APPENDIX R

PROTECTIVE RELAY REQUIREMENTS AND APPROVALS

PG&E INTERCONNECTION HANDBOOKS

R.1 REQUIREMENTS

Transmission and Distribution interconnections to PG&E require reliable relays to protect the electrical system for faults in the system or in the interconnected facilities as well as safeguard the service quality of other customers during abnormal operating conditions. Many different types of relaying may be required depending on the point of interconnection and if the connection is generation or load. See the Distribution Interconnection and the Transmission Interconnection Handbooks for details. PG&E maintains Tables of pre-approved relays for different functional requirements. See the Distribution Interconnection Handbook, and Tables G2-4 and G2-5 in the Transmission Interconnection Handbook. PG&E required protection functions must be applied with relays on the approved relay tables. **This appendix details the requirements to approve new relays that are not already on these tables.** Protection elements included in Inverters are not covered by this process.

Redundant relaying is required if multifunction three-phase relays are applied. These relays can be the same model or different model relays as long as they are both on the PG&E approved relay tables. Refer to Section L2.2 or G2.2 of the Transmission Interconnection (TIH) Handbook or to the Distribution Interconnection Handbook (DIH) for more information. These relays must be certified by the manufacturer to meet the following specifications:

- Relay must be utility grade for use in utility type environment and applications
    - The minimum and maximum operating temperatures are in the range of -40° to 70° C
    - Must meet Current Transformer (CT) and Potential Transformer (PT) circuit burden carrying requirements
    - Current transformers must have nominal secondary current of 5A and all relays must have 5A nominal AC input current

  Must be certified by the manufacturer to meet the following standards:

    - Dielectric testing requirements per ANSI/IEEE C37.90-2005 or latest approved version
    - Surge Withstand Capability (SWC) and Fast Transient testing per ANSI/IEEE 37.90.1-2012 or latest approved version
    - Radio Frequency Interference (RFI) withstand capability in accordance with ANSI/IEEE C37.90.2 -2004 or latest approved version
    - Electrostatic Discharge Tests per ANSI/IEEE C37.90.3-2001 or latest approved version
    - Power Frequency Magnetic Field Immunity per IEC 61000-4-8-2009 or latest approved version
    - Output contact Load Break Capability tests – through an inductive network per UL-1054 and ANSI C37.90-2005 or latest approved version
    - Airborne Arcing Noise susceptibility per ANSI/IEEE C62.41.2-2002 and C62.45-2002 or latest approved version
    - DC Hipot Test or Megger with no leakage or breakdown of the components per IEC 61000-4-11 and 60255-11 or latest approved version
    - Vibration test per IEC 60255-21-1 Class 1 or latest approved version
    - Shock and bump tests per IEC 60255-21-2 Class 1 or latest approved version
    - Seismic test per IEC 60255-21-3-1993 Class 1 or Class 2 or latest approved version
    - UL and FCC test requirements as necessary

If the interconnector selects a relay that is not on PG&E's approved list, the interconnector or Relay Manufacturer will be required to arrange for the device to be tested by an independent testing company at their own expense. The testing must be done by an International Electric Testing Association (NETA) accredited testing company by a NETA level 3 or level 4 certified technician. On an exceptional basis, relay manufacturers can request PG&E for testing at the manufacturer's facility, with PG&E personnel witnessing the tests. PG&E must be provided a list of relay elements that are going to be tested for approval and PG&E must approve the test procedure before the tests are conducted. PG&E must approve the test results and is the final arbiter of the approval. The interconnector will also provide to PG&E a copy of the detailed manufacturers' instruction manuals. The tests should be designed to confirm the following:

- The contact outputs (programmable or fixed) shall be immune to 4 to 6 msec transient spikes at 60% of the station DC voltage.
- The relay must be D.C.-voltage operated
- Relay must perform under DC transients
- The relay shall have the following self-diagnostic alarms (solid state & microprocessor only). Any Self-Test, Non-Volatile Memory, EPROM data error, Watchdog error, Program error, Battery fail (if applicable), Firmware error, Unit-out-of-calibration (measuring elements are not within tolerance), DSP interrupt error.

Acceptance testing requirements

- Testing is required to be much more extensive than typical installation tests. This relay type testing must include any possible connection and system configuration that the relay could be applied with. The tests must consider extremely high or low settings and test values to cover all likely conditions. Any element trip blocking or trip delays due to setting conflicts, sudden voltage or frequency changes, or other reasons must be documented and provided to PG&E.
- Tests must be performed with calibrated test equipment capable of producing at least 50 amps of three-phase AC current.
- A test plan designed to cover all PG&E required testing must be provided to PG&E for review and acceptance prior to commencing the testing. The test plan must clearly list which elements of the relay are being submitted for approval.
- All test results must include enough information for the reviewer to determine that the tests were performed to PG&E requirements. This includes testing notes on special connections or settings used during each test.
- Test results must include percent error from the relay settings applied.
- All test results must be within the manufacturer's published tolerances. PG&E requires all protection element tolerances be within 1% or better of the measuring elements.

Verifying relay metering values

- Apply balanced 3 phase current and voltage at 25%, 50%, 75% and 100% of nominal ratings and verify that relay current, voltage and power readings are within tolerances. Apply 100% nominal voltage and 50% nominal current and verify power readings at various phase angles sufficient to prove all four power quadrants. All Real and Reactive power readings must match hand calculated power values for applied voltage and current.

50/51 AC Instantaneous/Time Phase Overcurrent Elements

- Verify 50 and 51 element ranges by testing pickup and dropout of each element at a minimum setting, a mid-range setting and a maximum setting (or as high as the testing equipment used will permit). Test at least 3 points to plot the knee of the 51 curves for a very inverse characteristic. Perform curve tests at 54 Hz, 60 Hz and 64 Hz to ensure that timing is independent of system frequency. Test for three phase and all phase-phase combinations.

51C Voltage Controlled Time Overcurrent Elements

- Perform tests to prove the voltage pickup and dropout control of the 51C element. Test at minimum, mid-range and maximum voltage control settings.
- Perform current pickup and dropout tests on the 51C elements at a minimum setting, a mid-range setting and a maximum setting. Test at least 3 points to plot the knee of the 51 curves. Test for three phase and all phase-phase combinations.

51V Voltage Restrained Time Overcurrent Elements

- Perform minimum pickup and dropout tests of the 51V time overcurrent element at 0%, 25%, 50%, 75% and 100% of the nominal input voltage. Test at least 3 points to plot the knee of the 51 curves at 0%, 50%, and 100% of the nominal input voltage for a very inverse characteristic. Test for three phase and all phase-phase combinations.
- If not described in the instruction manual, define how the voltage restrained overcurrent elements perform when connected to voltage and current on the low-side of a delta-wye transformer. How does the relay algorithm compensate for the transformer phase shift during line-line faults on the primary side of that transformer? Which elements in the relay are affected by the phase shift compensation? PG&E will provide test values to use that will test this compensation with +30° and -30° delta-wye and delta-delta transformer connections for three phase and all phase-phase combinations.

50/51N AC Instantaneous/Time Ground Overcurrent Elements

- Verify calculated $3I_0$ and I_2 relay readings by applying unbalanced 3 phase current inputs without input to the neutral current input (if applicable). Compare the $3I_0$ and I_2 relay readings to hand calculations. The relay values must match the hand calculated values. With currents applied verify zero current reading in the relay on the neutral current (if applicable).
- Verify neutral current input to relay by applying single phase current to the neutral current input (if applicable) and reading the current in the relay. The relay values must match the applied input current within tolerance. With the current applied verify zero current in the relay on Ia, Ib, Ic, I_2 and $3I_0$.
- Verify 50N and 51N element ranges by testing pickup and dropout of each element at a minimum setting, a mid-range setting and a maximum setting (or as high as the testing equipment used will permit). Test at least 3 points to plot the knee of the 51 curves for a very inverse characteristic. Perform curve tests at 54 Hz, 60 Hz and 64 Hz to ensure that timing is independent of system frequency.

67/67N Phase/Ground Directional Elements

- Test the 67 element to determine the minimum sensitivity at the maximum torque angle.
- Test all 67N polarization elements to determine minimum sensitivity at the maximum torque angle. Apply 1 amp at MTA and increase V_2 to determine the value at which the relay determines direction forward. Decrease V_2 to determine the element dropout value. Repeat the test varying $3V_0$. The 67N element must be able to determine a forward direction with inputs down to 0.8 Volts V_2 and/or 1.5 Volts $3V_0$ secondary.
- If applicable test external neutral current polarizing to determine minimum sensitivity (pickup and dropout) at MTA.
- Test the 67 and 67N elements to determine MTA. Perform pickup/dropout tests by applying a voltage and current at 110% of minimum and varying the phase angle out-to-in and in-to-out on each side of the MTA to determine the zero torque line and dead-band. Perform tests using V_2, $3V_0$ and if applicable external current polarizing.

21 Distance Elements

- Test impedance elements at minimum, 50%, and maximum settings of each range. Test minimum reach at 25% of nominal input voltage value, test mid-value reach at 50% of nominal input voltage value and test maximum reach at 75% of nominal voltage input value. Test points at MTA and enough points in 20 degree increments on each side of the MTA to define the **entire** reach characteristic. Perform these tests for 3 phase and all phase to phase combinations. Using these test results provide plots of the entire mho circle, quadrilateral or lenticular characteristic. If applicable, test with and without offset. Perform additional tests for any blinders or load encroachment elements that may affect the characteristic. Describe the setting changes made for each test.
- If not described in the instruction manual, define how the impedance elements perform when connected to voltage and current on the low-side of a delta-wye transformer. How does the relay algorithm compensate for the transformer phase shift during line-line faults on the primary side of that transformer? Which elements in the relay are affected by the phase shift compensation? PG&E will provide test values to perform that will test this compensation with +30° and -30° delta-wye and delta-delta transformer connections for three phase and all phase-phase combinations.
- If not described in the instruction manual, define how the relay loss of potential logic operates, which elements are affected and how. Propose a test plan to test these functions.
- If not described in the instruction manual, define how the voltage memory function operates, what keys it and how long it lasts. Perform a bench test to prove its function (include pickup and time delay) if it is within the capabilities of the test equipment used.

Pilot Relaying Functions

- Pilot relaying logic functions and timers must be proven using simulated relay end-end testing. Sufficient tests must be run to cover all aspects of a pilot relaying scheme (i.e. in-section faults, out of section faults, ground reversals etc.). Provide a proposed test plan to PG&E protection that will prove all pilot features of the relay being evaluated.

32 Power Elements

- The 32 element must function on a per-phase basis. Test pickup and dropout values at minimum, 50% and maximum settings on all three phases. PG&E requires a minimum sensitivity of less than 5 watts forward or reverse power.
- Perform a test to simulate a reverse over-power trip with a large watt flow on two phases in a forward direction and a low watt flow with low voltage in a reverse direction on the third phase. Repeat for the remaining two phases.
- Perform a test with all three phases having a large watt flow in the reverse direction. Drop one phase to 1 watt (still in the reverse direction) and verify an under-power trip. Repeat for the remaining two phases.
- If the 32 element is supervised by an under-voltage or underfrequency element, test to prove the voltage and/or frequency level of the block.
- If a timer is associated with the element, test the timer at minimum, mid-range and maximum time delay settings.

81 Frequency Elements

- The relay must provide a minimum of 2 over-frequency and 3 under-frequency elements.
- Test all elements at minimum, 50% and maximum frequency settings.
- Each element must have separate definite time capability. Test definite time characteristic at minimum, mid-range and maximum settings.
- Under-voltage blocking must be capable of an 80% of nominal voltage setting. Provide tests proving the under-voltage block level and function. If the under-voltage block function is a setting test at minimum, mid-range and maximum settings.
- If the frequency elements are supervised by a rate of change detector or other elements, describe its function and propose a test plan to prove its function.

27 AC Under-voltage Element

- Test the 27 element at minimum, mid-range and maximum settings.
- Test for 3 phase and single phase undervoltage.
- Perform tests at 54 Hz, 60 Hz and 64 Hz to ensure that pickup and dropout is independent of system frequency.
- If the under-voltage element is affected by the internal phase shift compensation for a delta-wye transformer explain the effect and perform testing with and without the compensation to prove the effect.
- The element must have a definite time capability that is capable of a 3-5 second setting. Test at minimum, 50% and maximum settings.

59 AC Over-voltage Element

- Test the 59 element at minimum, mid-range and maximum settings.
- Test for 3 phase and single phase undervoltage.
- Perform tests at 54 Hz, 60 Hz and 64 Hz to ensure that pickup and dropout is independent of system frequency.
- If the over-voltage element is affected by the internal phase shift compensation for a delta-wye transformer explain the effect and perform testing with and without the compensation to prove the effect.
- The element must be capable of operating with no intentional time delay (instantaneous). Perform testing to prove tripping with no intentional time delay.

59N Overvoltage Ground Fault Detection Element

- Test the 59N element at minimum, mid-range and maximum settings.
- Test the 59N time delay at minimum, mid-range and maximum settings.

15/25 Synchronizing/Synchronize Check Element

- Test the auto-synchronizing element (15) or synchronizing check element (25) for the requirements outlined in the PG&E Transmission Interconnection Handbook Section G2.9.1
    - Slip frequency (relay must be capable of a setting of 0.1 Hz or less)
    - Voltage matching (relay must be capable of a setting of ±10% or less)
    - Phase angle acceptance (relay must be capable of a setting of ±10 degrees or less)
    - Breaker compensation time
- Each function listed above must be tested independently of the other functions.

Prove the functionality of the voltage and/or speed control outputs (raise and lower) for the 15 element.62 Timer

- Relay must be DC powered.
- Provide minimum to operate and dropout tests.
- Provide test results for timer settings at minimum, mid-range and maximum range.
- Perform one test at 54 Hz, 60 Hz and 64 Hz to ensure that timing is independent of system frequency.
- Provide test results for each timer characteristic (i.e. inverse, definite time, etc.).

94 Auxiliary Tripping Relay

- Auxiliary tripping relays must be DC operated, high burden with a high pickup rating to prevent operation on transient spikes.
- Provide test results for minimum pickup and dropout of the coil.
- Provide test results proving the contact rated continuous and break current ratings.
- Provide pickup and dropout timing tests at full nominal coil voltage.

Automatic Transfer Switches

- Automatic Transfer Switches operate to open the customer's main breaker on power fail and close in the customers system to a backup power source. Upon PG&E power restoration the customer's main breaker will check synchronizing and then close paralleling the customer's backup source to the PG&E system. The customer's backup breaker must then be immediately opened to keep the parallel time to a minimum. Refer to Section 5 in the Distribution Interconnection Handbook and Section G2 of the Transmission Interconnection Handbook.
- Provide test results on the Automatic Transfer Scheme for the following required features:
    - Pickup and dropout voltages of the under-voltage sensing that initiates the transfer.
    - Pickup and dropout voltages of the over-voltage sensing that initiates the parallel operation.
    - Pickup and dropout of the following synchronizing functions:
        - Slip Frequency (0.1 Hz or less)
        - Phase angle acceptance (± 10° or less)

        - Voltage acceptance (± 10% of nominal or less)
    - Breaker compensation time.
    - Timing to transfer from the main source to the backup power source upon power failure.
    - Timing to parallel and then open backup power source upon power restoration.
    - Timing to trip the backup breaker(s) should the transfer fail to prevent excessive parallel time.