Commission Testing Methods for Protection Systems

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Agenda

- Introduction
- Goals and objectives of protection system commission testing
- Maintenance Testing
- Re-commission testing
- Case Studies
- Conclusions

Introduction

- Protection systems require testing to assure proper operation
- 3 separate stages of testing over protection system's life
  - Type testing
  - Commission testing
  - Life-cycle maintenance testing
- Commission testing is critical
  - Assure safety
  - Functional operation
  - Equally critical in both utility and industrial systems
- Commission testing provides baseline data for maintenance
  - Critical for utility installations subject to NERC PRC-005
- Commission and maintenance testing have different goals and objectives

Goals and objectives of protection system commission testing

- Commission tests are preformed to assure that the protection system is performing correctly as required for the unique application
- Must commission test all 5 NERC PRC-005-2 components
    - Voltage and current sensing devices
    - Protection system DC supply (including batteries, chargers, monitoring circuitry, and power supplies/inverters whether they include batteries or not)
    - Control circuitry (including wiring, trip coils, electro-mechanical auxiliary relays and lock-outs, etc.)
    - Communication systems required for protection system operation
    - Protective relays
- Must also perform energizing procedures and in service load checks

Voltage and Current Sensing Devices

- Magnetic core devices
  - VT commission tests
    - Ground leakage test - no unintentional grounds
    - Turns ration check (TTR)
    - Polarity check
    - Test voltage applied to a VT applied to the primary winding to avoid the presence unsafe high voltages
  - CT commission tests
    - Ground leakage test - no unintentional grounds
    - Turns ration check (TTR)
    - Polarity check
    - Excitation check

Voltage and Current Sensing Devices

- Non-magnetic core device commission tests
  - Optical VTs, CTs
    - Devices have self-testing functionality
  - Rogowski coils
    - Typically have unique calibration characteristics provided by manufacturer
    - Primary injection
    - In-service load checks

Protection system DC supply

- Batteries, chargers, monitoring circuitry, and power supplies/inverters whether they include batteries or not
  - Tests based on the technology used
  - Battery banks - verify the bank meets design specs and industry standards
    - Battery load/capacity tests
    - Cell impedance measurement
    - Inter-cell connection resistance measurement
    - Specific gravity measurement
    - Cell voltage checks

Protection system DC supply

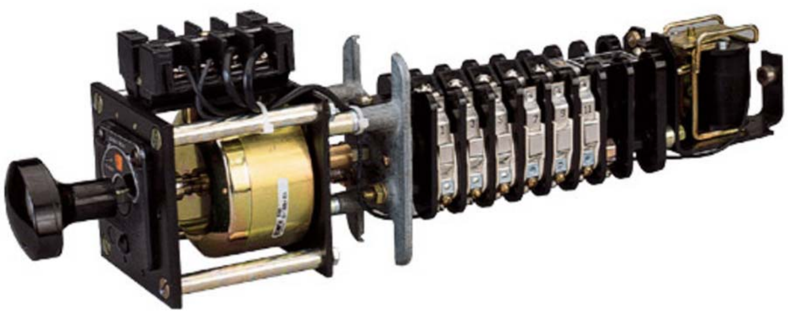
- Batteries, chargers, monitoring circuitry, and power supplies/inverters whether they include batteries or not
  - Battery chargers
    - Function testing
    - Verification of battery charger settings
    - Alarm verification
  - Methods and tools used for testing and the results of the tests should be saved as base-line data for future maintenance tests

Control circuitry

- Includes wiring, trip coils, electro-mechanical auxiliary relays, lock-outs, etc.
- AC and DC wiring should be checked physically and electrically
    - Point to point wire checks
        - Wiring is physically in agreement with the design documents
    - Injection of electrical quantities
        - Wiring performs the necessary functions
        - Helps to identify any errors in the design
    - Develope a system to document each test

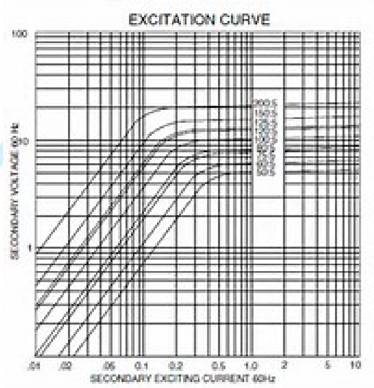
Control circuitry

- AC and DC wiring electrical tests (cont.)
  - Check DC circuits before energizing
    - Pull fuses to isolate
    - Use an ohm meter to verify there are no short circuits
    - Reinstall load fuses one circuit at a time
      - Verify no DC grounds are acquired



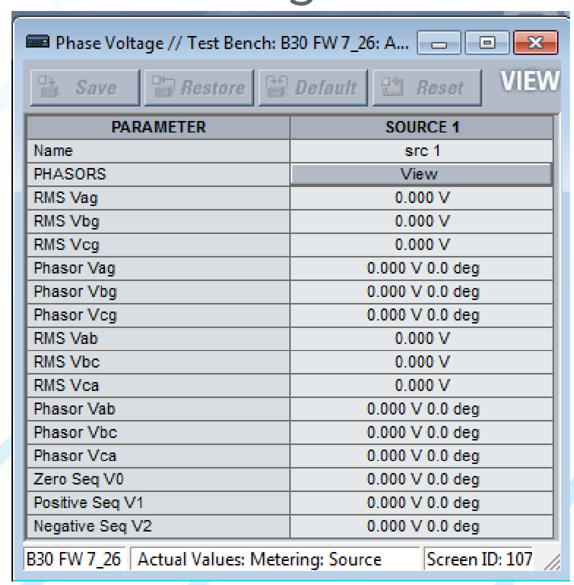
Control circuitry

- CT secondary injection
  - Inject 3-phase test set currents into CT circuit
  - Clipping onto the CT wires (no lifting wires)
    - Directly on the CT secondary terminals if accessible
    - Otherwise on the CT shorting block terminals
  - Virtually none of the injected current goes into the CT
  - Inject varying magnitudes of current on the three phases
    - Ex: 0.5, 1.0 and 1.5 amps into phases A, B and C respectively
  - Verify with receiving relays' metering functions



Control circuitry

- VT secondary injection
  - Isolate the VT winding from the secondary wiring
    - Pull the VT secondary fuses
  - Clip test set to the load side of the open fuse block
  - Wye connected VTs
    - Apply varying magnitude phase-neutral voltages
  - Open delta connected VTs
    - Apply varying magnitude phase-phase voltages
  - Verify with the relays' metering
    - Check each device that receives the VT signal


Phase Voltage // Test Bench: B30 FW 7_26: A...

Save | Restore | Default | Reset | VIEW

PARAMETER	SOURCE 1
Name	src 1
PHASORS	View
RMS Vag	0.000 V
RMS Vbg	0.000 V
RMS Vcg	0.000 V
Phasor Vag	0.000 V 0.0 deg
Phasor Vbg	0.000 V 0.0 deg
Phasor Vcg	0.000 V 0.0 deg
RMS Vab	0.000 V
RMS Vbc	0.000 V
RMS Vca	0.000 V
Phasor Vab	0.000 V 0.0 deg
Phasor Vbc	0.000 V 0.0 deg
Phasor Vca	0.000 V 0.0 deg
Zero Seq V0	0.000 V 0.0 deg
Positive Seq V1	0.000 V 0.0 deg
Negative Seq V2	0.000 V 0.0 deg

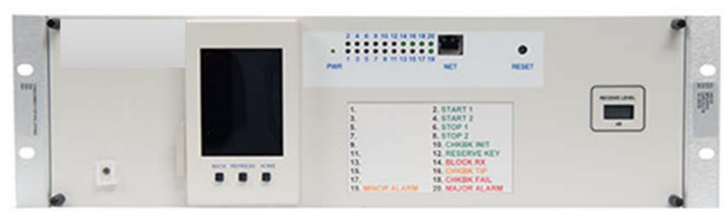
B30 FW 7_26 | Actual Values: Metering: Source | Screen ID: 107

Control circuitry

- Primary injection less common than secondary injection
  - Use a 3-phase generator (typically LV) to energize the substation bus
    - Apply loads on each circuit to cause current flow
    - Check relays' metering to assure functionally correct
    - Magnitudes and angles
  - Requires a thorough understanding of relay phasor angle referencing
    - Often subject to or controlled by relay settings
    - Take care when interpreting the metered values to assure correct phase identification
  - DC control wiring electrically tested while function testing the relay

Communication systems

- All communication systems need to be verified
  - Used by protection system for protection
    - Pilot channels, transfer trip, etc.
  - Used for operation and control
    - SCADA, voice, LANs, data remote access, etc.
    - Typically not subject to PRC-005 requirements
  - Point to point communications functionally verified and documented
    - Signal levels and data transfer rates
  - SCADA remote control functions
    - Verify perform as expected



Communication systems

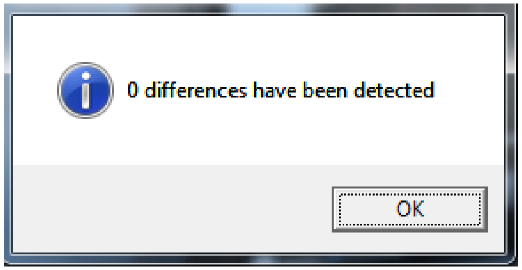
- All communication systems need to be verified (cont.)
  - SCADA remote control functions
    - Verify perform as expected
  - SCADA metering from standalone metering devices (transducers, meters, etc.)
    - Inject current and voltage device
  - SCADA metering from relay memory registers
    - Test as part of relay functional tests

Communication systems

- All communication systems need to be verified (cont.)
  - Stand-alone communications for transfer trip and/or pilot wire (power line carrier, audio or digital tone systems, etc.)
    - Verify end-end functionality before protective relay functional tests
  - Digital relay communications used for transfer trip and/or pilot wire
    - Verify end-end functionality as part of relay functional tests

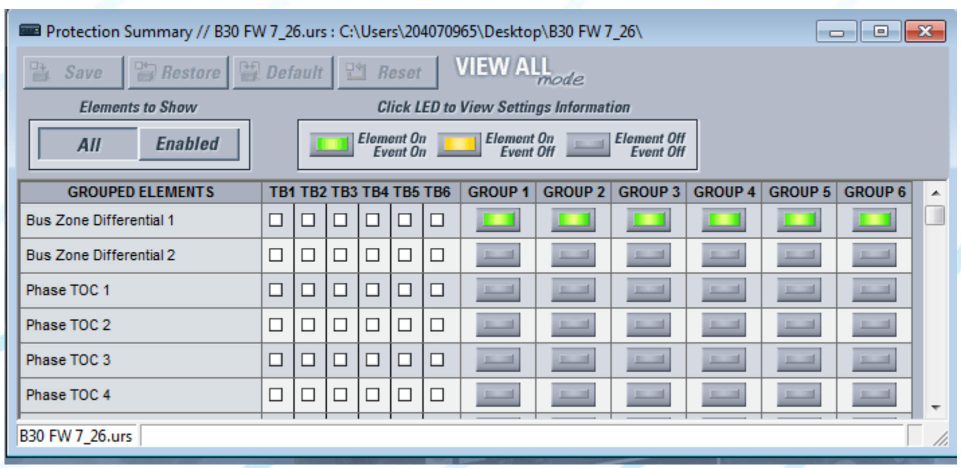
Protective relays

- Relay acceptance testing
    - Owner preferences
        - Verify 100% of all included analog and digital I/O
            - Even if not all the I/O are used
- Load Relay Settings
    - Digital relays
        - Setting files loaded into relays
        - Vendor specific software tools
        - Verify by comparing relay to setting file
        - Should be no differences
        - If differences resend or manually correct
        - Save an image of the compare report showing no differences



Protective relays

- Load Relay Settings (cont.)
  - Non-digital relays
    - Settings entered (adjusted) manually
    - Verify with current and/or voltage injection
- Function testing
  - Verify all enabled feature as a complete system
  - Protection elements, metered values, logic, communications and I/O
  - Demonstrate system functions as designed

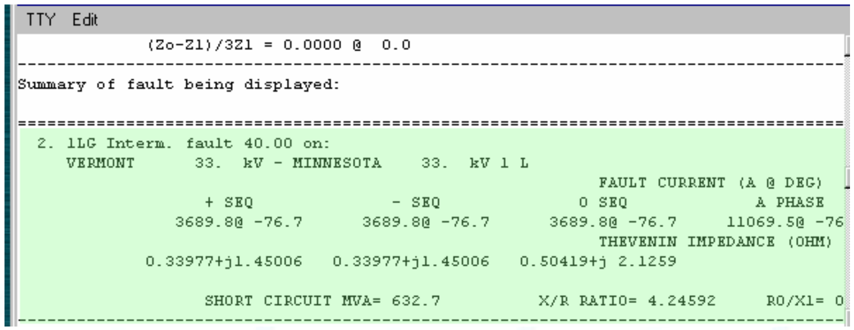


Protective relays

- Function testing (cont.)
  - Automated testing programs are not suited for commission function testing
    - Inject current and voltage based on relay's settings
    - Not be able to detect setting errors
      - Typos
      - Bad system data
    - Do not test programmed logic or specific I/O functions
    - Used at end to establish a base-line testing report for future maintenance

Protective relays

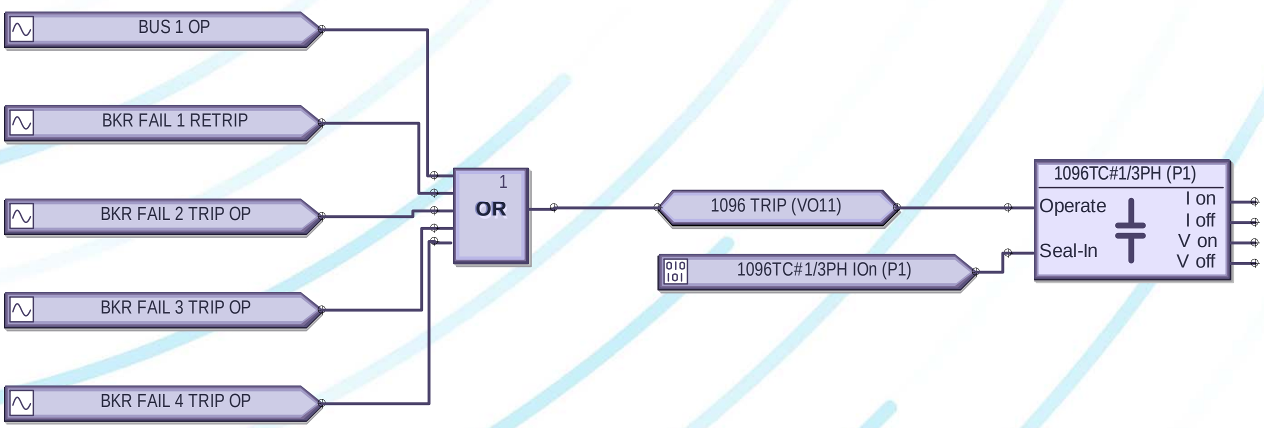
- Function testing (cont.)
  - Use test values derived from system studies
    - Not values calculated from relay settings
  - Line protection test values from SC program
    - Close-in reverse fault
    - Close-in forward fault
    - Mid-line or balance point fault
    - Remote end fault



  - Run tests with the pilot communication system operational
- Transformer protection
  - Test values derived based on the transformer winding connections and SC program

Protective relays

- Function testing (cont.)
  - Programmed logic functional testing (including I/O)
    - Inject current and voltage to operate protection functions used in the logic
    - Operate inputs to the relay that are used in the logic
    - Verify outputs that are operated by the logic
      - Verify DC circuitry correct to end device
        - Auxiliary relays, lock-out relays, trip coils, etc.
    - Logic diagram useful for complex logic



Energizing procedures and in service load checks

- Energizing procedures vary widely from owner to owner
  - Common goal of energizing the equipment in a logical and safe manner
    - Associated protection systems in service
- In service load checks
  - Phase identification
    - Voltage readings taken after energization
      - All voltage measuring devices
      - Assure secondary levels and phase identification are correct
    - Challenging on a totally new power system
      - References from existing facilities not available

Energizing procedures and in service load checks

- In service load checks (cont.)
  - Phase identification (cont.)
    - Use end-end communication signal (ex: transfer trip)
      - Temporarily trigger waveform capture reports in relays
        - At new substation and in remote existing system
      - Compare waveforms to assure correct phase identification
    - Phasor measurement unit (PMU) data

Energizing procedures and in service load checks

- In service load checks (cont.)
  - Phase identification (cont.)
    - Cellular based phase checking systems
      - Compare phase angle between remote and local voltages
    - Remove any temporary settings after test complete
  - Examine metering of current measuring devices
    - Assure correct ratios, phasing and phase shifts

Energizing procedures and in service load checks

- In service load checks (cont.)
  - Current based differential elements
    - Examine differential and restraint quantities
    - Differential quantity is near or equal to zero
    - Restraint quantity is significant
    - Requires a significant amount of load for reliable results
  - High impedance bus differential
    - Examine operating quantity
    - Voltage across or current through the resistor
    - Measure current from each CT to verify ratios
  - Record load check data for future comparison

Maintenance Testing

- Commission testing data is baseline for the life-cycle maintenance
  - Date of commissioning records define time 0 for PRC-005
  - Current and voltage measuring device insulation failure detected
  - Battery and charger performance degradation observed
  - Communication channel degradation flagged
  - As-left relay settings are base-line for maintenance
    - Changes must be researched and validated
  - Automated testing program results remain consistent

Re-commissioning

- Re-commissioning required if significant changes are made
  - Only re-commission aspects of system affected
  - Physical equipment replacement
    - Communication equipment
    - CT/VT
    - Battery or charger
    - Relay
    - Re-commission replaced equipment

Re-commissioning

- Re-commissioning required if significant changes are made
  - Wiring changes
    - Re-commission anything that might have reasonably been affected
  - Setting changes
    - Re-commission those elements/systems affected
  - Firmware upgrade that requires setting file conversion
    - Complete relay re-commission

Case Study: Protection problems at mine ID need to re-commission switchgear

- New cubicles added to existing gear
  - No commission testing performed on additions
  - Trips during loading attempts
  - Wiring errors discovered
  - Missing settings discovered
- Similar problems found in existing cubicles
  - No commissioning records found
- Safety concerns – workers no longer comfortable
- Re-commission entire line-up during next outage

Case Study: Modelling error discovered during commissioning

- New replacement 115 kV line panel
  - Test quantities for distance elements from SC program
  - Ground distance zone 1 operated for remote bus fault
    - Math check confirmed that test fault was within reach
  - Zero-sequence line impedance error discovered in SC program data base
    - Caused wrong Z0/Z1 ratio
    - Resulted in element over-reach
  - Modelling error corrected and settings (Z0/Z1) changed
    - New test values issued for 1LG faults
    - Ground distance performed correctly
  - Avoided future false trip

Case Study: Setting errors discovered while commissioning replacement generator protective relay

- New generator protection to replace existing obsolete relay
  - Settings calculations based on previous relay's settings
  - Tech ran automated testing program
    - Report indicated no errors
  - Field Engineer and Tech performed commissioning tests
    - Discovered logic and setting omissions
      - Trip output for field breaker wired but not programmed
      - Bus ground detection voltage input wired
        - No associated element enabled and set
        - No output contact programmed or wired

Case Study: Verification of relaying functions in relay using simulated faults discovered firmware issues

- New replacement 115 kV line panel
  - Test quantities for distance elements from SC program
  - Phase distance failed to operated for 3LG faults
  - Examination of SER data discovered that Loss of Potential (LOP) was operating and blocking the elements
  - No similar problems observed with other panels using same relay models
  - This terminal is weak-feed
    - Voltage drops unusually low during 3LG faults
    - LOP blocks even though memory voltage available for correct distance element operation
  - Waiting for a firmware fix from manufacturer

Conclusions

- Protection systems require testing to assure proper operation
- 3 separate stages of testing over protection system's life
  - Type testing
  - Commission testing
  - Life-cycle maintenance testing
- Commission testing is critical
  - Assure safety
  - Functional operation
  - Equally critical in both utility and industrial systems
- Commission testing provides baseline data for maintenance
  - Critical for utility installations subject to NERC PRC-005
- Commission and maintenance testing have different goals and objectives

Thank You

Questions?