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Powering Business Worldwide

COOPER POWER SERIES

Distribution/Substation or Padmount Transformer

Functional Specification Guide

Type AR-VFI, Arc-Reduction Vacuum Fault Interrupter Transformer **PS202013EN**

Functional specification for 15 kV, 25 kV or 35 kV arc-reduction vacuum fault interrupter distribution/substation or padmount transformer

Ratings

- 45-12,000 KVA
- Copper/Aluminum Windings
- 2400 V – 35 kV Primary
- 120 V – 14.4 kV Secondary
- Envirotemp FR3 fluid (recommended)
- 55, 65 or 75 deg C rise temp

Features

Reference AR-VFI Transformer:

- [Select: Substation; Padmount] style transformer, built per customer specification
- VFI w/ aux contacts + differential relay control (e.g. ETR-4000, ETR-5000, SEL-787 or approved equivalent) – (no TPG SCADA)
- NEMA 4X UL Listed relay control box (Relay, test Switches, integral CPT & 24VDC UPS System, Heater, Status lights)
- Primary OCP + Secondary OCP + Primary Voltage monitoring (optional) + Maintenance Mode (INST) + Direct Trip + power metering (optional) + directional protection + zone interlocking + remote data acquisition + event recording + additional protective elements available (relay dependent)
- [Optional: Motor op, Alarms/gauges/accessory packages, E-series RTD Module (Eaton relays only)]

1. **Scope**

1.1. This specification is intended to be a supplement to the PS202002EN Padmount Distribution Transformer specification guide or PS202005EN Substation Distribution Transformer.

1.2. This specification applies to three-phase, 50-60 Hz, fully dead front, [select: pad-mounted distribution; substation] transformers. Differential overcurrent protection shall be accomplished utilizing a 24VDC microprocessor-based differential relay paired with a resettable vacuum fault interrupter (VFI) which shall be provided with three-pole ganged operation. [select: The unit shall have a motor operator; or the unit shall be manually operated].

1.3. The VFI unit is to be used for transformer differential protection & local/remote on/off switch

1.4. The unit is to be insulated with Envirotemp™ FR3™ less-flammable dielectric fluid. The unit shall utilize vacuum interrupters for all fault current interruption such that the dielectric media is not consumed or contaminated by normal operations of the interrupters. The unit shall be designed for installation on a concrete or fiberglass pad at ground level.

1.5. The transformer shall use resettable interrupter controls and shall not use expulsion fuses (use of PRCLFs for increased interrupt rating are allowable).

1.6. This specification shall only cover the purchase and shipment of transformers. The purchaser and/or user shall be responsible for all site-work, electrical connections, and installation.

2. **Applicable Standards**

2.1. IEEE Std C37.60™-2003 standard – IEEE Standard Requirements for Overhead, Pad-Mounted, Dry Vault, and Submersible Automatic Circuit Reclosers and Fault Interrupters for Alternating Current Systems Up to 38 kV

2.2. IEEE Std 386™-1995 standard – Standard for Separable Insulated Connector Systems for Power Distribution Systems Above 600 V.

2.3. IEEE Std C37.90™-1989 standard – IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus.

2.4. IEEE Std C37.90.2™-1995 standard – Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

2.5. IEEE Std C57.12.00™ standard – Standard for Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

2.6. IEEE Std C57.12.28™ standard – Pad-Mounted Equipment - Enclosure Integrity.

2.7. IEEE Std C57.12.29™ standard - IEEE Standard for Pad-Mounted Equipment - Enclosure Integrity for Coastal Environments – applicable when stainless steel construction is specified.

2.8. IEEE Std C57.12.34™ standard – IEEE Standard Requirements for Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers (2500 kVA and Smaller) - High Voltage: 34500GrdY/19920 Volts and Below; Low-Voltage: 480 Volt 2500 kVA and Smaller (issued in March 2005 - combines C57.12.22 and C57.12.26). – applicable when padmount style transformer is specified

2.9. IEEE Std C57.12.36™ standard – IEEE Standard Requirements for Liquid-Immersed Distribution Substations Transformers – applicable when substation style transformer is specified

2.10. IEEE Std C57.12.90™ standard – IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers.

2.11. IEEE Std C57.12.91™ standard – Guide for Loading Mineral-Oil-Immersed Transformers.

2.12. IEEE Std C57.154™ standard – IEEE standard for the design, testing, and application of liquid-immersed distribution, power, and regulating transformers using high-temperature insulation systems and operating at elevated temperatures

2.13. IEEE Std 1584™ - 2018 – IEEE Guide for performing arc-flash hazard calculations

2.14. NEMA TR 1-1993 (R2000) – Transformers, Regulators and Reactors, Table 0-2 Audible Sound Levels for Liquid-Immersed Power Transformers.

2.15. NEMA 260-1996 (2004) – Safety Labels for Pad-Mounted Switchgear and Transformers Sited in Public Areas.

2.16. 10 CFR Part 431 – Department of Energy – Energy Conservation Program for Commercial Equipment: Distribution Transformers Energy Conservation Standards; Final Rule.

3. Vacuum Fault Interrupter Ratings

The transformer Vacuum Fault Interrupter shall be rated* as [select: 15kV (12.5 kA interrupt); 15 kV (16 kA interrupt); 25 kV (12.5 kA interrupt); 35 kV (12.5 kA interrupt)] per the table below.

Nominal Voltage		15 kV	15 kV	25 kV	35 kV
Maximum Design Voltage, kV		15.5	15.5	27.0	38.0
BIL, kV		95	95	125	150
1-Minute Withstand Voltage (60 Hz), kV		35	35	60	70
Momentary Current, 10 Cycles (sym.), kA		12.5	16.0	12.5	12.5
3-second Withstand Current (sym.), kA		12.5	16.0	12.5	12.5
Fault Interrupting	Continuous Current, (max), A	900	900	900	900
	Interrupting Current (sym./asym.)	12.5/20.0	16/25.8	12.5/20.0	12.5/20.0
	Making Current (sym.), kA	12.5	16.0	12.5	12.5
	Cable Charging Interrupting Current, A	10.0	10.0	25.0	40.0
Load-Break Switching	Continuous Current, (max), A	900	900	900	900
	Load Switching, A	900	900	900	900
	3-Shot Make and Latch (asym.), kA	20.0	25.8	20.0	20.0

Minimum Full Life Fault Interrupting Duty Cycle per IEEE Std C37.60™-2003 standard (2 duty cycles)		Number of Operations			
Percent of Interrupting Current Rating:	15-20%	88	88	88	88
	45-55%	112	112	112	112
	90-100%	32	32	32	32
Total		232	232	232	232

3.1 Vacuum Fault Interrupters

3.1.1 The transformer shall incorporate a vacuum fault interrupter for overcurrent protection, such that the major dielectric media is never contaminated by circuit interruption arc products. The device shall interrupt all fault currents up to its maximum rated current of [select (see table in Section 3): 12,500 (15, 25 or 35 kV) or 16,000 (15 kV only) RMS amperes symmetrical]. The interrupter shall be manually resettable, with no consumable parts (i.e. fuses). The maximum interrupting time from issuance of a trip signal from the electronic control shall be 2 cycles.

3.1.2 The vacuum fault interrupter may be tripped via the incorporated relay control by sensing anomalies in the system provided there is adequate sensing equipment also incorporated into the transformer. That is, the VFI may be tripped (opened) in the event of anomalies such as, but not limited to, overcurrent, over/undervoltage, over temperature, over pressure, under frequency, etc. provided the appropriate associated devices are also incorporated into the transformer (i.e. potential transformers, thermometers, pressure relief devices, transducers, etc.) and the appropriate relay control is selected.

3.1.3 To maximize safety to the operator, the interrupter shall incorporate a trip-free mechanism to prevent the possibility of holding the interrupter mechanism closed under a faulted circuit condition.

3.1.4 The vacuum fault interrupter shall act as a three-phase group operated circuit breaker. The trip mechanisms for each phase shall be mechanically linked and the electronic control shall be set so that an overcurrent condition on any one phase shall simultaneously trip all three phases. A single operating handle shall be provided for manual opening, reset and closing. The operating handle shall be mounted on the front plate of the tank in close relation to the VFI being controlled and shall have three distinct operating positions corresponding to the vacuum fault interrupter

positions of closed, open, or tripped. A pointer attached to the handle shall be provided for ready identification of the handle's position. The handle shall be designed for operation with a lineman's hot stick and have a push to close / pull to open / pull to reset operation requiring no more than 75 lbs. of force and 60 degrees of movement for complete operation. Except when equipped with the optional motor operator, when the vacuum fault interrupter is tripped by automatic action of the VFI control, the operating handle shall drop to an intermediate position between its closed and open positions, to provide indication that it is tripped. The operating handle assembly shall include provisions to padlock the handle in the open position.

4. **Electronic Trip Control**

4.1. The protective relays for the transformer protection shall be a single multifunction, microprocessor-based relay that incorporates restrained differential protection for two windings with fixed or variable percentage, using one or two settable slopes with adjustable intersection points and minimum pickup.

4.2. The relay shall be Eaton device type ETR-4000, ETR-5000, or approved equal differential relay having all, but not limited to, the features and functions herein specified.

4.3. Relay shall be wired to directly trip the VFI mechanism.

4.4. The relay shall be a solid-state microprocessor-based multifunctional type that operates from a 5 ampere or 1 ampere secondary output of current transformers. The relay shall provide ANSI 50/51 protective functions, and ANSI 50/51N or 50/51G ground fault protection functions for each winding as shown on the plans or as determined by the coordination study. The relay shall be configurable between true rms or fundamental sensing for each phase and ground. Ground element shall be capable of being utilized in residual, zero sequence, ground source connection schemes, or deactivated.

4.5. The current transformer ratings being used for percentage restraint differential protection, phase, negative sequence, and ground protection feeding the device shall be programmable for current transformers with primary current ratings from 1 through 10,000 amperes

4.6. Provide phase and ground (as applicable) CT's on transformer secondary. CTs will be connected to transformer relay via test switches within control cabinet. CT ratio shall be as appropriate for the full amp output of the given transformer kVA rating.

4.7. Provide phase and ground (as applicable) CT's on transformer primary. CTs will be connected to transformer relay via test switches within cabinet. CT ratio shall be as appropriate for the full amp output of the given transformer kVA rating.

4.8. Control cabinet will be equipped with ABB test switches as needed for application or approved equal

4.9. Control cabinet will be supplied with terminal block for customer connections

4.10. Control cabinet will be supplied with 24V UPS system supplied by 120VAC from internal CPT and 12VDC from cabinet mounted 12V battery capable of 24hour back up (optional: customer supplied power)

4.11. Control cabinet to include heater

4.12. Control cabinet will be NEMA 4X, UL listed, 100% stainless steel box

4.13. The relay shall provide, but is not limited to, the following protection devices:

4.13.1. Percentage Restrained Differential Protection (87). The relay shall incorporate restrained differential protection for two windings with fixed or variable percentage, using one or two settable slopes with adjustable intersection point and minimum pickup values.

4.13.2. Harmonic Elements. The relay shall incorporate second-, fourth-, and fifth-harmonic elements, with the choice of temporarily or permanently desensitizing the differential protection to prevent restrained differential element operation during inrush or overexcitation conditions; it shall be possible to set the fifth-harmonic element to warn user of overexcitation condition.

4.13.3. Unrestrained Differential Protection (87H). The relay shall include unrestrained differential protection to produce rapid tripping for severe internal faults.

4.13.4. Ground Differential Protection (87GD) or Restricted Earth Fault Protection(REF). The relay shall incorporate restricted earth fault protection for the detection of ground faults in wye-connected windings.

4.13.5. Phase overcurrent (50/51): Four inverse time overcurrent (51-1, 51-2, 51-3, 51-4) functions and four instantaneous overcurrent (50-1, 50-2, 50-3,50-4) functions with adjustable time delay. Each element can be assigned to either side of the transformer.

4.13.6. Ground overcurrent (50R/51R): Two inverse time overcurrent (51R-1, 51R-2) functions and two instantaneous overcurrent (50R-1, 50R-2) functions from calculated values with adjustable time delay. Each element can be assigned to either side of the transformer.

4.13.7. Ground overcurrent (50X/51X): Two inverse time overcurrent (51X-1, 51X-2) functions and two instantaneous overcurrent (50X-1, 50X-2) functions from measured values with adjustable time delay. Each element can be assigned to either side of the transformer.

4.13.8. The phase, negative sequence, and ground protection curves shall be independently field-selectable. Curves shall be selectable from the following:

4.13.8.1. IEEE: Moderately inverse, very inverse, extremely inverse

4.13.8.2. IEC: A, B, C or D

4.13.8.3. Thermal: Flat, It, I2t, I4t

4.14. The relay shall have 8 contact outputs that may be programmed for any protection function operation output

4.15. The relay shall have a front panel display of relay condition, and 14 programmable LEDs that can be used for trip condition or breaker status

4.16. The relay shall have a LCD display with LED background illumination capable of displaying the following information with metering accuracy of +/- half (0.5) percent of measured value (In) for In < 2 In and +/- one (1) percent of measured value (In) for In > 2:

4.17. Relay will be able to measure the following values from the transformer (*voltage and power measurements require inclusion of PTs and PT inputs):

4.17.1. Individual RMS and fundamental phase currents

4.17.2. Ground RMS and fundamental current

4.17.3. Phase-to-ground and phase-to-phase voltages with phase angles

4.17.4. Watts

4.17.5. Vars

4.17.6. VA

4.17.7. Frequency

4.17.8. Power factor – apparent and displacement

4.17.9. Minimum/maximum values of current, voltage, watts, vars, VA, frequency, apparent pf and displacement pf phase angles

4.18. Relay shall have the following features:

4.18.1. Trip coil-monitoring and IRIG-B

4.18.2. Zone selective interlocking capability

4.18.3. Real-time clock for stamping of events, trips and minimum/maximum values with

4.18.4. 1ms time resolution or better

4.18.5. User interface for programming and retrieving data from the front of the unit without additional equipment

4.18.6. Eight (8) contact inputs that are user programmable

4.18.7. Continuous self-testing of internal circuitry, self-diagnostic capability.

4.18.8. Programmable lockout/self-reset after trip function (86 lockout)

4.18.9. Programmable set points for device curve selection

4.18.10. Programmable inputs, such as current transformer ratios

4.18.11. Relay shall be suitable for operating temperatures from -20 degrees to 60 degrees C. Relay shall be suitable for operating with humidity from 0 to 95% relative humidity

4.19. Relay shall record information on the last 20 faults including:

4.19.1. Date, time, and currents at the time of fault

4.19.2. Relay shall record 3600 cycles of waveform data for the current

4.19.3. Relay shall record the last 300 events into an event log with date and time stamping

4.20. Relay shall have the following communications ports available if specified:

4.20.1. Rear communications port(s) that support: IEC61850, Modbus TCP, and DNP3.0 TCP via RJ-45 connector

4.20.2. A USB front communication port for programing and interrogation of the relay via personal or laptop computer

4.20.3. Communication ports shall have the ability to transmit all information contained in the relay such as currents, set points, cause of trip, magnitude of trip current, and open-close trip status over the connected network.

4.21. Relay trip contacts shall not change state if power is lost or an undervoltage occurs. These contacts shall only cause a trip upon detection of an overcurrent or fault condition based upon programmed settings

4.22. The relay shall be suitable for operating on control power with a nominal input voltage of 24Vdc

4.23. The Relay shall be fully programmable through the face of the relay. In addition, a means to be able to program the relay through a communication port needs to be provided.

4.24. Meet the specified time-current curve immediately upon energization.

4.25. No “warm-up”, initialization, or arming time delays adjustments shall be necessary.

4.26. No minimum load requirement or battery back-up device shall be necessary to meet the specified time-current characteristics.

5. **[Select: Optional Features]** ***(One or Multiple Selections can be made)***

5.1. **[Select: Motor Operators]**

5.1.1. When specified, a DC motor operator, with integral control shall be supplied for the AR-VFI transformer. The unit shall include the appropriate VFI mechanism for use with motor operation and all standard motor operator mounting hardware. The motor operator shall utilize 24-Vdc motor actuators to open and close the respective VFI. The time required to open or close the VFI shall be approximately 2.5 seconds. The motor control shall be equipped with a 50 amp-hour sealed lead acid gel-cell battery to supply energy to activate the motor operator and control functions. Battery charge shall be maintained by a temperature/voltage regulated charger within the motor control that shall be capable of fully re-charging a low battery within 24 hours.

5.1.2. The motor control shall utilize an integral 120-Vac potential transformer for control power supply. [optional: If a user supplied power supply to the motor control has been specified, the unit shall be provided with all necessary wiring connections.

The motor control shall include the following features:

- Open, Close, and Stop pushbuttons shall be provided for operation of the motor actuator.
- Open and Closed indicating lights shall be provided to indicate status of the VFI. These status lights shall use auxiliary switch inputs from the source VFI to determine open or closed status.
- Opening and closing indicating lights shall be provided to verify that the motor actuator is in process of opening or closing a switch. A lamp test pushbutton shall be provided to confirm that indicating lights are functional.
- A Power On/Off toggle switch shall be provided that shall disconnect the dc voltage supply from the control and the motor actuator and shall function as a dc circuit breaker to interrupt the dc supply in the event of a short circuit or overload.
- An indicator light shall be provided to verify that 12Vdc battery is healthy and voltage is present and that the battery charging circuit is providing a charging voltage to the battery.
- A Local/Remote toggle switch shall be provided. In the Local position, the switch shall allow operation of the motor actuator by the pushbuttons on the control panel only and shall not allow remote or SCADA operation. In the Remote position, the switch shall only respond to the remote or SCADA operation of the motor actuator.

5.2. **[Select: Visible-Disconnect Window]**

5.2.1. The VFI mechanism will be mechanically interlocked with a 3ph ganged disconnect switch such that the VFI must be in the 'open' position to operate the disconnect. The contacts of the visible disconnect switch will be clearly visible through a 4" x 11" view window. [when specified with motor operator: Visible disconnect switch must be interlocked with auxiliary contacts such that the motor cannot close the VFI mechanism when the visible disconnect is in the 'open' position].

5.3. **[Select: Open/Closed Semaphores]**

5.3.1. When specified, an Open (green) /Closed (red) mechanical semaphore shall be provided and shall indicate the open or closed status of the vacuum fault interrupter. The semaphore shall be visible through a window on the tank in direct logical proximity to the operating handle of its fault interrupter. [semaphore is provided as standard with motor operator kit].

5.4. **[Select: Kirk-Key Interlock Provisions]**

5.4.1. When specified, mounting provisions for Kirk key interlocks shall be provided on each switched and VFI protected way.

5.5. **[Select: Extra Auxiliary Switches]**

5.5.1. When specified, the VFI shall be provided with [select: one extra set; two extra sets (non-motor op only)] of stage "a" and "b" auxiliary switches for the purpose of remote indication of status. These auxiliary switches shall be rated for 15-amps @ 120-Vac / 1-amp @ 125-Vdc and wired to an external terminal strip.

5.6. **[Select: Partial Range Current Limiting Fuses in series with VFI]**

5.6.1. When specified, the VFI shall be provided with separate partial range current limiting fuse. The VFI will be connected in series with the partial range current limiting fuse. The partial range current limiting fuse will provide protection up to 50 kA.

5.7. **[Select: Arc-flash relay (w/ light sensing)]**

5.7.1. When specified transformer LV compartment or LV throat connection will be outfitted with arc-light sensors that are wired to an arc-flash relay. The arc-flash relay will work in conjunction with the over current protection system, Simultaneous detection of arc-light and overcurrent events will send a trip signal to the integral VFI and open the transformer primary circuit.

5.8. **[Select: Close-coupled to Eaton Arc-Quenching Switchgear]**

5.8.1. When specified transformer will be specifically designed to be close-coupled to the Eaton LVA "Arc-Quenching Switchgear" or "AQS" lineup. This design will utilize the Eaton arc-flash relay within the AQS and light sensors within the AQS and transformer throat to initiate the tripping of the VFI while simultaneously creating a low impedance fault within the Arc-Quenching Device (AQD) located in a Magnum DS breaker slot of the Eaton AQS. Primary and secondary current transformers and microprocessor-based relay for overcurrent sensing/protection shall be included in the main transformer structure/control cabinet. Eaton arc-flash relay within AQS shall communicate with relay within AR-VFI transformer to initiate VFI trip. (more information see: Eaton Arc-Quenching Switchgear).

6. **Quality Assurance**

6.1. The manufacturer shall be a company specializing in medium voltage distribution transformers with at least fifteen years of documented experience.

6.2. Equipment shall be built in accordance with the industry standards for medium voltage equipment.

6.3. The manufacturer shall be registered and certified as ISO 9001 compliant by a recognized international and independent body.

7. **Approved Manufacturers**

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