PART 1 – GENERAL

1.01 SECTION INCLUDES

A. General
B. Overload requirements
C. Ratings
D. Rectifier transformers
E. Rectifiers
F. Factory testing
G. System factory functional testing
H. 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 78 23 Operations and Maintenance Data
D. Section 01 45 24 Testing Program Requirements
E. Section 34 21 01 General Requirements for the Traction Power System
F. Section 34 21 75 Traction Power Facility System Factory Functional Testing
G. Section 34 21 80 Traction Power System Field Acceptance Testing

1.03 MEASUREMENT AND PAYMENT

A. Measurement: Oil filled transformers 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: Oil filled 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 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 C37.20.1 Standard for Metal-Enclosed Low Voltage (1000 VAC and below, 3200 VDC and below) Power Circuit Breaker Switchgear

2. IEEE C37.20.2 Standard for Metal-clad Switchgear

3. IEEE C57.12.00 Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers

4. IEEE C57.12.10 Standard Requirements for Liquid-Immersed Power Transformers

5. IEEE C57.12.70 Standard Terminal Markings and Connections for Distribution and Power Transformers


7. IEEE C57.12.91 Standard Test Code for Dry-Type Distribution and Power Transformers

8. IEEE C57.13 Standard Requirements for Instrument Transformers


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

11. IEEE 1653.1 Standard for Traction Power Rectifier Transformers for Substation Applications up to 1500 VDC Nominal Output

12. IEEE 1653.2 Standard for Uncontrolled Traction Power Rectifiers for Substation Applications up to 1500 VDC Nominal Output

C. National Electrical Contractors Association (NECA):

1. NEIS National Electrical Installation Standards
D. National Electrical Manufacturers’ Association (NEMA):
   1. NEMA ICS 4  Application Guideline for Terminal Blocks
   2. NEMA TR 1  Transformers, Step Voltage Regulators and Reactors

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. Schematic drawings
   4. Brief description of devices and their functions and protective relay settings
   5. Equipment nameplate
   6. Transformer oil data including toxicity and liquid flash point temperature
   7. 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.
   8. Product data for the 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. Operations and Maintenance Manuals: Provide the following Operations and Maintenance Manuals in accordance with Contract Specifications Section 01 78 23, Operations and Maintenance Data. Standard off the shelf manuals shall be submitted as pre-final manuals.
   1. Manual outlines
   2. Complete draft
   3. Pre-final manuals
   4. Final approved manuals
   5. Manual revisions
   6. Recommended (annual) schedule periodic tests
R. Design calculations for the rectifier transformer, including power rating, windings turn ratio, impedance, commutating reactance, no-load losses, full-load losses, 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.
1.06 QUALITY ASSURANCE AND SUPPLIER QUALIFICATIONS

A. Electrical components, devices, and accessories shall be listed and labeled in conformance with NFPA 70, Article 100. Electrical components, devices, and accessories and their installation shall comply with NECA’s National Electrical Installation 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 shall have a minimum of five years manufacturing experience with three winding, liquid filled power transformers, utilizing IEEE 1653.2 Circuit 31 configurations.

D. The engineer responsible for the design of the rectifier transformers and rectifier must have a minimum of 5 years of project-proven experience in the design of 3-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 site undamaged by handling and weather.

1. Temporary braces, guides, skids, crates and other shipping devices necessary for transporting and temporary storage of the equipment shall be furnished.

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

1.08 WARRANTY

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 between installation and the start of revenue service, five years from the date of system in revenue service for rectifier transformers and components, and two years from the date of system in revenue service of traction rectifiers and components.

1.09 GENERAL REQUIREMENTS

Refer to Contract Specifications Section 34 21 01 for contract general requirements.
PART 2 – PRODUCTS

2.01 GENERAL

A. Manufacturer shall coordinate the requirements of associated substation equipment to provide a 1000 VDC 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 will receive 34.5 kV, 3-phase, 60 Hz, three-wire power from 34.5 kV switchgear and shall transform the high voltage to a low AC voltage rated as required by the traction rectifier.

F. The rectifier transformer and traction rectifier shall be designed for interconnection by aerial AC busway, as indicated. Connections between the rectifier and the DC switchgear may be by either DC cables or bus, depending on the rectifier and switchgear design.

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 two hours, with superimposed five periods of one minute duration at 300 percent of rated current each, equally spaced throughout the two-hour period, and

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 six percent. The regulation shall be linear from light transition (one 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 VDC at rated primary voltage of 34.5 kV. The light transition load voltage shall be approximately 1,060 volts DC at the rated primary voltage of 34.5 kV, while the full-load (nominal) voltage shall be 1000 VDC, with plus-or-minus six 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 C57.12.00 and C57.12.10.

2. All parts 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 AC circuit breaker.

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: See Section 2.04 for rectifier transformer ratings.
G. Voltage Transients

1. A plan of the design techniques, construction methods, and equipment employed to protect against transient surge voltages shall be submitted for approval.

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 with the transformer operating at 100 percent load and nominal voltage shall not exceed 55 dBA.

3. The noise level measured at a distance of five feet from the rectifier with the rectifier operating at 100 percent load and nominal voltage shall not exceed 60 dBA.

4. Submit proof in the form of calculations or empirical data that the rectifier transformer meets the noise level requirements.
2.04  RECTIFIER TRANSFORMERS

A. General

1. Rectifier transformer shall be self-cooled, oil-immersed, 60 Hertz transformers suitable for outdoor service, designed for extra heavy-duty traction service as specified, conforming to the applicable requirements of IEEE C57.12.00, IEEE C57.12.10, IEEE C57.12.90, IEEE C57.18.10, IEEE 1653.1, and NEMA TR-1. The rectifier transformers shall be suitable for operation on 34.5 kV line-to-line, effectively grounded neutral system.

B. Ratings: Rectifier transformers shall have the following minimum ratings:

1. Capacity: MVA rating as required to meet the specified ratings and performance requirements for the transformer-rectifier units.

2. Primary Winding Nominal Voltage: 34.5 kV

3. Secondary Winding Nominal Voltage: As required to meet the specified performance requirements for the transformer-rectifier units.

4. Frequency: 60 Hz

5. No. of Phases: Primary shall be three. Secondary shall be six.

6. Cooling Class: KNAN

7. Average Winding Temperature Rise above 50 degrees Celsius Ambient after Stabilized Continuous Operation at 100 percent load: 55 degrees Celsius maximum

8. Hottest-Spot Temperature Rise above 50 degrees Celsius Ambient after Stabilized Continuous Operation at 100 Percent Load: 65 degrees Celsius maximum

9. Basic Insulation Level (BIL) Peak:
   a. Primary Winding: 200 kV minimum
   b. Secondary Windings: 45 kV minimum

10. Connections:
    a. Primary Winding: Delta

11. Bushings: Rated voltage and BIL peak ratings not less than winding ratings.
C. Taps and Tap Changer:

1. Taps: The high voltage winding shall have four no-load, full-capacity taps: two 2.5 percent above, and two 2.5 percent below the rated line-to-line voltage of 34.5 kV.

2. Changer: An off-load tap changer shall be provided with an operating handle mounted on the exterior of the tank. A position indicator and provision for padlocking shall be provided in an accessible location.

D. Alarm and Trip Devices: Transformer shall be equipped with the following:

1. Sudden pressure relay, device 263/SP with alarm and trip contacts.
   a. The sudden pressure device seal-in relay shall be equipped with an undervoltage relay with a closed auxiliary contact that shall activate the Device 286 lockout relay if control power is lost on the device 263/SP seal in relay.

2. Pressure relief device 263PR

3. Liquid level gauge, device 263/QL with two low-level alarm contacts. One low level alarm and low low-level trip.

4. Pressure/vacuum gauge.

5. Two stage top oil temperature indicator, device 226/QT with alarm and trip contacts with adjustable temperature set points.

6. Hot-spot winding temperature indicator, device 249/WT, minimum two stages, with alarm and trip contacts with adjustable temperature set points.

7. Alarm and trip annunciations due to activation of any of the above protective devices including control power alarms shall be communicated via an I/O module located in the control cabinet through fiber optic cable to the station CO2 panel.

8. The top of the transformer control panel shall not be more than 6.5 feet above the finish grade level where personnel accessing the control cabinet stand; the bottom of the transformer control panel shall be less than 3.5 feet from finish grade above the finish grade level where personnel accessing the control cabinet stand.

E. Heaters

1. The main transformer control cabinet shall have thermostatically controlled anti-condensation heaters.

2. Heater capacity shall be equally divided into two and located at the sides of the cabinet to maintain adequate clearances from entering cables.
F. Construction Requirements

1. The rectifier transformers shall be designed for high voltage enclosed cable connections on the primary side and throat connection accommodating aerial busway to the rectifier. The rectifier transformers shall be provided with incoming line section for terminating the 35 kV power cables entering from below as indicated. The section shall be large enough to accommodate built-up tape stress cones.

2. The incoming 34.5 kV incoming line section and the control cabinet shall be NEMA 4X with doors located on either side of the transformer tank and within reach of person standing on the transformer base level. Doors shall be hinged and provided with stops to hold the doors in open position. Door shall be provided with handle and three-point lockable latch.

3. The incoming 34.5 kV incoming line section shall be provided compression lugs for terminating the 35 kV, # 2/0 AWG power cables entering from below as indicated.

4. Transformers shall be provided with lifting lugs located at the top of the unit in such a manner to allow the unit to be lifted by a boom-type crane or hoist without tilting of the unit.

5. The transformer shall be designed for mounting on a concrete pad.

6. The transformer tank shall be a sealed tank liquid preservation system.

7. The transformer shall include the following:
   a. Top filter press connection and sampling device.
   b. Tank bottom drain valve and sampling device.
   c. Gasketed, roof-mounted inspection covers to gain access to internal devices or connections.
   d. Nameplate with connection diagram. As tested information stainless steel nameplate shall be provided.
   e. Warning signs as required.
   f. Weatherproof, oversize connection box with provision for extension throat and access to end or side, removable for termination of low-voltage cables.
   g. Primary and secondary bushings shall be side mounted.

8. Coating:
   a. Color:
      1) Powder coat: Medium beige, Sherwin Williams number PLT6-1S4 or equal.
      2) Wet paint color: Medium beige, Sherwin Williams number F63RXN28022-4337 POLANE S or equal for touch up
3) Aerosol can: Medium beige, Sherwin Williams number J22XXN28029-4337 or equal for touch up

b. Weather, graffiti, and ultra-violet (UV) resistant
c. Radiators may be painted or galvanized, unpainted per manufacturer’s recommendations.

9. Transformer Tank

a. The tank shall be mounted on a structural steel base that is adequate to provide support for the completely assembled transformer filled with oil and to prevent distortion during operation or relocation. Internal bracing shall not interfere with oil drainage. 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. The undersides of all members shall be in the same plane. The spacing of the base member shall be such as to permit the completely assembled transformer with or without oil to be safely tilted 15 degrees.

b. Transformers shall be of the sealed tank, welded steel plate and cover construction, outdoor type, liquid tight, with bolted and gasketed manhole(s) on top of tank. They shall be mounted on steel skid base, suitable for skidding in any direction. Use care to avoid tank or component distortion during welding operations. Assembled transformer base shall be sufficiently flat to be installed on a flat concrete foundation without supplemental shims. They shall be adequately designed and braced to allow full vacuum filling and vacuum drying operations in the field.

c. Provide jacking lugs and pulling eyes for lifting or moving along either axis when completely assembled and oil-filled. Lifting lugs are to be mounted near the top of the tank. Jacking lugs shall be installed with suitable clearance to the bottom of the base plate.

d. Provide two NEMA two-hole silver-plated copper ground pads at diagonal opposite corners of transformer tank near base, with two-bolt terminal connectors for 250 kcmil copper conductors.

e. Maintain positive pressure continually to prevent ingress of moisture during shipping.

f. Provide an adequately braced domed or sloped top on major surfaces. Design tank and fittings to prevent water puddling on surfaces or in cavities.

g. Provide raised flanges with thru-bolts for removable cover penetrations, including bushings, manhole/handhole covers, and removable equipment. Welded studs are not acceptable.

h. Gasketed joints shall have machined surfaces on both sides and shall be provided with gasket retainers and metal-to-metal stops to assure even and effective pressure and to avoid over-stressing the gasket. Gaskets shall maintain oil-tight joints under service and fault conditions.
10. Core

a. Each core shall be fabricated from non-aging, cold-rolled, grain-oriented, stress-free, thin silicon steel laminations, with permeability and hysteresis loss characteristics necessary to satisfy design and performance requirements.

b. Provide each sheet with an insulated surface treatment that is impervious to hot transformer oil. Anneal properly with smooth surfaces at edges.

c. Core shall be rigidly clamped and blocked to prevent deteriorating vibrations, interference with oil circulation, objectionable noise conditions, and short circuit and shipment distortions.

d. Provide a core ground lead connected to an external bushing for each core. Provide a flexible ground strap to connect the terminal of the bushing to the transformer tank, thereby grounding the transformer core. Provide a suitable cover or deflector to protect the core ground bushing from damage from falling objects. Provide an engraved nameplate clearly indicating the function of the bushing. Provide a separate core ground bushing and ground strap for each separate core.

e. Serial number shall be stamped on core or core clamp in conspicuous place and shall be visible without the necessity for untanking or otherwise removing enclosure.

f. Provide means for properly handling core assembly when untanked.

11. Windings

a. The windings shall be of copper and have insulation of high dielectric and mechanical strength and shall be arranged to permit free circulation of oil. Proper internal barriers shall be provided. Additional insulation shall be provided on end coils to protect against line disturbances.

b. The coils shall be fabricated and braced to provide for expansion and contraction due to temperature changes and to avoid abrasion of insulation. The coils shall be braced to prevent distortion due to any abnormal operating conditions, and designed to withstand short circuit conditions in accordance with IEEE C57.12.90.

c. Each lead for connection to tap changers, bushings, etc. shall be permanently identified.

12. Instrument Transformers

a. Instrument transformers shall conform to IEEE C57.13 and NEMA EL 21.2. The current transformers (CTs) shall comply with the IEEE C57.13 relaying and metering accuracy standards, and shall have C200 accuracy class or better, under the burdens imposed by the connected services.

b. Instrument transformers shall be insulated for 1.0 kV voltage class, and shall have basic impulse insulation (BIL) level of 45 kV full-wave.
c. Current Transformers

1) The CTs shall be dry type, of molded rubber or epoxy construction, toroidal, bushing, or wound-type.

2) Ratio and phase-angle characteristics of CTs shall be suitable for the relaying as indicated.

3) CTs shall be installed in a manner such that they are easily accessible for inspection and maintenance.

4) Each CT per phase shall be rated as indicated.

5) CTs and their secondary wiring shall be protected from induced voltages by metallic shielding. Secondary wiring shall utilize No. 10 AWG copper wire, and shall be run to readily identifiable terminal blocks in the transformer control cabinet. The terminal blocks for the CTs shall be suitable for ring type wire connections, shall have covers, and shall feature integral shorting bars for the CT leads.

6) CTs shall be capable of withstanding thermal, magnetic, and mechanical stresses from the flow of current equal to the interrupting and momentary ratings.

13. Radiators

a. Radiators shall be detachable. The transformer cooling radiators shall be equipped with shut-off valves top and bottom and shall be bolted to the main tank to facilitate removal from the transformer main tank. The transformer shall be shipped with the radiators on at least one side removed to allow for the use of a standard size trailer, if necessary. The oil required to fill the removed radiators shall be shipped with the transformer or be provided by a local supplier.

b. Shut-off valves shall be equipped with a valve position indicator to indicate “valve open” or “valve closed”. The valves shall be lockable in the open and closed position. Steel blanking plates for openings shall be supplied.

c. Each radiator shall have a solid hex steel plug provided at the top and ball type drain valves at the bottom for drainage.

d. Each removable radiator shall be equipped with one lifting lug on top and one lifting lug on the bottom.

e. The design and construction of the radiators shall be such as to eliminate pockets where moisture can accumulate or which can prevent application of a continuous film of paint. Radiators shall be either hot dipped galvanized or painted in a fashion which ensures complete coverage of radiator surfaces. The radiators shall be provided with adequate bracing to prevent leakage from vibration.

f. Radiators are to have the same vacuum capability as the main tank.
14. Transformer Oil

a. The transformer shall be provided with enough transformer oil for filling its tank and radiators to the proper level.

b. Transformer oil shall be biodegradable natural ester-based insulating fluid that provides for a low-vapor-pressure, low-viscosity, high-flash-point, stable insulating oil.

c. Supplier shall certify, 60 Days before delivery that oil used in rectifier transformers contain less than one ppm PCB at time of manufacture.

d. The oil shall be Environtemp FR3 or approved equivalent.

e. Containment drain valve shall incorporate hardware that will allow for water to flow out of the containment pit at a flow rate equivalent or greater than a 1-1/2” diameter pipe. The same hardware shall cease all liquid flow from the containment pit if transformer oil is detected. The hardware shall detect oil using a passive system that does not require control power.

G. Special Tools

1. Special tools required for installation and maintenance of the equipment shall be identified by the manufacturer at time of bid.

H. Marking

1. Every transformer shall be provided with a rating plate showing the information required by the applicable IEEE Standard.

2. The rating plate shall indicate the type of conductor used for high voltage and low voltage windings (e.g. copper).

3. The rating plate shall indicate the transformer is constructed for Extra-Heavy Traction Duty as defined in IEEE C57.18.10.

4. The transformer shall be provided with nameplate that reads:

   “Transformer oil contains less than one parts per million polychlorinated biphenyls at time of shipment.” and “Refill with Envirotemp FR3 or approved equal.”

2.05 RECTIFIERS

A. General

1. 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.

2. The rectifier shall be the indoor type, with natural convection-cooling, and shall be designed to operate at 50 degrees Celsius ambient temperature.
3. 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.

4. 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. 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 specifications. The calculations shall be signed by a California-registered professional engineer specialized in noise suppression field.

5. 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.

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

B. Rectifier Enclosures

1. 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.

2. Insulation shall be provided between the rectifier (including the DC main breaker cubicle) and the DC feeder breaker switchgear, 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.

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

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

5. Heat transfer surfaces and ducts shall be designed with smooth surfaces that minimize accumulation of dust and other contaminants.
6. Convenient access, including doors on both front and rear sides, shall be provided for normal maintenance and inspection of the rectifier.

7. Each enclosure door shall be equipped with:
   a. A mechanical latch to hold the door closed; and
   b. Door stops to hold door open for inspection of rectifier components.

8. 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.

9. 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.

10. Separate compartments shall be provided to isolate control and auxiliary circuits and functions from the 1000 VDC buses and diodes.

11. 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.

12. Components installed in the rectifier shall be capable of withstanding 4600 VDC 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.

13. Provide rectifier unit with provisions to establish rectifier electrical clearance such that potentials inside the rectifier enclosure are connected together with conductors capable of withstand a fault if the rectifier unit is inadvertently energized during at least 0.5 seconds for protection devices to clear the fault. AC incoming power supply, DC positive, DC negative, and the rectifier frame must be connected together to provide adequate and safe physical access for maintenance of the rectifier unit by maintenance personnel.

14. The enclosure shall be connected to the high resistance ground relay (Device 164A/164G) in the associated DC switchgear main breaker cubicle.

15. Devices mounted within rectifier enclosures that use 125 VDC 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.

C. Diodes

1. 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.
2. 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.

3. 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.

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

5. 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.

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

7. 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.

8. The number of diodes per leg shall not exceed 10 for 3-MW and 4-MW units, and 12 for 5-MW units, unless otherwise approved by the District.

D. Terminus

1. The rectifier shall be connected to its associated rectifier transformer through a metal enclosed busway, as indicated.

2. The rectifier DC output shall be connected either through a metal-enclosed positive bus or cables to its associated 1000 VDC switchgear.

3. 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 switchgear.

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

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

6. 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.
E. Negative Disconnect Switch

1. The rectifier shall be furnished with a negative disconnect switch, that shall be:
   a. 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 1000 VDC nominal, and with current ratings matching the overload and short-circuit capability of the rectifier.
   b. Provided at a minimum with one normally-open and one normally-closed auxiliary contact.
   c. Designed with ample space and contact surface for pulling and terminating the negative cables from the negative bus enclosure.
   d. 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.
   e. Equipped with insulated handle.

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

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

F. Relaying, Metering, and Indicating Devices

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

2. 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 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 station circuit breakers through the lockout relay (Device 286) as indicated.

3. Monitoring devices (180DM) shall be furnished to detect the loss of one or more diodes:
   a. Failure of any diode in any string shall initiate local and remote alarms.
   b. Failure of a second diode in a rectifier bridge shall initiate the tripping of the substation circuit breakers via a lockout relay (Device 286) as indicated.
   c. Rectifier doors to normally energized buses or components and to the negative disconnect switch shall be electrically interlocked to trip the AC and DC cathode circuit breakers through the lockout relay (Device 286), when a door is opened as indicated.
4. Control and Communication Function:
   a. Provide the following:
      1) Binary (device contact) inputs, for collection and inclusion in custom control logic, and signal re-transmission.
      2) IOM connected by hardwire to protection devices and connected to C02 control panel via fiber optic cable over an Ethernet connection.
      3) Internal programmable logic controller (PLC) capability, including:
         a) User-defined logic
         b) Programmable function keys
         c) Ethernet interface capability
         d) Binary (relay contact) outputs, for interface with other relays and for circuit breaker control capability.
   b. Coordinate with the CO2 panel design to implement controls, indications, and data transfer between the transformer-rectifier protection devices and the CO2 panel for local and remote control, indication, and data transfer functions and processes.

2.06 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 all components of the involved equipment, and to verify that local temperatures of the transformer, the rectifier are within the limits indicated in IEEE C59.12.90, IEEE C57.12.00, and IEEE C57.18.10.

      2) The transformer-rectifier units shall be operated at 100 percent full-load until 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 throughout 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 the AC circuit breaker’s protective devices 250/251, 250N/251N, or 287T, set the same as it will be on the installed system.

3) Each phase of the AC circuit breaker 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 mounted in its permanent location. Noise level shall be tested during the short circuit test but must be verified after rectifier installation on the real system while loaded and shall subject to IPT replacement if exceed the prescribed noise level.

2) The noise level at full load, measured in accordance with NEMA TR1 and IEEE C57.12.90, 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 Contractor shall conduct tests to obtain data for the indirect derivation of the required parameters via calculations.

2. Production Tests: perform per IEEE requirements.

C. Rectifier Transformers

1. The following design tests as applicable to power-type transformers listed in IEEE C57.12.90, IEEE C57.18.10, IEEE 1653.2, and NEMA TR1 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 TR1 and IEEE C57.12.90

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 C57.12.00 and IEEE C57.12.90, shall be performed to evaluate fully the capability of all 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 C57.18.10 and IEEE 1653.2:

a. Resistance and impedance measurements including zero sequence impedance of all windings on the rated voltage connection of each unit and at all taps.

b. Ratio tests at the rated voltage on all tap changer connections.

c. Phase-rotation tests on the neutral tap connection.

d. No-load loss at rated voltage on the neutral tap connection.

e. Excitation current at rated voltage on the neutral tap connection.

f. Dielectric tests: low frequency withstand, including applied and induced potential tests.

g. Load losses and impedance voltage at rated current on the rated voltage connections and on all taps.

h. Partial-discharge tests: The partial discharge test shall be in accordance with IEEE C57.12.00 and IEEE C57.113, and shall be used to verify that the transformer insulation is free of partial discharges for voltages up to 120 percent of the rated primary voltage.

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 also 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) Include in these reports 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 all tests shall be well beyond any 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. In general, 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, with the latter:
   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.

2.07 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.

END OF SECTION 34 21 21