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Why Testing Digital Relays Are Becoming So Difficult! Part 3 Advanced Feeder Protection

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Abstract - The paper identifies more of the developing issues in relay testing - what has previously been well understood protection elements/functions used in designing feeder protection systems has become intertwined with modern complex programmable logic. The core issue is the same modern algorithms and combined protection element scheme logic that enables modern feeder protection to operate securely and reliably also prevents us from using legacy testing techniques we relied on for our "understood" elements.

The paper compares various traditional single function protection relays to their modern replacements and illustrates how legacy testing becomes inadequate. This includes modern combinations of overcurrent, directional overcurrent, over/under voltage, and frequency elements. But also investigates the scheme logic employed: sympathetic trip, broken conductor, SOTF, BF, cold load pickup, CT/VT supervision, etc… Combine these with Distrbuted Generation and Distribution Automation deployments and today's feeder protection relay does not test at all like our legacy electromechanical devices. In some instances for today's feeder protection scheme only a network simulator tool can provide a resonable test case. The paper reviews these new challenges and explains why new testing methods are required.

Index Terms— Feeder Protection, Overcurrent, directional overcurrent, testing, relay, characteristic

1 Introduction

Testing of today's digital feeder protection relays requires an understanding of their characteristics, algorithms, and embedded logic in order to be successful. Using simplified test methods for today's feeder protection that ignores proper fault simulations may or may not result in a satisfactory operation of the overall feeder protection scheme much less its individual elements. If we were simply testing a traditional electro-mechanical overcurrent protection scheme, then it would not be as difficult. Visually verifying a single phase overcurrent relay's initial condition before injecting a test current (e.g. multiple of the tap value) has always been straight forward and easy to instruct others on what to look for. But the operating principles and algorithms implemented in the modern digital feeder relay now consider more than "is the disk returned to the stop" as the initial condition for starting a test injection. The application, including the protected object, CT performance, scheme logic employed, and the operational power system conditions force us to take into consideration a much different test approach.

Our legacy testing traditionally applied test current magnitudes with no respect to phase angles. (Generally because we were only injecting a single current.) But as feeder protection relays evolved into digital protection platforms, three phase current injections became more the norm, and correct phase angles important. And if we also add in all the other local system functions, like bus voltages, switch and breaker status, interlocking of adjacent feeders and transformer status; we nearly have the entire distribution substation to consider. Where previously we had two goals in our tests; one to verify the overcurrent characteristic settings, and two, to verify the relay's calibration - modern digital feeder protection presents us with a "whole new ball of wax" as my granddad used to say. If we do not test it correctly, it will get real messy.

2 Traditional Feeder Protection Testing

In general, the basic requirements for signal injection into a legacy feeder protection relay was one current source. The protection elements being tested were/are simple non-directional overcurrent elements as depicted in Fig. 1. There were three basic tests performed: 1) minimum pickup of the Overcurrent (OC) inverse element, 2) timing test of the Overcurrent (OC) inverse element, and 3) pickup test of the Instantaneous (INST) element (also verifying its operate time).

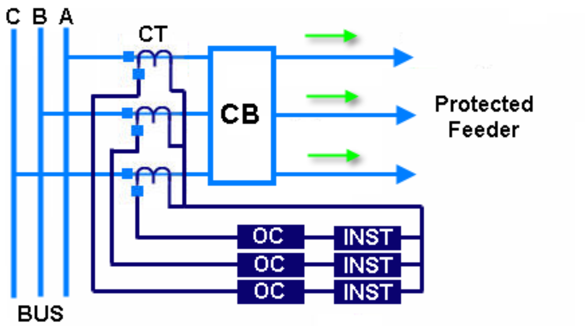

Fig. 1: Basic Feeder Protection

Inverse overcurrent characteristics were introduced early in protection history [1] and in North America best known by their Westinghouse and GE monikers, CO's and IAC's.

For inverse characteristics, the time of operation is inversely proportional to the fault current level and the actual characteristic is a function of both time and current. Even these simple characteristics when implemented in electro-mechanical relays were precision engineered marvels. But in order for them to work properly we had to maintain their calibration, and as with any mechanical system, components wear; and this was the main purpose of testing them, ensuring proper calibration. Verifying the settings was simple: read the tap, time dial, and instantaneous settings, then verify the nameplate for the curve type; and plot the time response from the curve in its reference manual. (Fig. 2) This would then be used to establish the test injection values and expected operate times.

However, as utilities fought the resource, training, cost, and scheduling cyclic business battles even this simple testing process got lost. Instead of educating those testing these devices many turned to simplifying the testing method. Calibration was ignored and correct feeder coordination suffered often resulting in miss operations.

The correct test method for the pickup test is based on the induction disk design, a multiple of minimum pickup is applied until the contact asserts and then slowly ramped down until it drops out, and then slowly ramped up to its pick up again and that value noted. In modern day testing an improved algorithm performs a binary divide by two search of the pickup/dropout values until the threshold meets a minimum tolerance.

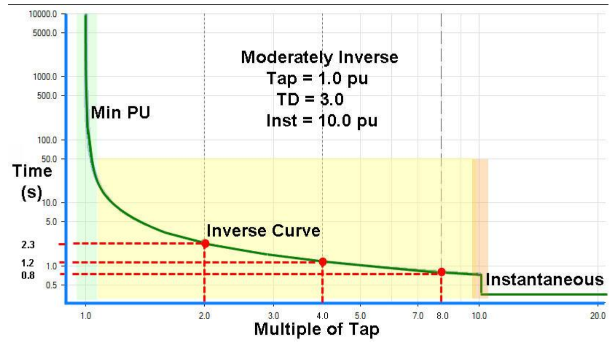

Fig. 2: Overcurrent relay MI characteristic

The test method for the points on curve and instantaneous is straight forward - making a step injection from zero current to the test current value and timing from that inception to the relay operation (trip) should match the published curve. Results could be a simple table where a basic tolerance is used for pass or fail assessment. (Fig 3) (Slow ramps are not recommended for high current tests, a pulse ramp is much safer.)

State	Type	Angle	Trip Value	Resolution	I Pick-up				I Drop-off
					nom	min	max	act	act
✓	A-N	n/a	2.0 In	50.0 ms	1.0 In	0.99 In	1.01 In	1.003 In	0.997 In

State	Type	Relative To	Factor	Magnitude	Angle	tnom	tmin	tmax	tact
✓	A-N	I #1 Phase	2.000	2.000 In	n/a	2.303 s	2.231 s	2.376 s	2.283 s
✓	A-N	I #1 Phase	4.000	4.000 In	n/a	1.178 s	1.130 s	1.226 s	1.198 s
✓	A-N	I #1 Phase	8.000	8.000 In	n/a	802.5 ms	758.9 ms	846.2 ms	782.5 ms

State	Type	Relative To	Factor	Magnitude	Angle	tnom	tmin	tmax	tact
✓	A-N	I #1 Phase	10.10	10.100 In	n/a	100.0 ms	60.00 ms	769.8 ms	120.0 ms

Fig. 3: Results for PU, Inv. Time points, Inst.

Since these E/M relays are single phase and tested as single function elements, they did not require complex test equipement or procedures, just methodical execution. Precluding any application errors, if they had been properly calibrated and commissioned, then they would provide many years of reliable service. Misoperations were typically attributed to future routine testing where human error was the most common problem.

As our power systems evolved, so did the complexity of the protection and control applications and we looked for new technologies to address them.

3 Feeder Protection Evolution

Testing of E/M feeder protection applications span more that just the individual overcurrent elements. Most schemes included controls, metering, reclosing, (Fig 4) interlocking to bus and transformer protection, and maybe underfrequency load shedding. Auxilary devices were added to provide features like Cold Load Pickup, Sympathetic Trip Logic, Breaker Failure, Switch Onto Fault, Fuse Saving plus others.

The test methods required for these increasingly complex schemes and elements required a well designed PAC system (Fig 5) to provide easy access for testing. [2] Dedicated test links with safe isolation for maintenance and testing were the norm for E/M PAC systems in most utilites because the relay manufacturers recommended them.

Fig. 4: Retrofit of E/M scheme w/Digital OC

This was half the testing battle, the remaining part was eliminating human errors and bad testing habits and procedures.

The evolution of the test equipment from single phase current sources and timers to multi-phase sources and later 3-phase power system simulators followed this trend too. But as imagined, the more variables you have to control in a test the more knowledgable you need to be or smarter the tools need to be. For the system in Fig 5, entire panel injections are possible where the entire feeder protection scheme can be tested as designed, but this also requires a good understanding of the application, power system configuration, operational philosophy, and of course creating proper test cases. Those utilties who did whole panel testing were much better prepared for the coming digital evolution.

If a utility followed a conservative protocol, it would introduce the new digital technology in stages, while the field testing unaltered followed established procedures. Figure 4 shows a hybrid scheme of both E/M devices and a digital retrofit. Very often the testing of the digital OC device would be attempted using the single current source test method commonly used for the E/M relay scheme.

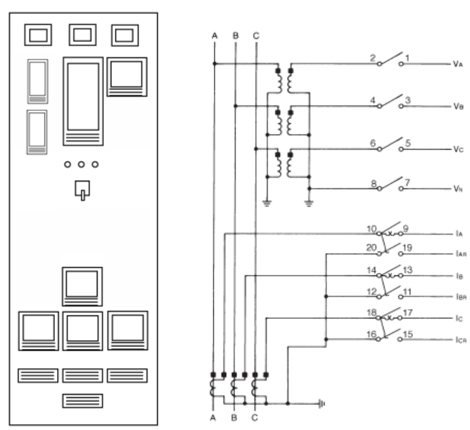

Fig. 5: E/M Feeder Panel with Test Links

Depending on the digital OC relay design, logic, and level of scheme integration with the E/M system, this could prove frustrating if not impossible without compromising its settings, configuration, and/or wiring. Thus a process was often begun that became the stereo typical, "that's the way we always did it."

The common practice of withdrawing the E/M relays to bench test them also proved difficult for digital relay manufacturers to duplicate via electronic boards which were not mechanically hardened for such repetitious insertion/removal. In reality, it was never really necessary and only added to the unreliability of the electronic packaging and protection system.

Most scheme integration of E/M and digital technology was an unnecessary compromise - many protection or feeder control issues could only be solved with digital technology. So why create new issues when it was designed to completely replace and upgrade the existing protection? A lack of trust in the technology or a lack of proper acceptance testing? In most cases it was the trust issue since comprehensive acceptance testing had nearly been eliminated in most companies by the early 80's.

Despite the trust issue, the digital technology proved to be more accurate, more sensitive, could record events, perform self-checks, and provide remote access to data; all true benefits but it also introduced many new issues; programmability and complex logic, algorithm-based elements, electronic component mortality, environmental challenges, security, and operational unknowns. Testing became necessary to both prove and disprove all of the above "features" of the digital technology. The core problem was trying to apply conventional testing methods to what was now a completely integrated protection system. System is the key word here, only a system testing approach can properly test a "system."

4 Modern Feeder Relays

Figure 6 illustrates the complexity of using a modern digital feeder protection system with so many protection and control elements being possible. The more options offered to protection engineers usually means more complex schemes.

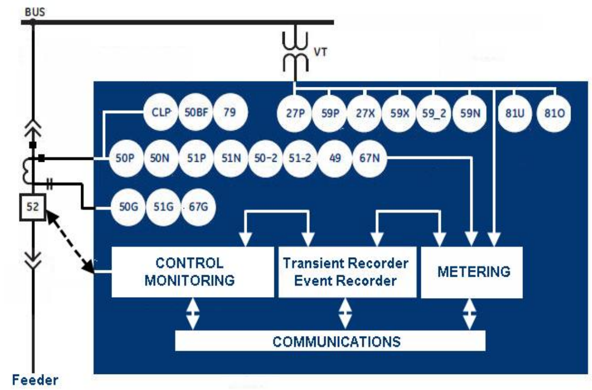

Fig. 6: Digital Feeder Protection

There are always multiple elements, logic, and programmed variables applied to tripping masks that are mapped to a single trip output. (Fig 7) Even where the devices have multiple sets of outputs, the protection and logic functions are seldom organized and segregated for the purpose of easy commissioning or testing and this is an oversight of the engineering process. (Even the E/M relays typically provided functional isolation.)

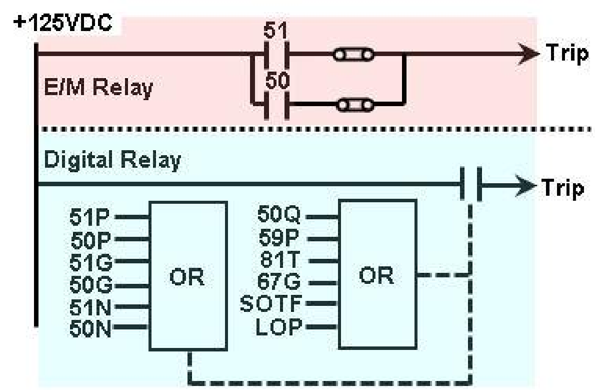

Fig. 7: Tripping Element Comparison

There are many elements used strictly for internal logic schemes and control applications, yet they often go untested because they are not externally accessible. In modern feeder protection, the scheme logic settings make you more vulnerable to a miss operation than the timing of an algorithm based OC element. So what is the purpose in making tens to hundreds of shots on digital OC elements that cannot change unless their settings or programming is changed?

If provisions are not inherently engineered into the design of the relay as noted, then any reprogramming of the relay just to test it effectively invalidates the commissioning. This is especially true for routine testing. Add to this that remapping each tested element individually to an output contact (let's hope it is NOT the used main tripping contact) effectively proves little other than that output contact operates. The real protection scheme and logic remains unproven.

5 Using Proper Test Methods

Testing a modern digital feeder relay is really pretty simple: 1) have proper testing access to all relevant wiring via test switches and safety isolation points; 2) it must measure voltage and current accurately per its application and the power system configuration. (A proper meter check executed well determines this and more, correct CT/VT ratios and nominal setting values for instance); 3) using the manufacturer's communication software [3] and HMI interface allows monitoring of all wired I/O and internal elements utilized. Proper simple test cases easily verify any setting or logic without reprogramming anything; 4) use of modern test kits with proper software tools for correct power system simulations allow testing the "system" and only require a dozen or so test cases.

As a minimum, a proper test kit and software tools should provide - 3-phase voltage/current sources with control of magnitude, phase, frequency, and proper fault simulations using a 3-phase power system fault calculator or optionally (Fig 8) single/double ended system models, or a configurable multi-bus/node system model.

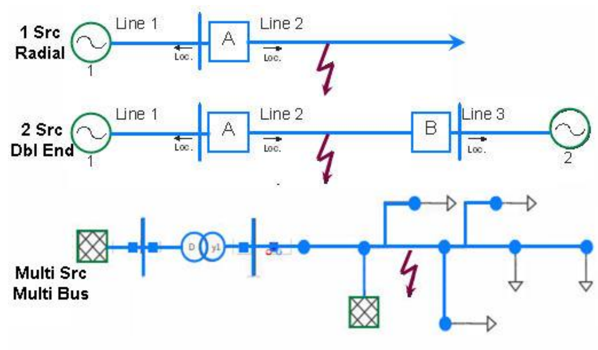

Fig. 8: System Models in Test Software

Using a proper Fault Calculator, 52a simulation, adequate prefault times, and system configuration will allow conflict free testing of the digital relay mapped elements as shown in Figure 7. No reprogramming required, just proper test cases used in context of the application. Switch Onto Fault (SOTF), Loss of Potential (LOP), Cold Load Pickup (CLP) Sympathetic Trip (STL) and other logic schemes will not interfere with the element tests and each can be tested easily with correct test cases. Better than this, the number of overall tests can be reduced significantly by using a model based system test approach. This saves both time and money.

A system test approach reveals the true coordination of today's feeder protection schemes. A proper simulation requires all scheme logic AND protection elements to work together correctly. The same efficiencies realized in HV Line Protection End to End testing can be realized for today's modern feeder protection, Distribution Automation, and Distributed Generation applications. It may seem excessive to some to use this system test approach, but if you are presently reprograming and decommissioning your feeder relay just to test some points on an inverse curve, then who is being excessive?

If performing proper system simulations for routine tests is outside your scope, then at least perform routine testing responsibly and discontinue the excessive and invasive testing procedures of reprogramming your relays.

It would be more effective to perform adequate Acceptance/Commissioning tests and then for routine testing a meter check, I/O verification, file settings comparison, and then actual CB trip check from the relay than continuing a process of invasive testing.

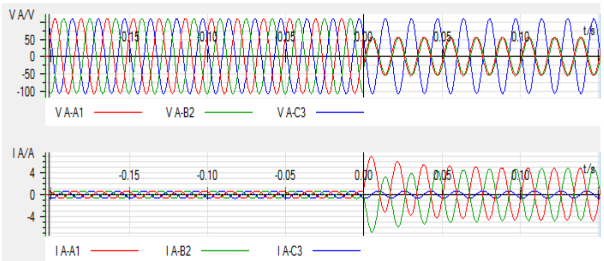

Fig. 9: Fault simulation, radial model of Fig.8

6 Conclusions

As digital relays continue to evolve and become more complex, our methods for testing them must also evolve. Legacy test methods cannot properly quantify the health, status, and availability of these complex relays nor simulate the power system adequately in order to prove their operational performance and compliance. Education, training, proper testing tools, and power system knowledge are required in order to verify these increasingly "simple" feeder protection devices.

7 References

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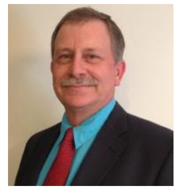
8 Biography



Benton Vandiver III received BSEE from the University of Houston in 1979.

He was with Houston Lighting & Power for 14 years and Multilin Corp. for 4 years before joining OMICRON electronics in 1995 where he is currently Principal Engineer residing in Houston, TX. A registered Professional Engineer in TX, he is also an IEEE / PSRC senior member, USNC member, CIGRE corresponding member. He holds a US Patent for "Communication-based Testing of IED's" and has authored, co-authored, and presented over 90 technical papers and published numerous articles.