SECTION 34 21 22
TRANSFORMER-RECTIFIER UNITS – DRY TYPE TRANSFORMER, UNCONTROLLABLE RECTIFIER

PART 1 – GENERAL

1.01 SECTION INCLUDES

A. General
B. Overload requirements
C. Ratings
D. Transformer – rectifier unit
E. Factory testing
F. System factory functional testing
G. Field acceptance testing

1.02 RELATED SECTIONS

A. Section 01 33 00 Submittal Procedures
B. Section 01 33 23 Shop Drawings, Product Data, and Samples
C. Section 01 43 00 Quality Assurance
D. Section 01 45 00 Quality Control
E. Section 01 78 23 Operation and Maintenance Data
F. Section 01 45 24 Testing Program Requirements
G. Section 07 41 00 Sample Conformed Contract Specifications
H. Section 34 21 01 General Requirements for the Traction Power System
I. Section 34 21 07 Prefabricated Portable Substations
J. Section 34 21 25 DC Switchgear
K. Section 34 21 75 Traction Power Facility System Factory Functional Testing
L. Section 34 21 80 Traction Power System Field Acceptance Testing
1.03 MEASUREMENT AND PAYMENT

A. Measurement: Dry type transformer and uncontrolled rectifier units will be measured for payment per individual unit of each type that is tested and furnished in accordance with the Contract Documents.

B. Payment: Dry type transformers and uncontrolled rectifier units will be paid for at the Contract unit price per each individual unit of each type as indicated in the Bid Schedule of the Bid Form.

1.04 REFERENCES

A. American National Standards Institute (ANSI):

1. ANSI C34.2 Practices and Requirements for Semiconductor Power Rectifiers (Withdrawn).

2. ANSI C37.45 Standard Specifications for High-Voltage Distribution Class Enclosed Single-Pole Air Switches with Rated Voltages from 1 kV through 8.3 kV.

B. Institute of Electrical and Electronics Engineers (IEEE):

1. IEEE C57.12.01 Standard for General Requirements for Dry-Type Distribution and Power Transformers.


5. IEEE C57.113 Recommended Practice for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors.

6. IEEE C57.124 Recommended Practice for the Detection of Partial Discharge and the Measurement of Apparent Charge in Dry-Type Transformers.

7. IEEE 519 Recommended Practice and Requirements for Harmonic Control in Electric Power Systems.

8. IEEE 1653.1 Standard for Traction Power Rectifier Transformers for Substation Applications up to 1500V DC Nominal Output.

9. IEEE 1653.2 Standard for Uncontrolled Traction Power Rectifiers for Substation Applications up to 1500V DC Nominal Output.
C. National Electrical Contractor’s Association (NECA):
   1. NEIS National Electrical Installation Standards.

D. National Electrical Manufacturer’s Association (NEMA)
   1. NEMA EL 21.2 Instrument Transformers for Revenue Metering (125 kV BIL Through 350 kV BIL).
   2. NEMA TR 1 Transformers, Regulators and Reactors.
   3. NEMA RI-9 Silicon Rectifier Units for Transportation Power Supplies (Withdrawn).

E. National Fire Protection Association (NFPA):
   1. NFPA 70 National Electrical Code (NEC).

F. JEDEC Solid State Technology Association
   1. JESD282B.01 Silicon Rectifier Diodes.

1.05 SUBMITTALS

A. General: Refer to Section 01 33 00, Submittal Procedures; and Section 01 33 23, Shop Drawings, Product Data, and Samples for submittal requirements and procedures.

B. Product Data: Submit product data to include the following:
   1. Physical arrangement and assembly drawings of rectifier transformer and traction rectifier.
   2. Wiring connections.
   3. Shop drawings.
   5. Equipment nameplate.
   6. Transformer data including rated kVA, frequency, primary and secondary voltages, percent taps, polarity, impedance and certification of transformer performance efficiency at indicated loads, percentage regulation at 100 percent and 80 percent power factor, no-load and full load losses in watts, percent impedance at 75 degrees Celsius, hot-spot and average temperature rise above 40 degrees Celsius ambient temperature, sound level in decibels, and standard published data.
   7. Product data for traction rectifier including diodes, fuses, heat sinks, over-voltage protection devices, fuse monitoring, and door interlocks.
C. Design calculations for the transformer-rectifier unit, including extended voltage regulation curve from light transition load to short-circuit condition, no-load voltage, power factor as function of loading, efficiency as function of loading, harmonics on the DC and AC side, and sizing of dummy (base) resistor.

D. Test plan and procedures for factory testing of the rectifier transformer.

E. Test report for factory testing of the rectifier transformer.

F. Test plan and procedures for factory testing of the traction rectifier.

G. Test report for factory testing of the traction rectifier.

H. Test plan and procedures for factory testing of the transformer-rectifier unit.

I. Test report for factory testing of the transformer-rectifier unit.

J. Test plan and procedures for field testing of the rectifier transformer.

K. Test report for field testing of the rectifier transformer.

L. Test plan and procedures for field testing of the traction rectifier.

M. Test report for field testing of the traction rectifier.

N. Test plan and procedures for field testing of the transformer-rectifier unit.

O. Test report for field testing of the transformer-rectifier unit.


Q. Operation and Maintenance Manuals: Provide the following operations and maintenance manuals in accordance with Contract Specification Section 01 78 23, Operation and Maintenance Data.

R. Design calculations for the rectifier transformer, including power rating, windings turn ratio, impedance, commutating reactance, no-load losses, full-load losses, performance over specified temperature range, and seismic calculations.

S. Design calculations for the traction rectifier, including determination of the number of diodes per rectifier leg, continuous current and short-term overload capability, fuse ratings and transient voltage suppression devices.

T. Rectifier transformer mounting, cable or busway entry, and conduit design for cable connections to the rectifier transformer shall be submitted for review and acceptance by the Engineer.

U. Plan of design techniques, construction methods, and equipment employed to protect against transient surge voltages.
V. Submit proof in the form of calculations or empirical data that the rectifier transformer meets the noise level requirements.

W. Submit the methods and procedures for replacement of the rectifier transformers.

X. Submit paint type and color to be reviewed and approved by the Engineer.

Y. Submit a recommended spare parts list.

1.06 QUALITY ASSURANCE AND SUPPLIER QUALIFICATIONS

A. Electrical components, devices, and accessories shall be listed and labeled in conformance with the NFPA 70, Article 100. Electrical components, devices, and accessories and their installation shall comply with NECA’s National Electrical Installations Standards (NEIS).

B. Transformers and rectifiers shall be proven standard products, or equivalent to the standard products of manufacturers engaged in the production of such equipment for at least the past five years.

C. The manufacturer of the rectifier transformers must have a minimum of five years manufacturing experience with three-winding, dry type power transformers, utilizing IEEE 1653.2 Circuit 31 configurations.

D. The engineer responsible for the design of the rectifier transformers and rectifier shall have a minimum of five years of project-proven experience in the design of three-winding rectifier transformers.

1.07 DELIVERY, STORAGE, AND HANDLING

A. Delivery, loading/unloading, handling, storage, and protection of transformer shall be in accordance with manufacturer’s guidelines.

B. Equipment shall be packaged for arrival at the Jobsite undamaged by handling and weather.

C. Temporary braces, guides, skids, crates, and other shipping devices necessary for transporting and temporary storage of the equipment shall be furnished. Temporary bracing shall be labelled “Remove Before Operation”.

D. Equipment shall be protected against corrosion, dampness, damage due to vibration, and other damage during transportation and handling. Openings to the external environment shall be sealed before shipping. Products shall be packed in weatherproof containers for storage outdoors.

1.08 WARRANTY

A. A warranty for the rectifier transformers, traction rectifiers, and associated system components shall be provided and signed by the manufacturer and installer agreeing to correct system deficiencies and replace components that fail in materials or
workmanship. The warranty shall be for the period of five years from the date of issuance of the Substantial Completion of each substation.

PART 2 – PRODUCTS

2.01 GENERAL

A. The Supplier shall coordinate the requirements of associated substation equipment to provide a 1000 V DC traction power supply.

B. Transformer windings, rectifier buses, and interconnecting AC buses shall be made of copper conductors.

C. The transformer-rectifier units shall be designed and fabricated in accordance with the latest revision of the applicable ANSI, IEEE, and NEMA standards as listed in Section 1.04.

D. Each unit shall consist of a rectifier transformer and a traction rectifier with necessary hardware, wiring, and devices as indicated, and as required for a complete and operating installation.

E. The rectifier transformer shall receive 34.5 kV, three-phase, 60 Hz, 3-wire power from 34.5 kV vacuum fault interrupter switchgear and shall transform the high voltage to a low AC voltage rated as required by the traction rectifier.

F. The rectifier transformer shall be designed with an enclosure for outdoor use.

G. Rectifier transformer shall be housed in portable substation house trailer as specified in Section 34 21 07, Prefabricated Portable Substations and shall meet requirements for underground devices in IEEE C57.13.28 and IEEE C57.12.29.

H. Rectifier transformer shall be mounted to the 34.5 kV switchgear and rectifier transformer house trailer as shown in the Contract Drawings.

2.02 OVERLOAD REQUIREMENTS

A. The transformer-rectifier unit shall be rated for extra heavy-duty traction load. The unit shall be able to operate at the following overload cycle, beginning from operation at nominal load and stabilized temperature:

1. 150 percent of rated current for 2 hours, with superimposed 5 periods of 1 minute duration at 300 percent of rated current each, equally spaced throughout the 2-hour period.

2. 450 percent of rated current for 15 seconds at the end of the two-hour period.

B. The transformer-rectifier unit shall withstand two overload periods as specified above on a daily basis, spaced 8 hours apart, each preceded and followed by the continuous 100 percent load level.
C. The transformer-rectifier units shall be designed to meet the above daily duty cycle without damage to any parts or the insulation for a period of 25 years.

D. Current unbalance caused by loss of one diode per phase shall be taken into consideration in the design, and shall not reduce the specified overload capability of the rectifier.

2.03 RATINGS

A. Unit Capacity

1. The kW rating of the transformer-rectifier units shall be as indicated. The units shall be designed to deliver the rated kW output at rated terminal voltage.

2. The units shall withstand continuous operation at 110 percent rated voltage without exceeding the equipment temperature limitations.

B. Efficiency: The overall efficiency of the transformer-rectifier shall be greater than 97.5 percent at its continuous rating. No-load core losses shall not exceed 0.25 percent of the rated unit capacity.

C. Power Factor: The displacement power factor of the transformer-rectifier units shall be 0.95 or greater from 25 percent to full load with rated AC input voltage.

D. Voltage Regulation: The transformer-rectifier units’ initial regulation shall be 6 percent. The regulation shall be linear from light transition (1 percent) load to at least 300 percent of full load. Manufacturing tolerance shall not exceed 10 percent of the specified regulation value. The voltage at the rectifier output at no-load shall not exceed 1350 V DC at rated primary voltage of 34.5 kV. The light transition load voltage shall be approximately 1,060 V DC at the rated primary voltage of 34.5 kV, while the full-load (nominal) voltage shall be 1000 V DC, with plus-or-minus 6 V maximum deviation allowed for manufacturing tolerance.

E. Short-Circuit

1. Each transformer shall be designed to withstand a full short-circuit at the low-voltage terminals at rated voltage on the high-voltage terminals for one second, in accordance with IEEE C57.12.01 and C57.12.91.

2. Components of the rectifier unit, including the terminal connections and buswork, shall be designed to withstand a bolted fault on the DC positive bus, without damage, for the time period required for the backup protection to operate and open the 34.5 kV vacuum fault interrupter.

3. The transformer shall be designed to withstand the short-circuit power available from the 34.5 kV subtransmission lines at the switching stations which is expected to be up to 500 MVA.
4. The secondary windings of the rectifier transformer shall be coupled magnetically, so that at a given fault level of 500 MVA at 34.5 kV, the sustained short circuit current on the rectifier bus for a bolted fault does not exceed nine times the full load current.

F. Additional Rating Requirements:

1. See Section 2.04 for rectifier transformer ratings.

G. Voltage Transients

1. Transformer-Rectifier unit shall be protected against transient surge voltages per IEEE 1653.2.

2. If fuses are used in surge suppression networks, they shall be monitored by visual indicators, and shall be equipped with devices capable of being monitored both locally and remotely.

3. A surge protection network at the input terminals shall protect each rectifier unit from damage due to switching voltage transients up to 2.5 times normal voltages in the 34.5 kV AC system. Failure of the surge protection network shall be annunciated both locally and remotely as indicated.

4. A static voltage surge suppressor rated to withstand expected voltage transients, shall protect each rectifier from lightning surges transmitted along DC contact rails and from voltage transients on the DC system due to breaker switching. A counter shall be provided for the surge suppressor. Failure of the surge suppressor shall be annunciated both locally and remotely as indicated.

5. The surge suppressor shall absorb surge energy of 50 kilojoules minimum with bus potential below 2600 volts at instantaneous current of 4000 amperes.

6. The peak value of contact rail transient voltages are expected to be 3000 volts for 8 milliseconds or 6000 volts for 50 microseconds with rise time of 1.2 microseconds.

H. Noise Levels

1. Equipment design, enclosures with acoustic mitigation capability, and other measures, as appropriate, shall be employed to achieve compliance with the specified audible noise level criteria.

2. The noise level measured at a distance of 15 feet from the rectifier transformer enclosure with the transformer operating at 100 percent load and nominal voltage shall not exceed 65 dBA.
2.04 TRANSFORMER – RECTIFIER UNIT

A. Rectifier Transformer:

1. The rectifier transformer shall comply with the requirements of IEEE C57.12.01, C57.12.91, ANSI C57.18.10, IEEE 1653.1, and NEMA TR 1. Each rectifier transformer shall be solid cast coil or resin encapsulated type, self-cooled, three-phase, 60 Hz, three-winding, suitable for outdoor service for the duty cycles indicated. Each cast coil shall be cast under vacuum to ensure complete, void-free epoxy resin impregnation throughout the insulation system. Coils for resin encapsulated type transformers shall be fabricated using the multi-cycle vacuum pressure encapsulation (VPE) process. Resin encapsulated type transformer manufactured with vacuum pressure impregnation (VPI) followed by encapsulation with a polyester resin mixture are acceptable.

a. Winding Connections. High and low voltage windings shall be copper. Winding insulation shall be 180 degrees Celsius for cast coil and 220 degrees Celsius for VPI/VPE. High-voltage windings shall be three-phase, 60 Hz, 34.5 kV Class with a minimum BIL of 200 kV. Low-voltage windings to be six-phase with a minimum BIL level of 45 kV. High voltage winding connectors to vacuum fault interrupter switchgear shall be made of #2/0, 35 kV EPR cable entering from below as indicated in the Contract Drawings.

b. Temperature Rise:

1) Winding Temperature Rise above 50 degrees Celsius ambient after stabilized continuous operation at 100 percent load: 55 degrees Celsius.

2) Hottest-Spot Temperature Rise above 50 degrees Celsius ambient after stabilized continuous operation at 100 percent load: 85 degrees Celsius.

c. Impedance. Select the transformer impedance to provide the specified rectifier output voltage as specified in Section 2.04B, Rectifiers.

d. Taps. The high voltage windings to have four 2.5 percent, full capacity off-load taps, two above and two below the rated voltage of 34.5 kV. Tap changing shall be by movable links. Tap connections shall be brought out and rigidly supported on a terminal board located in the transformer enclosure, and be accessible through removable access panels. Access panels shall contain observation windows for observing the connected tap. Tap connections shall be clearly marked so that the tap selected is clearly identifiable through the observations window.

e. The tap changing links shall be securely bolted in position. The design of links and connectors shall make it impossible to short out sections of windings, or to select taps outside the prescribed range, by incorrectly connecting the links.

f. Accessories. Provide standard and indicated accessories and protective devices. Contacts shall be electrically separate. Provide a winding temperature indicator, Device 249, with maximum reading pointer to detect transformer winding over-temperature and with a factory set, two-stage contact. Provide the first stage with a normally-closed contact that opens on temperature increase to initiate local and remote supervisory control
annunciations. Provide the second stage with a normally-open contact that closes on temperature increase to initiate tripping of the unit lockout relay, Device 286.

g. Provide lugs required for cable interconnections between rectifier-transformer and rectifier and rectifier. Size and number of NEMA 2-hole lugs shall be as indicated.

h. Assembly. Design the transformer so that parts that require maintenance are readily accessible.

1) Transformer Enclosure. Enclose the transformer in a rigid, self-supporting and self-contained, electrically-welded, outdoor steel structure. Design the structure to be sufficiently rigid to withstand maximum short-circuit currents. Provide bolt-on doors on front and rear of enclosure to permit ready access for inspection and maintenance. Provide door switch (33T) on transformer doors. Operation of door switches shall initiate local and remote supervisory control annunciations and operate the unit lockout relay, Device 286. Provide nameplate in accordance with IEEE C57.18.10.

2) Lifting Hooks. Provide lifting hooks or eyes on the transformer core and coil assembly and on the enclosure to facilitate lifting parts of the unit separately.

2. Construction Requirements

a. Transformers shall be replaceable.

b. Transformers indicated for portable use shall be designed for trailer mounting, and shall be designed such that their portability does not reduce their specified service life. Transformer parameters, including overall dimensions and weight, shall be coordinated with the design of the Supplier supplied prefabricated portable substation and trailer. Refer to the requirements of Contract Specifications Section 34 21 07, Prefabricated Portable Substations.

c. Transformers indicated for permanent mounting shall be designed for installation as indicated (e.g., on a steel floor within a prefabricated portable module). Floor loading: Transformer base shall be compatible with floor design loading of 250 pounds per square foot.

d. Transformer supporting steelwork and enclosures shall be painted as indicated.

e. Transformer shall meet the following:

1) Provide nameplate with connection diagram and tap arrangement.

2) Provide warning signs as required.

3) Provide ancillary equipment control cabinet on the outside of transformer enclosure housing the alarms and trip signals due to activation of the protective devices including control power alarms shall be communicated via the I/O module located in the control cabinet. These signals shall be transmitted via for the optic cable to the C02 panel at the DC switchgear house.
4) The main transformer control cabinet shall have thermostatically controlled anti condensation heaters rated for 120 V single phase power supply.

f. Base Construction:

1) The structural steel base shall consist of at least two members parallel to the transformer major axis and at least two members parallel to the minor axis.

3. Transformer Enclosures:

a. Panels comprising the transformer enclosure including doors shall be constructed of sheet steel, not less than No. 11 gauge, and mounted on rigid, self-supporting structural steel framework.

b. Glastic-type insulation shall be provided between the low voltage AC busway and the uncontrolled rectifier unit.

c. Convenient access, including doors on both front and rear sides, shall be provided for maintenance and inspection of the transformer.

d. Each enclosure door shall be equipped with:

1) A mechanical latch to hold the door closed. Mechanical latches shall withstand seismic events for which the rectifier transformer is rated.

2) Door stays to hold the door open for inspection of rectifier transformer components.

e. Openings and mounting holes for front-mounted indicating and control devices shall be cut out, drilled, or punched without marring or distorting the exposed finished surfaces of the control cubicles.

f. Separate compartments shall be provided to isolate control and auxiliary circuits and functions.

g. Readings, controls, and observations shall be made without the exposure to live parts.

h. Frame and base design shall be sufficient to comply with floor design loading of 250 pounds per square foot.

i. If transformer is not to be placed on a trailer, base shall be suitable for skidding the transformer unit in any direction on rails or rollers and have jacking facilities at each corner.

j. Grounding bus integral to the transformer enclosure shall be provided and connected to the transformer core and supporting steelwork. The transformer enclosure shall be provided with two (2) grounding pads on opposite sides, suitable for connection to the substation ground grid. If the transformer is mounted on a trailer, bond transformer ground pads to the trailer frame and ensure trailer frame is connected to the facility ground grid.
4. Core:

a. Core and Coil Assembly:

1) Joints in winding or at terminals shall be either brazed or clamped.

2) Core-bolt insulation shall be high-temperature resistant. Stepped mitered lap core construction and entire assembly shall be braced or bolted adequately to prevent displacement and distortion under normal conditions of handling and operation under normal, overload, and short circuit conditions.

3) Bolted core members and connections shall be made by at least two bolts equipped with locknuts and lock washers.

4) Serial number shall be stamped on core in a conspicuous place.

5) Core laminating shall be high-grade, non-aging, grain oriented silicon steel with high magnetic permeability, low hysteresis and eddy current loss. Magnetic flux densities shall be kept below saturation to allow for a minimum of 10 percent overvoltage excitation. The outside surfaces of the core shall be protected against corrosion by a resin coating.

6) The core shall be stacked in the step or cruciform method to best accommodate a round coil.

7) Core lamination shall be free of burrs and stacked without gaps.

8) The individual coil shall be assembled on the core and arranged coaxially so that the electrical centers are reasonably matched.

9) Even compression on the coils shall be maintained throughout the transformer’s complete temperature range. The compression shall also remain constant in case of unequal movement of the primary and secondary coils.

10) Coils shall be supported axially by bottom supports and constant pressure blocks, with the blocks support the coil concentrically. The core clamping structure shall be of rigid construction and designed to provide full clamping pressure on the core and to provide locations for applying blocking and jacking points to support the coils. The top and bottom core clamps shall maintain constant pressure through the life of the transformer’s complete temperature range. The core shall be adequately clamped to prevent excessive humming and chattering.

11) Core and coil shall be mounted on vibration suppressors within the enclosure if necessary to keep the noise level of the transformer below 65 db.

5. Windings:

a. The High Voltage winding shall be thoroughly reinforced with fiberglass matting to adjust the expansion so that it is close to that of the copper conductor.

b. Fiberglass matting shall reinforce the winding so that the winding will withstand thermal stresses during the load cycle. The fiberglass matting shall
enhance the pure epoxy or polyester to increase its mechanical strength, arc resistance, and adhesion to the conductor, plus change its coefficient of expansion to be closer to that of the conductor. The vacuum cast coils shall be reinforced with fiberglass mat.

c. The finished primary and secondary coils shall be hermetically sealed in epoxy or polyester utilizing a proven manufacturing process demonstrating its ability minimize hot spots and partial discharge. Control, auxiliary power, and alarm circuits shall be completely wired in the factory. Wiring shall run in the rigid metallic raceway, with an exception for watertight fittings to be used on runs of two feet or less. Auxiliary connections to external circuits shall be brought to one NEMA 3R junction box and terminated on terminal blocks. Manufacturer shall provide documentation supporting the temperature rating of 150 degrees Celsius.

d. The rectifier transformer primary windings shall be close coupled with the secondary windings.

6. Special Tools:
   a. Special tools required for installation and maintenance of the equipment shall be identified by the manufacturer at time of bid.

7. Marking:
   a. Every transformer shall be provided with a rating plate showing the information required by IEEE 1653.1.
   b. The rating plate shall indicate the type of conductor used for both high voltage and low voltage windings (e.g., copper).
   c. The rating plate shall indicate that the transformer is constructed for Heavy Traction Duty as defined in IEEE C57.18.10.
   d. The rating plate shall show the physical layout of tap board and the turns ratios.

B. Rectifier:

1. General
   a. Each rectifier bridge or section shall be a complete self-contained unit consisting of silicon diodes, heat sinks, protective fuses, natural ventilation system, copper buses and bus connections, enclosure with doors, hardware, gaskets, and other necessary accessories and devices.
   b. The rectifier shall be indoor type, with natural convection-cooling, and shall be designed to operate at 50 degrees Celsius ambient temperature.
   c. The rectifier shall consist of two six-pulse, delta-wye, double-way circuits each having six legs of diode devices connected to the transformer delta wye secondary windings, per IEEE 1653.2 circuit No. 31.
   d. An interphase transformer shall be provided between the direct outputs of the two six-pulse sections to absorb the instantaneous direct voltage differences.
To achieve the lowest practical noise level, the core of the interphase transformers shall be designed to minimize the magnetostriction. Magnetostriction is the phenomenon of elastic deformation that accompanies magnetization. Noise damping treatment may be accepted in reducing the noise level by canceling some of the noise frequencies of the interphase transformer. However, the Supplier shall submit calculations showing that any noise treatment allows rectifier ventilation that meets the specifications. The Supplier shall submit calculations showing that the noise level expected for the transformer under full load or maximum excitation meets the specified noise level limits for the transformer-rectifier unit per Article 2.03H herein. The calculations shall demonstrate adequate magnetic core material is used to accept expected IEEE 1653.2, extra heavy-duty rectifier loading with a noise level that meets the Contract Specifications. The calculations shall be signed by a California registered professional engineer specialized in noise suppression field.

e. Materials shall be chosen to preclude the possibility of corrosive or galvanic action between dissimilar metals. Compatible materials shall be used for diode cases, studs, and heat sinks.

f. The rectifier enclosures shall be designed for high-resistance type enclosure-to-ground protective relaying.

2. Rectifier Enclosures

a. Panels comprising the rectifier enclosure including doors shall be constructed of sheet steel, not less than No. 11 gauge, and mounted on rigid, self-supporting structural steel framework.

b. Insulation shall be provided between the rectifier and the DC main breaker cubicle and between the rectifier and the negative return cabinet. Adequate electrical insulation shall be provided between the rectifier enclosure and the AC busway from the rectifier transformer, such that a person cannot simultaneously touch the rectifier enclosure and any adjacent ground structure.

c. Louvered or mesh openings shall provide ventilation and air-cooling of the components by natural convection.

d. Ventilation intake openings shall be located not less than six inches above the floor.

e. Heat transfer surfaces and ducts shall be designed with smooth surfaces that minimize accumulation of dust and other contaminants.

f. Convenient access, including doors on both front and rear sides, shall be provided for maintenance and inspection of the rectifier.

g. Each enclosure door shall be equipped with:
   1) a mechanical latch to hold the door closed and
   2) door stops to hold door open for inspection of rectifier components.
h. Openings and mounting holes for front mounted indicating and control devices shall be cut out, drilled, or punched without marring or distorting the exposed finished surfaces of the control cubicles.

i. Rectifier enclosure shall be furnished with viewing windows so that blown-fuse indicators and the position of the negative disconnect switch can be seen from the outside, without opening the rectifier doors.

j. Separate compartments shall be provided to isolate control and auxiliary circuits and functions from the 1000 V DC buses and diodes.

k. Readings, controls, and observations shall be made without exposure to live parts. Internal lights with an external switch shall be included. Lighting fixtures shall be provided with guards.

l. Components installed in the rectifier shall be capable of withstanding 4600 V DC for one minute, applied between completely assembled rectifier and ground, with control circuits connected and energized or grounded, except that ground connection to the 164A/164G relay shall be disconnected and its contact set in the OPERATE (tripped) condition.

m. Provide rectifier unit with provisions to establish rectifier electrical clearance such that potentials inside the rectifier enclosure are connected together with conductors capable of withstanding a fault if the rectifier unit is inadvertently energized for at least 0.5 seconds for protection devices to clear the fault. AC incoming power supply, DC positive, DC negative, and the rectifier frame shall be connected together to provide adequate and safe physical access for maintenance of the rectifier unit by maintenance personnel. The enclosure shall be connected to the high resistance ground relay (Device 164A/164G) as indicated.

n. Devices mounted within rectifier enclosures that use 125 V DC control power from an external power source, and where no means is used to electrically isolate the circuit, shall be mounted on glastic type insulating material to electrically isolate the device from the structure.

3. Diodes

a. Diodes shall be rated and tested in accordance with JESD282B.01. Parallel strings of diodes shall be geometrically similar and as symmetrical as practicable to balance the normal and surge electrical characteristics of each string.

b. In addition to the parallel strings necessary to handle loads, as specified, additional capacity shall be provided so that, with one diode per phase leg out of service, each current path will still handle specified loads and maximum short circuit current.

c. Each diode shall be able to withstand, at its maximum operating temperature, voltages 2.5 times higher than the no-load AC bus voltage of the rectifier, without a permanent change in diode characteristics.

d. The maximum current unbalance between parallel strings in each phase and between phases shall be such that the removal of any one diode per phase
does not impact the required thermal capacity or short-circuit withstand capability of the rectifier.

e. Each parallel diode string shall be protected against internal short circuits by a current-limiting, fast-acting fuse equipped with a microswitch for local and remote status indications, and visible blown-fuse indicator.

f. Diodes shall have uniform voltage division within plus or minus ten percent across each diode.

g. Each parallel diode string shall be protected by a current-limiting fuse equipped with an indicator. The fuses shall be sized to withstand any external DC fault or loading condition. The fuses shall blow to clear any failure permitting reverse conduction. A blown fuse indicator shall be visible from outside the rectifier enclosure. Alternative to fuses shall require District approval.

h. The number of diodes per leg shall not exceed 12 for 5-MW units, unless otherwise approved by the District.

4. Terminations

a. The rectifier shall be connected to its associated rectifier transformer through a metal enclosed busway with cables or braided copper connections on the transformer end to reduce bus vibration as indicated.

b. The rectifier DC output shall be connected either through a metal-enclosed positive bus or cables to its associated 1000 V DC main breaker cubicle.

c. The throat connections between equipment and busways shall be designed for close coupling and for installation and removal without the necessity of moving the transformer, rectifier, or DC main breaker cubicle.

d. Flanges shall be provided with gaskets to prevent entrance of moisture.

e. The negative DC terminal of each rectifier section shall be bus-connected to the negative disconnect switch through a metering shunt.

f. Configure the incoming negative cable connections to the negative disconnect switch to be in an enclosed negative bus box compartment separate from the rectifier. The only negative cables entering the rectifier shall be cable connections to the negative bus box.

g. Provide lugs required for cable interconnections between rectifier-transformer and rectifier and between rectifier and DC main breaker. Size and number of NEMA 2-hole lugs shall be as indicated.

5. Negative Disconnect Switch

a. The rectifier shall be provided with a negative disconnect switch, that shall be:

1) No-load, single-pole, single-throw, non-ferrous, non-magnetic, with solid copper current-carrying parts and silver-plated contacts. The switch shall be manually operated, bolted-pressure type, rated for at least 1500 V DC nominal, and with current ratings matching the overload and short-circuit capability of the rectifier.
2) Provided at a minimum with one normally-open and one normally-closed auxiliary contact.

3) Designed with ample space and contact surface for pulling and terminating the negative cables from the negative bus enclosure.

4) Key-interlocked with the associated DC main circuit breaker, so that the switch can be operated only with the main breaker in the open and withdrawn position.

5) Equipped with insulated handle.

b. NEMA 2-holes standard connectors shall be provided for the cable terminations as indicated.

c. A viewing window shall permit inspection of the disconnect switch position without opening the rectifier compartment.

6. Control and communication function shall be provided to include:

a. Binary (device contact) inputs, for collection and inclusion in custom control logic, and signal re-transmission.

b. Programmable logic controller (PLC) capability, including user-defined logic.

c. Programmable function keys.

d. Ethernet interface capability.

e. Binary (relay contact) outputs, for interface with other relays and for AC vacuum fault interrupter and circuit breaker control capability.

f. Coordinate with the C02 panel to implement controls, indications, and data transfer between the transformer-rectifier protection devices and the C02 panel for local and remote control, indication, and data transfer functions and processes. Communication between transformer-rectifier protection devices and the C02 PLC shall use the DNP3 protocol.

7. Relaying, Metering and Indicating Devices

a. Relaying, metering, and indicating devices shall be provided as indicated.

b. Temperature-measuring devices (126DT) shall be installed to detect an abnormal rise in diode heat sink temperatures. Each device shall have at least two stages. First stage contact shall be for local and remote annunciations and the second stage for AC vacuum fault interrupter and breaker tripping. The pickup point of each stage shall be adjustable and factory-set so that upon the heat sink temperature reaching the preset level the corresponding contact shall initiate an alarm or trip the AC vacuum fault interrupter and DC main breakers through the lockout relay (Device 286) as indicated.

c. Monitoring Devices (180DM) shall be provided to detect the loss of one or more diodes:

1) Failure of any diode in any string shall initiate local and remote alarms.
2) Failure of a second diode in a rectifier bridge shall initiate the tripping of the AC vacuum fault interrupter and DC main breaker via a lockout relay (Device 286) as indicated.

3) Rectifier doors to normally energized buses or components and to the negative disconnect switch shall be electrically interlocked to trip the AC vacuum fault interrupter and DC main circuit breaker through the lockout relay (Device 286), when a door is opened as indicated.

2.05 FACTORY TESTING

A. General: Testing shall be performed in accordance with the requirements specified in Section 01 45 24, Testing Program Requirements.

B. Transformer – Rectifier Units

1. The following design tests shall be performed on one transformer-rectifier unit complete with accessories. Unless specified otherwise the tests shall be performed with equipment fully assembled.

a. Basic Performance Parameters. Design tests shall be performed to verify the efficiency, voltage regulation, displacement power factor, and diode current balance at loads of 0, 25, 50, 75, 100, 150, 300, and 450 percent of rated load.

b. Temperature Rise Test

1) Locate the temperature probes in accordance with the industry standards, and use the test results from the individual probes to calculate the expected temperature rise on components of the involved equipment, and to verify that local temperatures of the transformer and the rectifier are within the limits indicated in IEEE C57.12.01 and IEEE C57.18.10.

2) The transformer-rectifier units shall be operated at 100 percent full-load till all parts have reached constant temperature before applying overloads. Constant temperature is deemed to be reached if the temperature rise change of any part becomes less than one degree Celsius per hour.

3) After constant temperature has been reached, the transformer-rectifier unit shall be operated at 150 percent full load for two hours with five cycles of 300 percent full load for one minute duration, each equally spaced through the two-hour period, followed by one period of 450 percent full load for 15 seconds at the end of the two-hour period.

4) The temperature rise tests may be performed with shorted rectifier output terminals, and at reduced AC input voltage sufficient to produce the required load currents.

c. Short-Circuit Test

1) Bolted short-circuit fault shall be made on the output terminals of the rectifier to verify the capability of the equipment to withstand the maximum fault current without damage. The source shall be three-phase, 34.5 kV AC, with fault level of no less than 500 MVA.
2) The fault shall be cleared by AC vacuum fault interrupter protective devices 250/251, 250N/251N, set the same as it will be on the installed system.

3) Each phase of the AC vacuum fault interrupter and the output of the rectifier shall be monitored. Test results of voltages and currents as a function of time shall be recorded on an oscillograph.

d. Noise Level Tests

1) Noise level tests shall be performed on one transformer-rectifier unit including the interphase transformer (IPT) mounted in its permanent location. Noise level shall be tested during the short circuit test and shall be field verified after rectifier installation on the real system while loaded. If field verification shows that noise level exceeds specified requirements, equipment shall be modified to provide noise within specified limits.

2) The noise level at full load, measured in accordance with NEMA TR 1 and IEEE C57.12.01, shall not exceed the specified levels.

e. Tests to establish the transformer-rectifier unit efficiency, voltage regulation, and power factor at 0, 1, 25, 50, 75, 100, 150, 200, and 300 percent of rated load. The tests shall be used to determine the required parameters by direct measurement; or, where direct measurement is not possible, the Supplier shall conduct tests to obtain data for the indirect derivation of the required parameters via calculations.

2. Production Tests: perform per IEEE 1653.1 and 1652.2 requirements.

C. Rectifier Transformers

1. The following design tests as applicable to power-type transformers listed in IEEE C57.12.01, IEEE C57.12.91, IEEE C57.18.10, IEEE 1653.2 and NEMA TR 1 shall be performed on one rectifier transformer of each size.

   a. Dielectric tests – impulse tests. Tests shall include one application of a reduced full-wave, two applications of a chopped wave, followed by one application of a full-wave. These tests shall be performed after the short-circuit tests and temperature rise tests on the rectifier transformer.

   b. Audible noise test as in NEMA TR 1, IEEE C57.12.91 and IEEE 1653.1.

   c. Impedance and load loss at rated current on the rated voltage connections and on all taps.

   d. Commutating reactance and resistance per IEEE C57.18.10.

   e. Short-circuit tests, as described in IEEE C57.12.01, IEEE C57.12.91, and IEEE 1653.1, shall be performed to evaluate fully the capability of windings. At least one extreme of the tap range shall be used in the tests. Short-circuits shall be applied on the secondary terminals of each winding.

2. The following production tests shall be performed on rectifier transformers in accordance with IEEE C57.18.01, IEEE 1653.1, and IEEE 1653.2:
a. Resistance measurements of windings on rated voltage connection and on all taps.

b. Ratio tests on the rated voltage connection and on all taps.

c. Polarity and phase relation tests on the rated voltage connection.

d. Impedance and load losses at rated current on the rated voltage connection and on all taps, including excitation loss and excitation current.

e. Dielectric low-frequency withstand, including applied-potential and induced-potential.

f. Partial discharge tests in accordance with ANSI C57.12.01, or as follows:
   1) The transformer shall be subjected to an induced voltage of 1.5 times the rated voltage at a frequency between 100 Hz and 400 Hz.
   2) Partial discharge measurements shall be performed with a selected instrument operating at a frequency of 1.9 MHz.
   3) Partial discharge extinction level shall be reached at an induced voltage higher than 1.2 times rated voltage.
   4) Partial discharge extinction level shall be considered to have been reached when the reading at 1.9 MHz is less than 10 microvolts or 13 picocoulombs.

D. Interphase Transformers

1. The following tests shall be performed on the interphase transformers in accordance with IEEE C57.12.91:

   a. Resistance measurement.
   b. Reactance excitation current and core loss measurements.
   c. Calculated DC loss at rated load.
   d. Insulation resistance test between windings and core.
   e. Applied voltage or Hi-pot test at the test voltage level of the rectifier.

E. Rectifiers

1. Design tests shall be performed on one rectifier, including the diode protection, monitoring and alarm functions, in accordance with IEEE 1653.2. Design tests shall be performed on the negative disconnect switch in accordance with ANSI C37.45.

   a. Diode types for use in the rectifier shall be fully tested in accordance with JESD282B.01.
      1) Included in these reports shall be two copies of the registration format outlined in JESD282B.01.
      2) The test results shall be certified by both the diode manufacturer and the rectifier manufacturer.
b. End points for tests shall be well beyond maximum values to be expected under any loading conditions. Diodes shall be dated as specified using the four-digit code and shall meet or exceed Class B requirements in accordance with JESD282B.01.

c. Rectifier-type instruments shall not be used in making any of the specified tests. Limiting or end point values for reverse current or forward voltage drop shall be at least twice the maximum rated values listed in the registration format. Each curve shall be clearly labeled to show test conditions and shall show actual data points.

2. The following production tests indicated in IEEE 1653.2 and ANSI C34.2 shall be performed on rectifier units:

   a. Dielectric strength test.

   b. Rated voltage test.

   c. Rated current test, including current imbalance:

      1) Between phases.

      2) Between each diode in each phase.

   d. Diode protective, monitoring and alarm functions.

   e. Applicable tests identified as Production Tests in IEEE C37.41 for the negative disconnect switch.

2.06 SYSTEM FACTORY FUNCTIONAL TESTING

   A. Refer to Section 34 21 75, Traction Power Facility System Factory Functional Testing for requirements.

PART 3 – EXECUTION

3.01 FIELD ACCEPTANCE TESTING

   A. Refer to Section 34 21 80, Traction Power System Field Acceptance Testing for requirements.

   B. Provide recommended field test procedures.

END OF SECTION 34 21 22