Commissioning & Periodic Maintenance of Microprocessor Based Protection Relay In Industrial Facilities

IEEE IAS Atlanta In-Person and Virtual Meeting
February 22, 2022

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Introduction

- The first relays were Electromechanical (EM): machines with moving parts actuated by coils connected to current and voltage sources.
- These required regular testing, adjustments and maintenance to ensure continued functioning. Relays contained bearings, springs, fixed and movable contacts, rotating disks or cylinders, air gaps, permanent magnets and other components.
- Static Relays containing analog and digital discrete electronic components and small ICs similarly required testing and adjustments but less maintenance.
- Microprocessor Relays use Digital Signal Processing and Protection Algorithms. They have no adjustments. What does test and maintenance mean, and when is it required?
- Relays have become Intelligent Electronic Devices (IEDs) in power systems, doing much more than protection.

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Relay Testing Safety

- When testing relays on energized equipment, safety precautions must be observed.
- Follow all OSHA and local site safety procedures
- Wear appropriate PPE and use safety gear as required.
- Check that you are only exposed to secondary voltages and currents (120V, 5A) unless performing primary injection testing.
- Verify that power system has sufficient redundant and back-up protection while relay is out of service for testing.
- Use test switches to isolate output contacts to prevent undesired tripping and alarms.
- Use shorting switch on CT circuits. Be aware of effect on other relays in system.
- When removing voltage sources from relays ensure other relays in system can still operate.
- Disable remote communication interfaces to prevent accidental notifications.

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Relay Testing Documentation

- All testing must be properly documented.
- Test procedures
- Equipment used
- Results
- Complex system tests require detailed documentation of steps taken to provide repeatability.
- Save software files of automated test equipment.
- As found and as left relay setting files.

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Microprocessor relay design block diagram

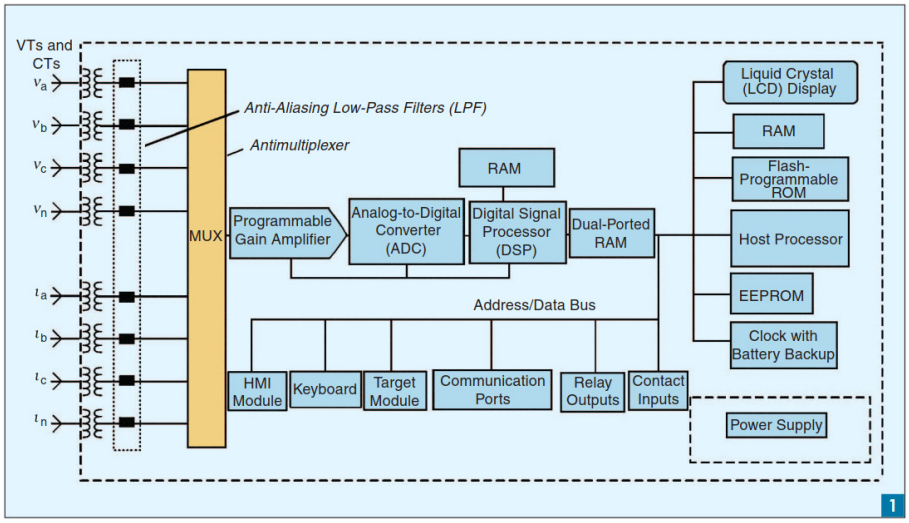

Figure from paper "Multifunction Digital Relay Commissioning and Maintenance Testing" [1]

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Microprocessor relay design block diagram

- Voltage and current inputs to magnetics module.
- Analog signals are filtered and multiplexed and scaled to feed the Analog to Digital Converter (ADC)
- The Digital Signal Processor (DSP) executes relay algorithms
- The Host Processor supervises and organizes relay operation
- Dual-port memory serves both processors
- Contact inputs and outputs (I/O) user interface and serial communication are from host processor.
- Redundancy is important in design and application

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Microprocessor relay design features

- Oscillography and event recording
- Multiple setting groups
- Multiple input and output contacts
- Metering – may replace traditional metering
- Monitoring – breaker trip circuits, CTs and PTs
- Communications. Local and remote.
- Self monitoring and diagnostics
- Programmable Logic – internal PLC.

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Microprocessor relay failure

- Mean time between (hardware) failures (MTBF) ~ 500 years (0.2% per year)
- Self-tests detect ~ 85% of failures (0.17% per year)
- Undetected failures ~ 15% of failures(0.03% per year)
- Failures detected during maintenance ~ 0.12% per year

Data from White Paper "SEL Recommendations on Periodic Maintenance Testing of Protective Relays" [3]

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Microprocessor relay failure

Damage from arcing caused by overvoltage from open circuited CT.
Photo from White Paper "Open-Circuited CT Misoperation and Investigation" [2]

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Microprocessor relay self-tests

- Self-test will activate alarm contact, send message, or other indication.
- Three main sections:
  1. Analog input section.
  2. Contact input/output.
  3. Processors and memory.
- Typical relay will have hundreds of types of self-tests.
- Self-test failure alarm may be available if the self-test system itself fails.

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Microprocessor relay monitoring features

- Programming functions to detect failures:
  1. Loss of Potential (LOP) – VT Failure, VTFF, ANSI 60. Detects decrease in positive-sequence voltage without simultaneous change in positive- or zero-sequence current magnitude or angle.
  2. Loss of Current (LOI) – open CT detection
  3. Metering errors – compare results with other relays or meters
  4. Event reporting – analyzing fault data can locate relay failures
  5. Output contact failure – contact monitoring

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Microprocessor relay testing – Type Testing

- When a new relay design is selected
- Type test on a single relay from that manufacturer
- Verify relay functions according to manufacturer specifications
- Verify relay hardware design, algorithms and characteristics
  1. Relay operating characteristics
  2. Design specifications and industry standards
  3. High current tests with low rated CTs
  4. Recertify product after hardware/firmware change
  5. Real-time digital simulation (RTDS) of difficult scenarios
  6. Laboratory tests of a new scheme

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Microprocessor relay testing – Acceptance Testing

- When a new relay is received
- Test relay before being put in storage or installed and commissioned
- Verify relay functions according to manufacturer specifications
- Verify relay was not damaged during shipment
- Verify relay calibration
  1. Metering test
  2. Relay operating characteristics

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Microprocessor relay testing – Commissioning Testing

- When a new relay is installed in the system
- When new firmware is installed in existing relay
- When relay is serviced, new cards installed, other major changes
- Commissioning test verifies:
  1. Relay was not damaged during installation
  2. Relay was installed correctly
  3. Relay protection scheme functions correctly
  4. Test system equipment which interfaces with relay, CTs, PTs, trip coils, lockouts, DC battery system, control panel switches, communication systems.

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Microprocessor relay testing – Commissioning Testing Requirements

- Must have:
  1. Safety rules must be known and followed
  2. Detailed commissioning checklist for each relay
  3. Detailed relay setting calculation sheets
  4. Relaying, elementary, three-line drawings and wiring diagrams
  5. Understanding of all relay functions being used
  6. Communication interface capability – IEC 61850, GOOSE, etc.
  7. Required test equipment

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Microprocessor relay testing – Commissioning Testing Procedures

1. Obtain manufacturer's instruction manual for specific type and model of relay.
2. Verify firmware revision and PC software version and obtain correct interface cables.
3. Use relay test set suitable for the relay and functions to be tested.
4. Download all settings programmed into the relay. Reload settings after testing completed.
5. Discuss any questionable settings with protection engineer.
6. Some settings may need to be disabled for testing other functions.
7. If settings groups are used, test all setting groups.
8. If only one group is used, recommended to copy its settings into all other groups.
9. Test every feature of programmable logic
10. Test all external inputs
11. Test target LEDs or other indicators
12. Test output contacts
13. Test metering of input quantities including magnitude, phase angles and phase sequence
14. Are metering quantities same as protection quantities in relay design? If not, test both.
15. Primary current injection to test entire CT circuit.
16. Secondary current injection for all other tests.
17. Test directional relay polarization
18. Test transformer differential relay winding configuration
19. Test event recording and oscillography – read COMTRADE files

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Microprocessor relay testing – Routine Maintenance Testing

- Testing on a regular basis to confirm relay functioning
- This is in addition to routine monitoring and self-test.
- Does not need to be as extensive as commissioning testing.
- Testing at the relay location with secondary injection
- Test functions which self-test does not cover
- Monitor the self-test failure alarm

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Microprocessor relay testing – Needs Based Maintenance Testing

- Relay has sent alarm or trip
- Failure to alarm or trip
- Improper operation of programmable logic
- Visual inspection indicates problem
- Self-test indicates a failure

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Testing Standards – NFPA 70B – Recommended Practice for Electrical Equipment Maintenance

- Section 11.12 Protective relays
- Recommended maintenance interval is “at least every 2 years.”
- Primary focus is on electromechanical relays
  1. Inspection
  2. Settings applied
  3. Pickup test
  4. Timing test
  5. Time delay settings
  6. Instantaneous test
  7. Target and seal-in unit
  8. Contact seal in verification
  9. Tripping circuit causes breaker to trip

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Testing Standards – IEEE C37.233™-2009 – IEEE Guide for Power System Protection Testing

- Focus is on overall systems including protective relays
- Very thorough 124-page guide
- Firmware covered in companion guide C37.231™-2006
- Covers many advanced utility schemes not seen in industry
- Discusses maintenance intervals and gives examples, not recommendations.

Table 3—Example of relay testing intervals

Relay voltage (kV)	Maintenance interval (years)
500	2
230	4
115	4
69	4
Less than 69	4

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Testing Standards – NERC (North American Electric Reliability Corporation)PRC 005-2 – Protection System Maintenance

- Part of a series of standards covering detailed protection needs of Bulk Electric System (BES)
- Audience is Transmission Owner, Generator Owner, and Distribution Provider
- Maintenance methods: time-based, performance-based or a combination
- Table 1-1 gives recommended maintenance activities and intervals for protective relays
- Also covers other protection system equipment
- Attachment A: Criteria for a Performance-Based Protection System Maintenance Program

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Testing Standards – NERC PRC 005-2 – Protection System Maintenance

Table 1-1 Component Type - Protective Relay Excluding distributed UFLS and distributed UVLS (see Table 3)		
Component Attributes	**Maximum Maintenance Interval[1]**	**Maintenance Activities**
Any unmonitored protective relay not having all the monitoring attributes of a category below.	6 calendar years	For all unmonitored relays: • Verify that settings are as specified For non-microprocessor relays: • Test and, if necessary calibrate For microprocessor relays: • Verify operation of the relay inputs and outputs that are essential to proper functioning of the Protection System. • Verify acceptable measurement of power system input values.
Monitored microprocessor protective relay with the following: • Internal self-diagnosis and alarming (see Table 2). • Voltage and/or current waveform sampling three or more times per power cycle, and conversion of samples to numeric values for measurement calculations by microprocessor electronics. • Alarming for power supply failure (see Table 2).	12 calendar years	Verify: • Settings are as specified. • Operation of the relay inputs and outputs that are essential to proper functioning of the Protection System. • Acceptable measurement of power system input values.

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PRC-005 — Attachment A
Criteria for a Performance-Based Protection System Maintenance Program

1. Develop a list with a description of Components included in each designated Segment
2. Maintain the Components in each Segment according to the time-based maximum allowable intervals established in Tables…until results of maintenance activities for the Segment are available for a minimum of 30 individual Components.
3. Document the maintenance program activities and results for each Segment, including maintenance dates and Countable Events for each included Component.
4. Analyze the maintenance program activities and results for each Segment to determine the overall performance of the Segment and develop maintenance intervals.
5. Determine the maximum allowable maintenance interval for each Segment such that the Segment experiences Countable Events on no more than 4% of the Components within the Segment…

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Testing Standards – NETA (National Electrical Testing Association) MTS-2019– Maintenance Testing Specifications

Section	Description	Visual	Visual and Mechanical	Visual and Mechanical and Electrical
7.9	Protective Relays			
7.9.1	EM and Solid State	1	12	12
7.9.2	Microprocessor Based	1	12	12
7.10	Instrument Transformers	12	12	36
7.11	Metering Devices			
7.11.1	EM and Solid State	12	12	36
7.11.2	Microprocessor Based	12	12	36

NETA Maintenance Testing Intervals in Months [4]

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Summary of recommended maintenance intervals for microprocessor-based relays

Standard	Interval (years)	Comments
NFPA 70B	2	Based on electromechanical relays
IEEE C57.233™-2009	4	Example for <69kV, not recommendation
NERC PRC 005-2	6	Unmonitored protective relay in BES
NERC PRC 005-2	12	Monitored protective relay in BES
NETA MTS-2019	1	Visual and Mechanical
NETA MTS-2019	3	Visual, Mechanical and Electrical

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Conclusions

- Microprocessor based protective relays do require initial and then periodic testing and may very occasionally require maintenance.
- This may seem counterintuitive because there are (almost) no moving parts and no adjustments to make.
- Self-test and reporting simplify testing and maintenance.
- Recommended maintenance intervals vary, user must make their own decision.

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References

1. "Multifunction Digital Relay Commissioning and Maintenance Testing," An IEEE/IAS Working Group report. by Charles Mozina , Chair & Michael Young , Vice Chair, IEEE Industry Applications Magazine, Sept/Oct 2005
2. "Open-Circuited CT Misoperation and Investigation" by David Costello, 67th Annual Conference for Protective Relay Engineers, March 2014, SEL reprint
3. "SEL Recommendations on Periodic Maintenance Testing of Protective Relays" by Karl Zimmerman, SEL White Paper LWP0005, 2014
4. "Testing and Commissioning Digital Protective Relays" by Drew Welton, NETA World Journal, June 1, 2020

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