

Standard Specification for Bridge Deck Cathodic Protection

AASHTO Designation: MP5-95¹

1. Introduction - This standard provides a specification for cathodic protection of a standard bridge deck, i.e. a reinforced, double mat rebar structure with a 152 to 230 mm thick slab.

2. Scope

2.1 This standard provides cathodic protection specifications for components, and installation of the system, for standard bridge decks.

2.2 *This standard may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety problems associated with its use. It is the responsibility of whomever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

3. Referenced Documents

3.1 AASHTO Designations

- M29 Fine Aggregate for Bituminous Paving Mixtures
- M43 Sizes of Aggregate for Highway Road and Bridge Construction
- M241 Concrete Made by Volumetric Batching and Continuous Mixing
- R9 Acceptance Sampling Plans for Highway Construction
- R18 Establishing and Implementing A Quality System for Construction Materials Testing Laboratories
- T245 Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
- TP51 Testing Cathodic Protection Materials and Systems for Bridge Decks

3.2 ASTM Standards

- A123 Hot Dip Galvanizing of Steel
- C876 Measurement and Interpretation of Half-Cell Potentials of Reinforcing Steel in Concrete
- D3515 Specification for Hot-Mixed, Hot-Laid

Bituminous Paving Mixtures
D3665 Random Sampling of Construction Materials

E380 Use of the International System of Units (SI)

3.3 Other Standards

3.3.1 ANSI (American National Standards Institute), C80.1, C80.4, and UL6, for Type I Rigid Steel Conduit

3.3.2 MIL (Military) Standard E917, for Transformers

3.3.3 NACE (National Association of Corrosion Engineers) RPO290-90 Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures

3.3.4 NEC (National Electrical Code) Article 240

3.3.5 NEMA (National Electrical Manufacturers' Association) Publication No. 250, Publication No. TC2 for PVC Conduit, and Publication No. TC3 for PVC Fittings

4. Terminology

4.1 Alternating Current - Electric current which repeatedly reverses direction on a periodic cycle, usually at a frequency of 60 cycles per second (60 Hz).

4.2 A. C. Service - Alternating current supply to the rectifier; usually 120 or 240 volts AC.

4.3 Anode - The electrode at which oxidation reactions (i.e. corrosion reactions) occur, and to which negatively charged ions migrate when an electric current is passed through an electrolyte. In a bridge deck cathodic protection system, the anode is an inert material which is used to distribute protective current to the reinforcing steel.

4.4 Anode Manufacturer's Installation Supervisor (IS) - Representative of the anode manufacturer who is

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familiar with all aspects of the product and its installation.

Note 1 - The IS gives advice in the field regarding the product installation and may perform necessary quality control field tests to ensure proper installation of the anode system. The IS should have a minimum 1 year of relevant experience on bridge deck cathodic protection systems.

4.5 Anode Mesh CPS - An anode mesh system used for cathodic protection of reinforced concrete structures consisting of a catalyzed titanium anode mesh, current distributors and plastic fasteners(used in conjunction with a rigid concrete overlay).

4.6 Anode Zone - An isolated anode circuit on the concrete deck occupying an area not exceeding 6500 square feet.

4.7 ASCII - Computer code given numerical equivalent of characters and numbers.

4.8 Attenuation - Electrical losses in a conductor caused by current flow in the conductor.

4.9 Carbon Strand - An anode conductor used in conductive polymer slot and mounded CPS. The material consists of multiple high purity carbon strand filaments wrapped with Dacron fiber.

4.10 Cast Iron Anode - A primary anode used in coke asphalt CPS. The anode consists of high silicon iron cast into a flat disc or pancake, with attached lead wire.

4.11 Cathode - The electrode at which reduction occurs, and to which positively charged ions migrate when an electric current is passed through an electrolyte. In a bridge deck CPS, the cathode is the embedded reinforcing steel.

4.12 Cathodic Protection Systems (CPS) - A system for reduction or elimination of corrosion by making the metal (reinforcing steel) a cathode. Cathodic protection of reinforced concrete is usually accomplished by means of an impressed D.C. current.

4.13 Cell - An electrochemical system consisting of an anode and a cathode in metallic contact and immersed in an electrolyte. The anode and cathode may be different metals.

4.14 Circular μm - A measurement of cross sectional

area, used in describing the size of copper conductors.

4.15 Coarse Taps - Large interval adjustment settings placed along the secondary of a transformer in a rectifier. The taps produce voltages corresponding to the number of turns at which they are connected.

4.16 Coke Asphalt CPS - A type of anode system for cathodic protection of reinforced concrete bridge decks. The system consists of one course of conductive asphalt containing coke breeze, powered by embedded cast iron anodes, and one course of conventional bituminous mixture constructed as a wearing surface.

4.17 Conductive Polymer Grout (Concrete) - A conductive polymer anode material used with mounded or slotted CPS. The material consists of three components (promoted resin binder, catalyst and carbon filler), which are pre-measured and mixed on site.

4.18 Constant Current - An operating mode in a rectifier in which the current is set at a fixed level, and the voltage varies. Variations in the rectifier output voltage and current will occur with the changes in the bridge deck resistance and AC line voltage and is limited by the tap settings of the transformer.

4.19 Constant Voltage - An operating mode in a rectifier in which the voltage is set at a fixed level, and the current varies. Variations in the rectifier output voltage and current will occur with the changes in the bridge deck resistance and AC line voltage and is limited by the tap settings of the transformer.

4.20 Corrosion - The natural tendency of a metal to revert to its native state because of a reaction with its environment. In order for corrosion to occur there must be an anode, a cathode, an electrolyte and a metallic path between the anode and cathode.

4.21 Corrosion Engineering Technician (CET) - An approved technician with at least one year of similar experience on bridge deck CPS installations.

4.22 Corrosion Product - Product resulting from a corrosion reaction. The term may apply to a solid compound (rust), gases or ions.

4.23 Corrosion Rate - The speed at which corrosion progresses, often expressed as a constant loss or penetration per year ($\mu\text{m}/\text{year}$, for thickness changes) or in units of milligrams per square meter per day ($\text{mg}/\text{m}^2/\text{day}$), for mass change.

4.24 Current - A movement of electricity through a solid or solution; commonly measured in amperes or milliamperes. In a cathodic protection system, the direct current flow is ionic (through the electrolyte) and electronic (through the metallic paths).

4.25 Current Density - The current per unit area of surface of metal or concrete. A common unit is mA/m² (milliamperes per square meter).

4.26 Current Distributor - An uncoated strip of titanium (~12 mm wide) which is used with the anode mesh CPS. The purpose of the current distributor is to feed current to the anode mesh system and connect adjacent rolls of mesh together electrically.

Note 2 - The current distributor is typically placed across the deck and welded to the mesh using a portable resistance welder.

4.27 Dead Front - Isolated panel used to shield electrical components.

4.28 Delamination - A separation along a plane parallel to the concrete surface, frequently found in reinforced concrete structures as a result of corrosion of reinforcing steel.

4.29 Depolarization Test - An acceptance test used for cathodic protection of reinforced concrete structures.

4.30 Design Specifications - A set of documents that, in aggregate, form the nucleus for installation or contract documents. These documents include written specifications and/or drawings.

4.31 Diode - An electrical device in a rectifier that allows passage of current in only one direction. The diode is used to convert A.C. current to D.C. current.

Note 3 - Silicon and selenium are common diodes.

4.32 Direct Current (D. C.) - Electric current that flows in only one direction.

4.33 Disconnect Switch - A device used for breaking the flow of electric current.

4.34 D.C. Wiring - All insulated conductors necessary for connecting the anode zones, reinforcing steel, reference cells and other instrumentation with

the rectifier and/or junction box.

4.35 Efficiency - One measure of the quality of a rectifier indicating the amount of input power reaching the output.

Note 4 - The efficiency of rectifiers may range from 50 percent to over 90 percent.

4.36 Electrode - A metal in contact with an electrolyte which serves as a site where electrochemical reactions occur.

4.37 Electrical Continuity - A closed circuit (unbroken electrical path) between metal components under consideration. For cathodic protection of bridge decks, continuity typically refers to the electrical connection of reinforcing steel.

4.38 Electrical Discontinuity - The physical separation between metal components under consideration. For cathodic protection of bridge decks, electrical discontinuity typically refers to discontinuous reinforcing steel, or isolation of the anode from the cathode (reinforcing steel).

4.39 Electrolysis - Chemical changes in an electrolyte brought about by the passage of an impressed electric current.

4.40 Electrolyte - Any medium which serves as a conductor for the passage of ionic current (i.e. concrete, soil and water).

4.41 E-Log I Test - An acceptance test for cathodic protection of reinforced concrete (See TP51).

4.42 Energize - (turn on) The process of initially applying power to a cathodic protection system.

4.43 Engineer - The owner's representative or project engineer.

4.44 Exothermic Weld - (thermite weld) A fusion weld of a copper wire to a metal surface (reinforcing steel). Exothermic welds for cathodic protection use a special alloy to provide minimum heat effect on the steel.

4.45 Filter - A device used to increase the conversion efficiency of a rectifier. Filters typically consist of an inductor or choke, which is used to reduce the ripple component in the D.C. Output.

4.46 Fine Taps - Low interval adjustment settings

placed along the secondary of a transformer in a rectifier. The taps produce voltages corresponding to the number of turns at which they are connected.

4.47 Ground Electrode - (ground rod) Electrical contact with earth ground.

4.48 Half-Cell - A single electrode in contact with an electrolyte and which, in contact with another half-cell, forms a full electrochemical cell. This term is sometimes used to designate a reference electrode or reference cell.

4.49 Heat Shrink - A heat shrinkable tube used to insulate a bare conductor.

4.50 Impressed Current System - The type of cathodic protection system in which an externally supplied direct current is forced between the anode and cathode by means of an external source, such as a rectifier.

4.51 Instant Off - The polarized half-cell potential of an electrode (embedded reinforcing steel) taken immediately after the protective current is turned off. The instant off potential closely approximates the IR drop free value when there was current flow.

4.52 Interrupting - The on and off cycling of a power supply (rectifier).

4.53 Interrupter - A device used for interrupting current flow. The interrupter may be internal within the rectifier or portable.

4.54 Ion - An atom or group of atoms that have lost or gained one or more electrons, and have therefore acquired an electric charge (i.e. Cl^- , OH^- , H^+ , Na^+).

4.55 IR Drop - The voltage drop in a conductor caused by current flow and resistance within that conductor. IR drop occurs in both metallic and electrolytic conductors.

4.56 LCD - (Liquid Crystal Display) Display on a digital meter which requires light from an external source.

4.57 Lead Acid - A type of battery used for solar power supplies.

4.58 LED - (Light Emitting Diode) Display on a digital meter that can be read well in low light, but which is very difficult to read in bright light such as

indirect sunlight.

4.59 Lightning Arresters - Devices which are used to protect electrical components from voltage surges.

Note 5 - Lightning arresters are typically placed on the A.C. and D.C. sides of a rectifier.

4.60 Link Bar - A metal strap which connects two terminals in an electrical device. In a rectifier, link bars are typically used to connect and adjust transformer tap settings.

4.61 Macro Cell - A corrosion cell with a large anode to cathode relationship. A macro cell is sometimes used to designate a rebar probe.

4.62 Metal Oxide Varistor - (MOV) A lightning arrester used to protect silicon diodes, SCR's, and other sensitive electronic components from voltage surges. MOV's are voltage sensitive resistors which react quickly to voltage surges and can conduct large amounts of currents for short periods of time.

4.63 Meters - An instrument which is used for measuring and recording such as in the case of rectifier voltage, current and reference cell potential. Rectifier meters may be analog or digital.

4.64 Micro Cell - A corrosion cell with a small anode to cathode relationship.

4.65 Mounded CPS - A type of cathodic protection system in which conductive polymer concrete is placed in longitudinal and transverse mounds on the surface of the deck and covered with a concrete overlay.

4.66 NEMA Grade XX - NEMA rating for insulating panel materials.

4.67 NEMA Type 3R Enclosure - Type 3R enclosures are intended for outdoor use primarily to provide a degree of protection against falling rain, sleet, and external ice formation.

4.68 NEMA Type 4 Enclosure - Type 4 enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against wind blown dust and rain, splashing water, and hose directed water.

4.69 NEMA Type 4X Enclosure - Type 4X enclosures are intended for indoor or outdoor use

primarily to provide a degree of protection against corrosion, wind blown dust and rain, splashing water, and hose directed water.

4.70 Nonconductive polymer concrete - A nonconductive polymer consisting of three components (resin binder, catalyst and sand), which are pre-measured and mixed on site. Nonconductive polymer concrete is typically used with conductive polymer concrete CPS, to insulate the anode material from contacting exposed or partially embedded steel.

4.71 Ohm's Law - The relationship between voltage, current and resistance ($E = IR$).

4.72 Oxidation - A chemical or electrochemical reaction involving the loss of electrons. Corrosion of metal at an anode is an example of oxidation.

4.73 pH - A value taken to represent the acidity or alkalinity of a solution. A pH of seven is considered "neutral", with lower numbers representing solutions which are acidic and higher numbers solutions which are basic or alkaline.

4.74 Platinized Niobium Copper Core Wire - A primary anode conductor (0.7874 or 1.5748 mm diameter) used in conductive polymer slot and mounded CPS. The wire consists of a copper core, clad with a layer of niobium and then a thin outer layer of platinum.

4.75 Polarization - The shift in potential of an electrode away from its open circuit potential resulting from the passage of current. In a cathodic protection system, polarization refers to the protective film that develops on the surface of the cathode (reinforcing steel).

4.76 Polarization Decay - The decrease in electrode (reinforcing steel) potential with time, resulting from the interruption of applied current.

4.77 Potential - A voltage measurement (i.e. half-cell potential).

4.78 Potential Survey - Obtaining half-cell potentials at multiple locations on the surface of a structure.

4.79 Potentiometer - An instrument used for measuring voltage. Also a variable or adjustable resistor.

4.80 Primary Anode - Any anode material which acts as a contact medium for the secondary anode and

distributes current from the power supply line to the secondary anode.

4.81 Corrosion Engineer - A Registered Professional Engineer with a National Association of Corrosion Engineers (NACE) certification as either a Corrosion Specialist or Cathodic Protection Specialist.

Note 6 - A Corrosion Engineer should provide advice and assistance to the owner concerning all critical operations and at other times upon request. The Corrosion Engineer should have at least 8 years of related experience on bridge deck CPS.

4.82 Protective Device - A device used to protect electrical components from voltage surges, such as a lightning arrester or MOV.

4.83 Rebar Probe - A monitoring probe used to evaluate cathodic protection performance. The probe consists of a segment of reinforcing bar which is attached to an insulated wire and cast into a salty mortar block (Chloride content is typically 8.9 kg/m³). The high chloride content simulates the most anodic location in the deck. A macro cell is sometimes used to designate a rebar probe.

4.84 Reduction - A chemical or electrochemical reaction involving the gain of electrons; as when a metal ion in solution goes to the metallic state at a cathode.

4.85 Reference Cell - (Reference electrode) A half-cell of reproducible potential (i.e. Ag/AgCl, Cu/CuSO₄ and Graphite). A standard against which the potentials of other electrodes can be measured and compared. Reference cells may be portable or permanently embedded in the concrete deck.

4.86 Reference Cell Ground - Wire connected to the reinforcing steel used for obtaining reference cell potential measurements.

4.87 Remote Monitoring System - A device used to collect and transfer rectifier operating data to a remote computer terminal, thus eliminating the need for monthly field inspections at the bridge. The remote monitoring system typically consisting of a data recorder, modem, telephone service and personal computer at the receiving end.

4.88 Resistance - Opposition offered by a conductor to the passage of electrical current, measured in ohms.

4.89 Resistivity - The electrical resistance of a substance (i.e. concrete, water and soil) commonly measured in ohm-centimeters (ohm-cm). Concrete of lower resistivity is likely to be more corrosive than concrete of higher resistivity.

4.90 Rectifier - A device used to convert alternating current to direct current. In a cathodic protection system the rectifier is used to control the voltage and current output to each zone.

4.91 Rectifying Element - A device which is used to pass current in one direction and to block it in the opposite direction. Fabricated from either silicon or selenium (see diode).

4.92 Ripple - Percent ripple = $\text{Ripple Voltage (RMS) / Volts DC} \times 100$. Ripple voltage shall be measured across the output terminals of the rectifier with a true RMS AC voltmeter. Volts DC shall be measured across the output terminals of the rectifier with a DC voltmeter.

4.93 Root Mean Square (RMS) - The RMS value represents both the D.C. and A.C. components of a rectifier waveform and is 70.7 percent of the peak value and 111 percent of average D.C. value.

4.94 Rusting - Corrosion of iron or iron-based alloys to form a reddish brown product known as rust, which is primarily iron oxide. A term properly applied only to ferrous alloys.

4.95 Saturable Core Reactor - A type of rectifier that provides constant current output. A saturable core reactor is a transformer type device in which the A.C. voltage is regulated by a D.C. current flowing on the iron core.

4.96 Secondary Anode - Any anode material that distributes the cathodic protection current to the entire surface of the structure under cathodic protection.

4.97 Shunt - A calibrated resistor used to measure D.C. current flow in a metallic conductor. The current is calculated by measuring the millivolt drop across the shunt, and multiplying this value by the calibration factor for the shunt (Amps/mV).

4.98 Sliding Terminal Blocks - A type of terminal block in an electrical circuit that allows "through" connections (from one side to the other) to be easily made or broken.

4.99 Slotted CPS - A non-overlay cathodic

protection system consisting of a series of saw cuts placed in the concrete deck. Primary and secondary anode conductors are then placed in these slots and backfilled with a conductive polymer concrete.

4.100 Solar Power Supply - An alternate power source which is used in remote areas where electric service is not available. A solar power supply consists of a photovoltaic solar array, battery bank and system controller/regulator.

4.101 Spalling - The cracking and separation of concrete caused by corrosion induced stresses.

4.102 Stray Current Corrosion (interference corrosion) - Corrosion caused by direct current from external sources through paths other than the intended circuit. Accelerated corrosion may result if such current is collected by a structure and leaves to enter the electrolyte.

4.103 System Negative Connection - Cable connection to the reinforcing steel from the rectifier negative (-) output.

4.104 Transformer - One or more coils of wire wound around a laminated iron core. Its purpose is to step a voltage up or down, and to isolate the D.C. circuit from its source in a rectifier.

4.105 Voltage - Difference of potential expressed in volts or millivolts (1 volt = 1,000 millivolts).

4.106 Voltage Probe - Graphite reference cell placed in contact with coke asphalt and used only with coke asphalt cathodic protection systems.

5. Summary

5.1 This standard presents specifications for the components, installation and testing of cathodic protection systems for standard bridge decks. It incorporates the use of other available standards which are applicable to the accomplishment of this task. The procedure allows adjustments to accommodate the needs of individual agencies.

5.2 The specifications and procedures consist of four major parts: (1) requirements for an electrically conductive asphalt overlay system, (2) requirements for a slotted anode system, (3) requirements for conductive polymer systems with a rigid overlay, and (4) requirements for tack-down, manufactured anode systems, with rigid overlay.

6. Significance and Use

6.1 Significance - Cathodic Protection is the only known fully developed means of mitigating the corrosion of reinforcing steel in existing bridge decks caused by the presence of chloride ions. The first installation of an impressed current CPS on a bridge deck took place in California in 1973, using high silicon cast iron anodes affixed to the deck and covered with a 2-inch lift of conductive coke breeze asphalt and topped with a 2-inch wearing course of asphaltic concrete. Since then the field of cathodic protection for reinforced concrete bridge decks has matured into a proven technology with several design options available. A CPS is one alternative for the rehabilitation of salt-contaminated bridge decks. This standard can be used to provide specifications for (1) materials and components used in CPS, (2) installation of materials used in CPS, and (3) testing the CPS.

6.2 Use

6.2.1 The electrically conductive asphalt CPS employs a layer of conductive asphalt, containing coke breeze aggregate, placed on the concrete deck surface, powered by high-silicon, cast-iron anodes, and overlaid by one course of dense graded asphalt concrete wearing course. The surface of the system provides a good riding quality, is suitable for any deck geometry, and can be applied to decks with active cracks. The service life of the system is generally limited by the life of the wearing course and for this reason, all cathodic protection hardware is embedded in the deck concrete to allow removal and replacement of the asphalt layers without damage to anodes, instrumentation, or system wiring. An important factor to consider in selection of structures in cold regions for repair with this system is the adequacy of the concrete air void system. The conductive asphalt mix is porous and has a tendency to retain moisture on the concrete surface. If the moist concrete is not properly air-entrained, and is subject to frequent freeze-thaw cycling, deterioration of the concrete may be accelerated.

6.2.2 The slotted-anode CPS for reinforced concrete bridge decks requires that a minimum of 95 percent (preferably 100 percent) of the reinforced concrete deck have concrete cover 25 mm or more over the top mat of rebar. In this system, the protective D.C. current is distributed across the deck in each of several uniformly sized zones through primary wire and strand anodes, which are installed in transverse

and longitudinal slots. These slots, properly spaced and saw-cut into the surface of the concrete deck, are subsequently filled with a secondary anode material (conductive polymer grout). The system is installed such that the average current density at the surface of the conductive polymer grout does not exceed 54.0 mA per m².

6.2.3 The conductive polymer mounds distributed anode CPS for reinforced concrete bridge decks requires that distributed anodes be placed on a blasted, cleaned, deck surface and then covered with a concrete overlay. In this system, conductive polymer mounds consisting of primary anode wires and strands which are placed on a prepared deck surface, covered with a secondary anode (conductive polymer grout), and overlaid with concrete to provide a new riding surface. These systems are designed and installed such that the average current density at the surface of the conductive polymer grout does not exceed 81 mA per m² of grout surface area.

6.2.4 The expanded mesh distributed anode CPS for reinforced concrete bridge decks requires that distributed anodes be placed on a blasted, cleaned, deck surface and then covered with a concrete overlay. In this system, mesh anodes consisting of expanded titanium mesh coated with a precious metal oxide catalyst is fastened to a prepared deck surface and overlaid with concrete to provide a new riding surface. These systems are designed and installed such that the average current density at the surface of the anode does not exceed 107.6 mA per m².

6.2.5 A critical concern with regard to the successful use of CPS is the necessity for later bridge deck maintenance procedures to be conducted in a manner that assures the continued functionality of the CPS.

7. Laboratory Apparatus and Materials

7.1 Personal safety equipment required by the specified test method.

7.2 Testing equipment required by the specified test method.

7.3 Receiving terminal equipment for controlling the remote monitoring unit shall conform, as a minimum, to sections 7.3.1 through 7.3.5.

7.3.1 A 486DX2-50 or higher IBM compatible computer, with keyboard, EGA color monitor, 12 Mb RAM, 2 serial ports, 1 parallel port, system

clock with battery backup, 120 Mb hard disk drive, and 1.44 Mb 90 mm floppy disk drive.

7.3.2 Windows 3.1 operating system or higher.

7.3.3 1200 baud Hayes compatible modem and all related communications software.

7.3.4 Epson LQ 850 printer or equivalent and printer paper.

7.3.5 All cables required for complete operation of the system.

8. Field Apparatus and Materials

8.1 Personal safety equipment required by the laboratory/field organization and/or OSHA for work in the CPS field installation areas.

8.2 Cathodic protection materials

8.2.1 Rectifier - The cathodic protection rectifier shall meet the requirements specified in Section 8.2.1.1. Each rectifier or group of rectifiers, when complete, shall be tested in accordance with the requirements of TP51.

8.2.1.1 The rectifier shall provide saturable constant current type with the capability for changing control to constant voltage. It shall have a rated DC output of each circuit, 24 volts, 10 amperes, and shall be manufactured in accordance with the schematic shown in Figure A1, with a variable load (D.C. circuit) resistance ranging from 0.25 to 2.5 ohms.

8.2.2 Rectifier Enclosure - Rectifier enclosures shall meet type 3R, 4 or 4X requirements of NEMA Publication No. 250, whichever is indicated in the project special provisions and shall conform to the requirements of Sections 8.2.2.1 through 8.2.2.8.

8.2.2.1 The enclosure shall be constructed of 11 gauge material or thicker and shall provide adequate convection cooling of internal components.

8.2.2.2 The enclosure shall be fitted for either pole, wall, or base mounting as required by the project specifications, and shall have provisions for locking and protection of the interior components from weather and vandalism.

8.2.2.3 Any enclosure opening for cooling 3 mm or larger shall be screened to prevent entry of nest

building insects.

8.2.2.4 The enclosures shall provide entries for wiring located in the bottom of the enclosure of adequate number and size to provide for input and output connections required in the project special provisions.

8.2.2.5 The enclosure shall be equipped with a grounding lug on the outside of the enclosure to accommodate a #6 AWG copper ground wire, and a permanent manual holder, attached to the inside of the enclosure cabinet door.

8.2.2.6 NEMA 3R enclosures shall have hinged removable front and side doors with bolts on adjustable stainless steel heavy-duty latches.

8.2.2.7 NEMA 4 air cooled rectifier enclosures shall have a single hinged front door with heavy duty, stainless steel latches and shall include a thermostatically controlled fan with filter to provide adequate cooling.

8.2.2.8 When a NEMA type 4 oil cooled enclosure is specified, the transformer and rectifier stack shall be mounted on separate removable racks.

8.2.3 Transformer - The transformer shall meet the requirements of MIL E917 and Sections 8.2.3.1 through 8.2.3.7.

8.2.3.1 The transformer shall be manufactured for use in a cathodic protection rectifier and have separate, isolated primary and secondary copper windings and a grounded copper Faraday shield between primary and secondary windings.

8.2.3.2 The transformer shall be capable of operating continuously at rated load and supplying rated output within the range of 5 percent low to 10 percent high line voltage without damage.

8.2.3.3 Wire size of both windings of the transformer shall be based on a minimum of $3.8003 \times 10^{-7} \text{ m}^2$ per ampere. Transformer regulation shall not exceed 3 percent when measured at 1/4 load and full load.

8.2.3.4 The transformer secondary shall contain a sufficient number of coarse and fine taps to allow adjustment of the output in 0.5 volt increments. All tap leads shall be sized for a minimum of $2.5335 \times 10^{-7} \text{ m}^2$ per ampere.

8.2.3.5 All taps shall be brought out to link bar arrangements or a terminal block for adjusting the output of the rectifier and shall be located on the instrument panel.

8.2.3.6 The transformer shall be vacuum impregnated (or preheated) and immersed in Class F (150 degrees C) transformer varnish until all tapes, insulating materials, outer wrapping and coil windings have been completely saturated and then oven baked until dry.

8.2.3.7 Prior to installation into a rectifier, the transformer shall be tested to verify its capability to withstand 2000 volts for one minute without breakdown between the primary and core, secondary and core, and primary to secondary.

8.2.4 Circuits - Each circuit shall have an isolated secondary winding or an individual transformer meeting the requirements of Section 8.2.3.

8.2.5 Rectifying Elements - Rectifying Elements shall meet the requirements of sections 8.2.5.1 through 8.2.5.4.

8.2.5.1 The rectifying bridge shall have a forward average current rating of at least 25 amperes.

8.2.5.2 Each diode shall have a peak reverse voltage rating of at least 800 volts.

8.2.5.3 Heat sinks shall be sized to provide continuous rectifier operation at rated ambient temperature and rated output.

8.2.5.4 When block style rectifying elements are used, heat sinks shall have isolation of at least 1200 volts in addition to satisfying the requirements of Section 8.2.5.3.

8.2.6 Protective Devices - The CPS shall be equipped with protective devices that meet the requirements of Sections 8.2.6.1 through 8.2.6.5.

8.2.6.1 The system shall be equipped with a thermal magnetic type circuit breaker of the proper voltage rating and sized to hold 100 percent of the rated load current for protection of the entire unit against overload and short circuit. The circuit breaker shall connect the AC power supply and the transformer primary, shall be the manual reset type that trips between 110 percent and 125 percent of rated input current, and shall be positioned and labelled to meet the requirements of the NEC article 240 sections 80

through 83C.

8.2.6.2 In the case of multiple circuit rectifiers with individual transformers, each circuit shall be equipped with its individual AC supply protected by a properly sized fuse in addition to the breaker.

8.2.6.3 Rectifiers shall be equipped with a quick acting magnetic breaker, rated at 120 percent of the circuit capacity, placed in one leg of the AC secondary of each circuit.

8.2.6.4 The unit shall be equipped with properly sized AC and DC lightning protection.

8.2.6.5 Each controlled output and every input to the rectifier shall be equipped with properly sized surge suppressors. Metal oxide varistors (MOV's) used to protect the AC input and DC output shall be rated at 500 joules and a voltage rating providing adequate protection to the internal circuitry.

8.2.7 DC Panel Meters - DC Panel Meters, when specified, shall meet the requirements of Sections 8.2.7.1 through 8.2.7.5.

8.2.7.1 DC panel meters shall be equipped with a scale 64 mm or greater, with a d'Arsonval pivot and jewel type movement, with an accuracy of 2 percent of full scale.

8.2.7.2 The meter circuit(s) will include a switch, hermetically sealed, which removes the meter(s) from the circuit when not in use.

8.2.7.3 The ammeter shall be connected to an external shunt plainly marked to show ampere rating and millivolt drop. A single ammeter may be used in conjunction with a hermetically sealed selector switch to read each circuit's output.

8.2.7.4 Combination volt/ammeters, when specified, shall have the volt scale and ampere scale clearly labeled.

8.2.7.5 Digital meters, when specified, shall monitor the voltage and current output of each circuit of the rectifier using hermetically sealed switches to select the reading required. The selector switch shall have an off position which removes all input signals from the meter sense leads. The meter shall be equipped with a meter power on/off switch and shall be equipped with an LCD (or LED) three and one half digit (minimum) display. The meter accuracy shall be ± 0.05 percent, with an operating temperature

range of $18 \pm 48^{\circ}\text{C}$, and a storage temperature range of $25 \pm 55^{\circ}\text{C}$. The meter input impedance shall be at least $10\text{ M}\Omega$.

8.2.8 Shunts - Shunts shall meet the requirements of Sections 8.2.8.1 through 8.2.8.3.

8.2.8.1 Each output circuit shall have a DC shunt readily accessible for meter accuracy checks.

8.2.8.2 Shunt(s) shall be mounted on the control panel and labeled.

8.2.8.3 Shunt(s) shall be placed in the negative circuit rated at 50 mV and 120 percent of the maximum circuit current, and have uninsulated ring tongue terminals, positioned for easy connection of test equipment or meters, fastened to the calibrated test points. The negative circuits shall not be connected together.

8.2.9 Ground Fault Interrupter - A 115 V AC, Ground Fault Interrupter (GFI), grounded AC convenience outlet shall be mounted on the panel face. The outlet shall be fused for 15 amperes and attached to the line side of the circuit breaker.

8.2.10 Terminals - Terminals shall meet the requirements of Sections 8.2.10.1 through 8.2.10.5.

8.2.10.1 A 600 volt AC input terminal block shall be provided with "dead front" located on the insulated control panel for connection of the input AC wiring.

8.2.10.2 The positive and negative output terminals for each circuit of the rectifier shall be solderless, compression lugs, spaced a minimum of 50 mm apart, sized to accommodate up to No. 6 AWG wire, and mounted on the control panel.

8.2.10.3 Binding posts, suitable for attaching No. 10 AWG wire, shall be provided for each zone to accommodate two reference electrodes and structure test leads.

8.2.10.4 Test jacks shall be provided for external monitoring of each voltage, current, or potential reading being taken.

8.2.10.5 All terminals shall be clearly identified on the panel.

8.2.11 Output Control - The output control shall meet the requirements of sections 8.2.11.1 through 8.2.11.12.

8.2.11.1 Saturable reactors shall be used to provide constant current output for each circuit.

8.2.11.2 Each circuit shall have its own reactor and control stack with individual adjustment so that adjustment of one circuit's output will not affect the output of any other circuit.

8.2.11.3 Adjustment shall be by means of a potentiometer and voltage taps that enable smooth circuit output adjustment throughout a range of at least 10 percent of maximum circuit current and not more than 100 percent maximum circuit design current.

8.2.11.4 The potentiometer shall be sized to handle 115 percent of the maximum RMS control winding current.

8.2.11.5 The minimum capacity control stack shall be sized to provide 110 percent of maximum RMS control winding current with a junction temperature of 100°C .

8.2.11.6 Both the control stack and potentiometer shall be properly heatsinked as required to provide continuous operation at maximum control current and the ambient temperature specified.

8.2.11.7 Current regulation from full load to short circuit shall not exceed 115 percent on any circuit.

8.2.11.8 The maximum hot spot temperature rise of any reactor shall be 75°C .

8.2.11.9 The constant current output shall remain within a range of ± 5 percent of the set value over a change of resistive loading from 0.25 ohms to 2.5 ohms with the input AC voltage remaining constant.

8.2.11.10 The constant current output may vary in proportion to changes in the AC line voltage input to the rectifier.

8.2.11.11 A link bar arrangement shall be provided to allow operation in constant voltage mode.

8.2.11.12 When connected, the link bar will bypass the rectifier, disabling constant current operation. This arrangement shall be located on the instrument panel of the rectifier and be properly labeled as to function.

8.2.12 Interrupter Connection - The Interrupter connection shall meet the requirements of Sections 8.2.12.1 through 8.2.12.3.

8.2.12.1 The interrupter connection shall be installed to allow interrupting the input power to the rectifier with a portable interrupter.

8.2.12.2 The hot line coming from the load side of the circuit breaker shall be connected to a stud and link bar arrangement, with studs spaced 3 inches apart.

8.2.12.3 The stud and link bar arrangement shall be "dead fronted" and labeled.

8.2.13 Wiring - Wiring shall meet the requirements of Sections 8.2.13.1 through 8.2.13.4.

8.2.13.1 All wiring and current carrying studs within the rectifier, except for meter circuits, shall be sized for not less than $2.5335 \times 10^{-7} \text{ m}^2$ per ampere.

8.2.13.2 All current carrying bolts, terminals and connections shall be of copper, brass or bronze.

8.2.13.3 Electrical connections made through the panel shall be either soldered to the bolt head or utilize the double nut method so as not to depend on the compression strength of the panel to maintain a tight connection.

8.2.13.4 All connections shall be clear coated to prevent corrosion.

8.2.14 Nameplate - A Metal Nameplate stamped or engraved with the name of manufacturer, serial number, AC input volts and Amps, number of phases, DC output volts and amps, maximum operating ambient temperature, model code, and frequency, shall be provided for each rectifier.

8.2.15 Enclosure Finish - The enclosure finish shall meet the requirements of Sections 8.2.15.1 through 8.2.15.7.

8.2.15.1 All welds shall be smoothed by grinding and all sharp edges rounded before finishing.

8.2.15.2 The entire enclosure shall be galvanized in accordance with ASTM A123 to a minimum coating thickness of 66 μm .

8.2.15.3 The enclosure shall be chemically cleaned

or steam cleaned followed by an air dry vinyl wash etching primer.

8.2.15.4 The enclosure shall include a homogeneous undercoat of at least 12 μm of epoxy-based primer. The epoxy-base primer shall be applied over the entire surface and oven dried before applying two top coats of paint.

8.2.15.5 The first top coat shall be a base enamel paint applied in a homogeneous coverage over the entire surface without holidays, spatter or runs and with a dry film thickness of at least 12 μm . This coat shall be bake dried before applying the final top coat of baked enamel.

8.2.15.6 The final coat shall be an enamel paint of the color specified for the project applied in a homogeneous coverage over the entire surface without holidays, spatter or runs and with a dry film thickness of at least 12 μm . The final coat shall be bake dried and allowed to cool to room temperature before handling.

8.2.15.7 The final dry film thickness of all coats shall be at least 27 μm .

8.2.16 Panel Material - The panel shall be constructed of 1/4-inch thick bakelite NEMA grade XX, or equal insulating material. All panel functions shall be legible and permanently labeled near the function being described using engraving techniques in the panel or by bolting on engraved plates.

8.2.17 Remote Monitoring - A terminal block(s), suitable for connection of No. 18 AWG wire shall be provided to allow remote monitoring of output voltage, output current, and structure potentials of each circuit.

8.2.18 Filters - All single phase units shall include a filter. All filters shall meet the requirements of Sections 8.2.18.1 through 8.2.18.5.

8.2.18.1 The output ripple of each circuit of the rectifier shall not exceed 5 percent of rated output voltage when measured at rated output voltage and current.

8.2.18.2 The output ripple shall not exceed 5 percent of measured output voltage when measured at 25, 50 and 75 percent of rated output current.

8.2.18.3 The filter shall be removable, using switches and/or link bar arrangements, unless the

filter is discharged completely when connected to the rated load, in less than 15 milliseconds after interruption of the input power.

8.2.18.4 Choke designs shall meet the applicable requirements of the transformer specification (MIL E917).

8.2.18.5 The capacitor shall have a DC working voltage of twice the rated voltage output of the rectifier.

8.2.19 Disconnect Switch - The rectifier power input circuit shall be furnished with a switch and enclosure separate from the rectifier. The disconnect switch shall meet the requirements of Sections 8.2.19.1 through 8.2.19.4.

8.2.19.1 The switch shall be a single-throw fuseable safety disconnect switch with solid copper neutral bus bar and shall be listed with the Underwriters Laboratory.

8.2.19.2 The switch rating shall be as required to supply the maximum voltage and current of the rectifier.

8.2.19.3 The switch shall be lockable in both the on and the off positions.

8.2.19.4 The switch enclosure classification shall be a NEMA 3R type enclosure with a baked enamel finish.

8.2.20 Solar Power Supply - The solar power supply, if required by the project specifications, shall be designed using the latest information concerning solar insolation for the area in which the power supply is to be installed as published by the Solar Energy Research Institute. If information is not published for the exact location of installation, then the nearest location for which information is published shall be used. The solar power supply shall meet the requirements of Sections 8.2.20.1 through 8.2.20.9.

8.2.20.1 The array shall be sized using the least favorable mean daily direct normal insolation figures as the design parameter and shall be able to supply 120 percent of the maximum daily (24-hour) output ampere/hour rating of the power supply.

8.2.20.2 The unit shall include an electronic battery charge regulator set up to supply 2.35 volts per cell in series (lead acid type battery). The charge rate

shall be temperature compensated at a rate of six millivolts per degree C per cell.

8.2.20.3 Solderless pressure type terminals shall be provided for solar array and battery connection.

8.2.20.4 The unit shall include an output regulator complete with solderless pressure type terminals.

8.2.20.5 Separate 50 millivolt shunts shall be provided for charge current and output current measurements.

8.2.20.6 A meter, to read output voltage and current, and an on/off switch, to remove the load from the output of the power supply, shall be provided.

8.2.20.7 A blocking diode shall be installed in series with the solar array output to prevent battery leakage through the solar panels during sunless periods.

8.2.20.8 Battery capacity shall be determined by the daily ampere per hour requirement of the load as well as the minimum ambient temperature of the area of installation. Batteries shall be sized to provide a minimum of five additional days of reserve capacity and shall be maintenance free lead acid shallow discharge type. The total battery shall be sized using the 10-hour discharge rate as published by the battery manufacturer.

8.2.20.9 All current carrying power wiring shall be sized for a minimum of $5.0671 \times 10^{-7} \text{ m}^2$ per ampere.

8.3 Reference Cells - Reference Cells shall be either silver-silver chloride or graphite. Only one type shall be used on a project. The cells shall conform to the test requirements of TP51.

8.3.1 Silver/Silver Chloride Cells - A silver/silver chloride cell shall meet the requirements of Sections 8.3.1.1 through 8.3.1.5.

8.3.1.1 The cell shall consist of a silver metal element covered in silver chloride electrolyte and encased in a concrete compatible jacket.

8.3.1.2 A single conductor lead wire shall be factory attached to the silver element. The single conductor wire shall be No. 14 AWG meeting the requirements of Section 8.5 and colored black. The black conductor shall be connected to the silver element and sealed against moisture.