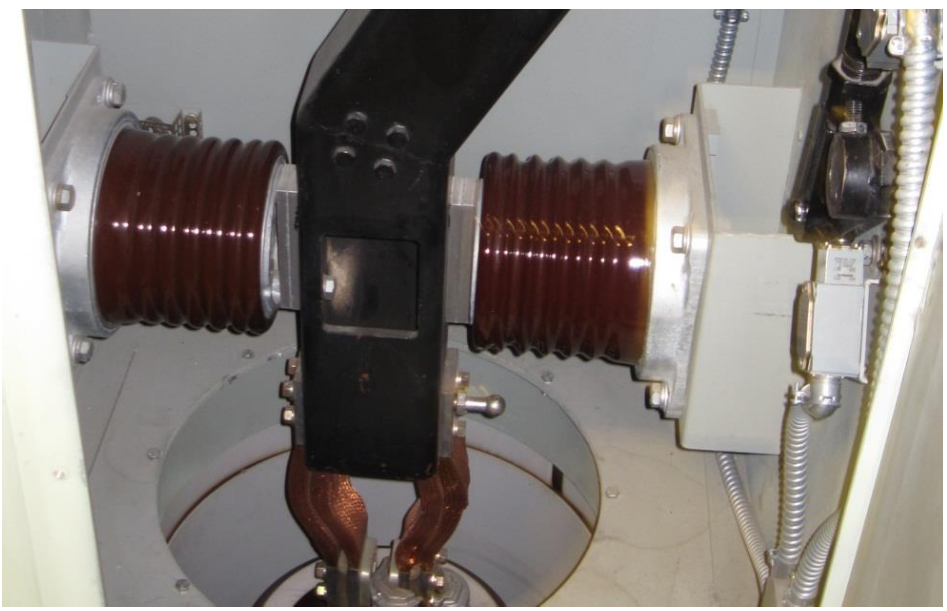

Figure 3.4.5.2.2-1. Ball stud installation on switchgear terminal to external isolated-phase bus entering from below.

3.4.5.3 Factory Testing and Inspection

Switchgear receives all the standard factory tests as outlined in the applicable standards. Note that the individual breakers, switches, and instrument transformers are tested at the original vendor’s factory in accordance with the standards for that equipment. The switchgear is then tested to the switchgear standards after all the equipment is installed.

Regarding Government inspections for metal-clad or station-type (circuit breaker) switchgear, it is highly recommended that factory inspection and test witnessing be performed. Discussion with the owner is necessary to ensure that they are in agreement with this requirement.

3.4.5.4 Standards

The following standards and their amendments should be consulted in the course of working on medium-voltage switchgear:

- FIST 5-14, Arc Flash Hazard Program
- IEEE® C37.04, Rating Structure for AC High-Voltage Circuit Breakers
- IEEE® C37.06, AC High-Voltage Circuit Breakers – Preferred Ratings and Related Required Capabilities
- IEEE® C37.09, Standard Test Procedure for AC High-Voltage Circuit Breakers
- IEEE® C37.013, AC High-Voltage Generator Circuit Breakers
- IEEE® C37.11, Electrical Control for AC High-Voltage Circuit Breakers
- IEEE® C37.20.2, Metal-Clad Switchgear
- IEEE® C37.20.3, Metal-Enclosed Interrupter Switchgear
- IEEE® C37.20.4, Indoor AC Switches for Use in Metal-Enclosed Switchgear
- IEEE® C37.20.7, Testing MV Metal-Enclosed Switchgear for Internal Arcing Faults
- IEEE® C37.22, Preferred Ratings and Related Required Capabilities for Indoor AC MV Switches Used in Metal-Enclosed Switchgear
- IEEE® C37.46, High-Voltage Fuse and Fuse Disconnecting Switches
- NEMA SG 4, AC High-Voltage Circuit Breakers

The following standard should be consulted and followed in the course of working on motor controllers:

- FIST 5-14, Arc Flash Hazard Program
- NEMA ICS 2, Industrial Control and Systems Controllers, Contactors and Overload Relays Rated 600 Volts
- NEMA ICS 3, Industrial Control and Systems: Medium Voltage Controllers Rated 2001 to 7200 Volts AC
- NEMA ICS 18, Motor Control Centers

3.5 Switches

3.5.1 General

Disconnecting switches are used to isolate power equipment for maintenance. In the machine-voltage circuits, they are used to isolate the unit circuit breakers, or they may be installed in-line in the bus to isolate sections or feeder bus, such as bus to station service systems. A phase-reversal switch is a special type of switch, which is not used to isolate, but to reverse phases of a pump-generator unit(s). Another special use is a grounding switch that is/may be used to ground the machine-voltage bus.

3.5.2 Description, Selection, and Application

Disconnecting switches are provided in the machine-voltage switchgear (station-type) or are provided in their own metal enclosure. It should be recognized that the ordinary no-load disconnecting switches may be safely operated **only** when the circuit is completely deenergized. They are not capable of safely interrupting even the smallest amounts of current. Disconnecting switches should not be used in rotating machine main leads without a circuit breaker. Disconnecting switches shall have a proper system interlocking scheme that will prevent improper operation of the switches (e.g., opening the disconnect switch under load with the breaker closed and machine running). Interlocking devices may consist of key interlocks or mechanically linked interlocks when the disconnecting switch is located in the same gear as the circuit-interrupting device. In the design of any disconnecting switch installation, the hazards of improper operation should be recognized, and the necessary safety and mechanical interlocking features shall be provided.

Disconnecting switches, grounding switches, phase-reversal switches, and removable links are designed for the same electrical and mechanical requirements as the bus structure and/or circuit breaker that they are associated with.

Bus grounding switches shall be furnished with a mechanical locking device so the switch can be locked in either the open or the closed position. The ground switch shall be mechanically interlocked or use a key interlock system with breakers and/or associated disconnect switches that ensure that the bus and equipment are de-energized, and that all potential sources of energy are isolated prior to enabling the closing of the ground switch. Key system interlocks are shown on switching or similar diagrams via a dashed line between the ground switch and the controlling device(s). Consult FIST 5-1, Personal Protective Grounding for Electric Power Facilities and Power Lines, on additional considerations for the application of double isolation grounding for high available fault current locations.

Switches shall have safety glass windows so that the contact position may be visually verified. The switch-operating handle should be located away from the blast zone (access door to the switch), when possible. Warning plates with cautionary operating instructions should be attached to the outside of the switch cubicle.

Phase-reversal switches are used to reverse the rotation of generator-motor units. They are **<u>not</u>** isolating switches and cannot interrupt any value of current. Only two phases are reversed, with one phase unchanged. The switches are typically motor gang operated and remotely controlled for safety. Typically, the phase-reversal switches are either mechanically or electrically interlocked to ensure that operation of the switch cannot be performed unless the system is deenergized.

3.5.3 Miscellaneous Considerations

3.5.3.1 Auxiliary Switches

All switches should be provided with auxiliary contacts that operate on disconnect switch position and are wired into the associated circuit breaker’s control circuit to prevent breaker operation if the disconnect switch is open, the bus ground switch is closed, or the phase-reversal switch is not in the proper position for pump or generate mode.

3.5.3.2 Structures

For in-line switches, the bus manufacturer typically determines the support structure location; however, the TSC C/S should be consulted for best locations and any other issues, such as building joints.

3.5.4 Ratings, Specifications, and Standards

3.5.4.1 Ratings

Equipment recommendations for disconnect switches such as the voltage, continuous current, and short-time or peak current ratings are generally provided by the TSC power systems engineer(s),

3.5.4.2 Specifications

There is no guide form specification for switches. Switches are included in the guide form specification for medium-voltage switchgear.

3.5.4.3 Contracting Considerations

The same contracting considerations are given to the timing of purchasing switches, as stated for the machine-voltage switchgear discussed above.

3.5.4.4 Standards

In addition to the standards for switchgear, the following standard should be consulted and followed in the course of working on disconnect switches and ground switches:

- IEEE® C37.20.4, Indoor AC Switches (1 kV to 38 kV) for Use in Metal-Enclosed Switchgear

- FIST 5-1, Personal Protective Grounding for Electric Power Facilities and Power Lines

3.6 Medium-Voltage Power Cables

3.6.1 General

Medium-Voltage power cables, which generally range from 5 to 34.5 kV, are used throughout Reclamation electrical infrastructure to connect various pieces of power equipment in plants, switchyards, and in and around facilities. This section will discuss the use of MV power cables inside plants. See DS 4 - chapter 5 for information on outdoor applications.

3.6.2 Description, Selection, and Application

Medium-voltage power cables are used for the machine-voltage bus installations where the use of a flexible, insulated, stranded power cable is more economical than the use of a bus with rigid conductors. The type of installation most likely to merit the consideration of insulated cable, rather than bus with rigid conductors, is when the length of the circuit is exceedingly great, and the cost of rigid bus becomes very high. Power cable is also better adapted to installations where the rigid bus would pose a problem, such as obstacles that the bus (which comes in standard section lengths) would have to be routed around. Rigid bus is better suited for continuous current requirements that approach or exceed 2,000 A.

MV power cables may also be used on station service systems in and around the plant or facility. See the section on station service systems in DS 4 - chapter 6.

3.6.3 Cable Construction

MV insulated power cables installed by Reclamation are predominantly flexible stranded conductor, single or three conductor, with solid-dielectric type insulation made of ethylene-propylene rubber (EPR). Cross-linked polyethylene (XLP) is another type of insulation.

Solid-dielectric cable consists of a metallic conductor surrounded by a combination of shields, screens, insulation, and jacket. Cable designs can consist of a combination of single conductor with or without concentric neutral and three conductor with or without interlocking armor. Refer to the manufacturer's catalogs for construction illustrations.

3.6.3.1 Insulation

The insulation (EPR) is extruded onto the conductor, and its thickness determines the voltage rating of the cable. The industry refers to this as the 'insulation level.' The selection of the cable insulation level in each particular installation should be based on the applicable phase-to-phase voltage and the general system category, as outlined below.

3.6.3.1.1 100-Percent Level

Cables in this category may be applied when the system is provided with relay protection, so ground faults will be cleared as rapidly as possible, and within 1 minute. While these types of cables are applicable for most cable installations of grounded systems, they may also be used on other systems when the application of cables is acceptable, provided that the above clearing requirements are met in completely deenergizing the faulted section.

3.6.3.1.2 133-Percent Level

This insulation level corresponds to that formerly designated for ungrounded systems. Cables in this category may be applied when the clearing time requirements of the 100-percent level category cannot be met, and yet there is adequate assurance that the faulted section will be deenergized within 1 hour. They may also be used when additional insulation strength over the 100-percent level category is desirable.

3.6.3.2 Screens

There are typically two screens applied (extruded) to dielectric cables. The first screen is referred to as the ‘conductor’ or ‘strand’ screen, and the second screen is known as the ‘insulation’ screen.

3.6.3.2.1 Strand Screen

This screen is usually constructed of a semi-conducting EPR material and is applied over the conductor strand circumference to screen out the overall conductor contour, as well as provide a suitable surface for the insulation to bond to. The strand screen also prevents the dielectric field lines from being distorted by the shape of the outer strands of the conductor.

3.6.3.2.2 Insulation Screen

The insulation screen is also a semi-conducting EPR material and is applied over the circumference of the insulation.

3.6.3.3 Shielding

Shielding of an electric power cable is the practice of confining the electric field of the cable to the insulation of the conductor(s). Shielding should be considered for nonmetallic covered cables operating at a circuit voltage above 2,000 V for single conductor cables and 5,000 V for assembled conductors with a common overall jacket. Nonshielded constructions (constructions not having an insulation screen and metallic shield) are not recommended for use above 5 kV.

3.6.3.4 Concentric Neutral

Concentric neutral are wires, usually coated copper, that are spun around the outside of the insulation layer. This type of cable is usually used on buried circuits, such as along a canal, for distribution of single-phase power for canal operations. Concentric neutral is used as a return path for unbalanced loads. This feature is not provided on plant machine-voltage leads.

3.6.3.5 Interlocking Armor or Sheath

Interlocking armor or sheath is usually a close fitting, impervious, continuous, corrugated aluminum material that encases the cable for physical protection. It is generally not provided on plant machine-voltage leads.

3.6.3.6 Jacket

The final layer on a power cable is referred to as the jacket and typically consists of a coating of polyvinyl chloride (PVC). However, better flame-retardant and low halogen jackets are available and may be considered in special applications, such as areas that are open and exposed to other equipment and/or personnel.

3.6.4 Miscellaneous Considerations

3.6.4.1 Installation

Power cables may be installed in cable trays or in conduit in accordance with IEEE® 422. Power cables shall be segregated from cables with lower insulation ratings in accordance with NEC.

3.6.4.2 Single-Phase Cables

When installing single-phase cables in conduit, **always** use nonmetallic conduits for the entire run to avoid hysteresis heating of the conduit, especially when passing through thick concrete walls, because this heating may intensify and heat up the concrete as well.

3.6.4.3 Shielded Cable Termination and Grounding Considerations

When terminating shielded cable, stress cones should be built up over the insulation, and the shielding tape should be properly grounded. Where conductors are individually shielded, each one must have its shielding grounded, and the shielding of each conductor should be carried across every joint to ensure positive continuity of a shielding from one end of the cable to the other end. Where grounding conductors are part of the cable assembly, they must be connected with the shielding at both ends of the cable.

For safe and effective operation, the shielding should be grounded at each end of the cable and at each splice. For short lengths, or where special bonding arrangements are used, it may be satisfactory to only ground at one point. All grounding connections shall be made to the cable shield in a way that provides a permanent, low resistance bond. The wire or strap used to connect the cable shield ground connection to the permanent ground must be of ample size to carry fault currents.

Installations of shielded single conductor cables must be studied to determine the best method of grounding. This is necessary because voltage is induced in the shield of a single conductor cable carrying AC, due to the mutual induction between its shield and any other conductors in its vicinity.

3.6.4.4 Field Acceptance Testing Techniques

Field testing for acceptance has traditionally involved a direct current (DC), high-potential (or ‘hipot’) test to determine if the cable installation is acceptable.

Industry, with help from IEEE®, has developed another test procedure that uses an AC voltage, but is performed at a very low frequency (VLF). This test, referred to as a VLF test, can be considered in lieu of the DC hipot test.

3.6.4.5 Vertical Runs

Solid-dielectric cable may be prone to insulation slippage in vertical installations, when the extruded materials move downward over time. Carefully consider the use of this type of cable in long vertical runs and during the design stage; consult with manufacturers for installation recommendations.

3.6.5 Ratings, Specifications, and Standards

3.6.5.1 Ratings

Equipment recommendations for power cables may or may not be provided by the TSC power systems engineer(s); however, the engineer(s) must be consulted for the short-circuit current magnitudes and clearing times for three-phase, phase-phase, and line-ground faults to properly select the appropriate insulation level, as discussed above. Typically, the plant electrical designer(s) determine the cable size and ratings, with primary focus on the current-carrying capacity and short-circuit withstand.

Cable sizes are selected from the ampacity tables in the NEC and other standards (NEMA, AEIC).

Voltage drop is typically not an issue with the lengths of MV cable installed at plants. Voltage drop should be considered during design; this process is discussed in DS 4 - chapter 6.

The final consideration on cable size is short-circuit capability, which can be determined from tables in the same way cable size is determined from ampacity tables. The short-circuit capability can be determined from tables, such as the one in the *Okonite Handbook,* referenced below. The TSC power system engineer(s) can also assist with short-circuit capability determination.

3.6.5.2 Specifications

The TSC electrical designers have developed a guide form specifications for MV power cables, which is presently titled as follows:

- Medium-Voltage Power Cable Systems

Note that Reclamation specifications require that MV power cables be manufactured using a triple extrusion process in which the insulation and screens are all extruded onto the cable conductor in the same manufacturing process. This yields the highest quality of construction. In addition, because power cable is an off-the-shelf product, Reclamation specifications require that any ‘new’ power cable supplied under any construction contract be no more than 2 years old. This must be evaluated when submittal data is provided. With regard to field testing, ensure that the contractor submittal data indicates which VLF test method will be used. The IEEE® VLF test standard 400.2 lists several waveform types. Presently, Reclamation has no preference.

Note also that medium- and high-voltage power cables should be indicated on switching and single line diagrams with the triangular-shaped cable terminator symbol, and it should be placed at each end of each continuous run of MV cable.

3.6.5.3 Standards and References

3.6.5.3.1 Power Cable Systems

Power cable systems designers should be familiar with the following industry standards associated with power cables and their accessories, procedures, and guides:

- AEIC CS8, Specification for Extruded Dielectric, Shielded Power Cables Rated 5 through 46 kV
- ASTM B8 and B496, Copper Conductors
- IEEE® 48, Cable Terminators
- IEEE® 400, Guide for Making High-Direct-Voltage Tests on Power Cable Systems in the Field
- IEEE® 400.2, Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)
- IEEE® 422, Guide for the Design and Installation of Cable Systems in Power Generating Stations
- IEEE® 525, Guide for the Design and Installation of Cable Systems in Substations
- NEC, National Electrical Code (NFPA 70)
- NEMA WC 50, Ampacities for 1-Conductor Solid-Dielectric Power Cable 15 kV through 69 kV
- NEMA WC 74, 5-46 kV Shielded Power Cable for Use in the Transmission and Distribution of Electric Energy

3.6.5.3.2 Engineering Information, Procedures, Tables

One source of engineering information, procedures, tables, etc., is The Okonite Company's *Engineering Data for Copper and Aluminum Conductor Electrical Cables.* The Electric Power Research Institute (EPRI) is another good resource for cable research.

3.7 References

3.7.1 Acronyms and Terms

3.7.1.1 Codes, Documents, and Organizations

AEIC	Association of Edison Illuminating Companies
ANSI	American National Standards Institute
ASTM	ASTM International (formerly named American Society for Testing and Materials)
C/S	Civil/Structural engineers/designers
EPRI	Electric Power Research Institute
FIST	Facility Instructions, Standards, and Techniques (Reclamation)
IEC	International Electrotechnical Commission
IEEE®	Institute of Electrical and Electronics Engineers
NEC®	National Electrical Code (NFPA)
NEMA	National Electrical Manufacturer's Association
NETA	International Electrical Testing Association
NESC®	National Electrical Safety Code (IEEE®)
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Administration
PEB	Power Equipment Bulletin (Reclamation)
Reclamation	Bureau of Reclamation
RSHS	*Reclamation Safety and Health Standards*
SI	International System
TSC	Technical Service Center (Reclamation)
UL	Underwriter's Laboratory

3.7.1.2 Equipment, Materials, and Technical

AC	alternating current
ATS	acceptance testing specifications
CT	current transformer
DC	direct current
EPR	ethylene-propylene rubber (insulation)
GCB	generator circuit breaker
GSU	generator step-up unit (transformer)
hipot	high-voltage potential (test)
HV	high voltage
HVCB	high-voltage circuit breaker
Hz	hertz (60 cycles per second)
LV	low voltage

MCC	motor control center
MCE	motor control equipment
MV	medium voltage
O&M	Operation and Maintenance
PCB	polychlorinated biphenyl
PPG	Personal protective ground
PVC	polyvinyl chloride (cable jacket)
RCRA	Resource Conservation and Recovery Act
SF_6	sulfur hexafluoride (gas)
USC	U.S. Customary Units
VLF	very low frequency
XLP	cross-linked polyethylene

3.7.2 Industry Standards

3.7.2.1 American National Standards Institute (ANSI)

ANSI C37.46	Standard for HV Expulsion and Current-Limiting Type Power Class Fuses and Fuse Disconnecting Switches

3.7.2.2 Association of Edison Illuminating Companies (AEIC)

AEIC CS8	Specification for Extruded Dielectric, Shielded Power Cables Rated 5 thru 46 kV

3.7.2.3 American Society for Testing and Materials International International (ASTM)

ASTM B8	Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft
ASTM B496	Compact Round Concentric-Lay-Stranded Copper Conductors

3.7.2.4 Institute of Electrical and Electronics Engineers (IEEE®)

IEEE® 48	Cable Terminators
IEEE® 400	Guide for Making High-Direct-Voltage Tests on Power Cable Systems in the Field
IEEE® 400.2	Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)

IEEE® 422	Guide for the Design and Installation of Cable Systems in Power Generating Stations
IEEE® 525	Guide for the Design and Installation of Cable Systems in Substations
IEEE® 693	Recommended Practice for Seismic Design of Substations
IEEE® 1247	Interrupter Switches for Alternating Current, Rated above 1000 Volts
IEEE® 1313.1	Insulation Coordination - Definitions, Principles, and Rules
IEEE® 1313.2	Guide for the Application of Insulation Coordination
IEEE® C2	National Electrical Safety Code
IEEE® C37.04	Standard Rating Structure for AC HVCBs
IEEE® C37.06	AC HVCBs Rated on a Symmetrical Current Basis - Preferred Ratings and Related Required Capabilities
IEEE® C37.09	Standard Test Procedure for AC HVCBs
IEEE® C37.013	AC High-Voltage Generator Circuit Breakers
IEEE® C37.11	Electrical Control for AC High-Voltage Circuit Breakers
IEEE® C37.20.2	Metal-clad Switchgear
IEEE® C37.20.3	Metal-enclosed Interrupter Switchgear
IEEE® C37.20.4	Indoor AC Switches for Use in Metal-Enclosed Switchgear
IEEE® C37.20.7	Testing MV Metal-Enclosed Switchgear for Internal Arcing Faults
IEEE® C37.22	Preferred Ratings and Related Required Capabilities for Indoor AC MV Switches Used in Metal-Enclosed Switchgear
IEEE® C37.23	Standard for Metal-Enclosed Bus

IEEE® C36.46	Power Fuses and Fuse Disconnecting Switches
IEEE® C57.13	Requirements for Instrument Transformers
IEEE® C57.13.1	Guide for the Field Testing of Relaying Current Transformers
IEEE® C57.13.3	Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases

3.7.2.5 InterNational Electrical Testing Association (NETA)

NETA ATS	Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems

3.7.2.6 National Electrical Manufacturer's Association (NEMA)

NEMA 250	Enclosures for Electrical Equipment
NEMA BU 1.1	Instructions for Handling, Installation, Operation, and Maintenance of Busways Rated 600 Volts or Less
NEMA BU 1.2	Application Information for Busway Rated 600 V or Less
NEMA ICS 2	Industrial Control and Systems Controllers, Contactors and Overload Relays Rated 600 Volts
NEMA ICS 3	Industrial Control and Systems: Medium Voltage Controllers Rated 2001 to 7200 Volts AC
NEMA SG 4	AC High-Voltage Circuit Breakers
NEMA VE 1	Metal Cable Tray Systems
NEMA VE 2	Cable Tray Installation Guidelines
NEMA WC 50	Ampacities for 1-conductor solid-dielectric power cable 15 kV through 69 kV
NEMA WC 74	5-46 kV Shielded Power Cable for Use in the Transmission and Distribution of Electric Energy

3.7.2.7 National Fire Protection Association (NFPA)

NFPA 70	National Electrical Code
NFPA 70E	Standard for Electrical Safety in the Workplace
NFPA 851	Recommended Practice for Fire Protection for Hydroelectric Generating Plants

3.7.3 Documents and Publications

FIST 3-29	Energized Facility Maintenance
FIST 5-14	Arc Flash Hazard Program

Electric Power Engineering: Reference and Applications Handbook, by C.J. Agrawal

Engineering Data for Copper and Aluminum Conductor Electrical Cables, by The Okonite Company

Standard Handbook for Electrical Engineers, published by McGraw-Hill Book Company