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 performed 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 of 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
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

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  • Life-cycle maintenance testing
• Commission testing is critical
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  • 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?