End to End Testing – What Should You Know?

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AGENDA

- Introduction
- Why End to End Testing?
- Engineering Preperation
- Better Testing Tools
- Test Simulation Requirements
- Critical Success Factors
- Conclusions

Introduction

> Protection Automation and Control (PAC) Systems are no longer single function devices implemented in groups or collections.

> Legacy single function testing methods on a modern IED are irrelavant with one exception – Acceptance Testing.

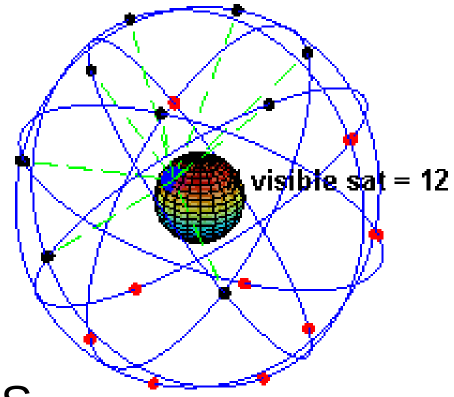
> For any IED – a proper Acceptance Test protocol should be employed to verify each and every function and specification claimed by the manufacturer before it is used. After this – no further functional test is required unless the hardware design or firmware has changed.

> Proper Testing of an IED requires duplicating the system application sources and I/O to put the IED in the correct operational conditions.

> System Testing is the ONLY test method that requires no setting changes of the IED in order to correctly verify its operational compliance.

> Proper Trouble Shooting of PAC miss operations should also use System Testing as the baseline for evaluations and proper scheme operations.

Why End to End Testing?



- It is a proven System Testing method.
- Most cost effective approach to test as much of the FCS (Fault Clearing System) in a reasonable way.
- Suitable for both Commissioning and Routine Testing requirements.
- Historical results are critical for understanding miss operations and can be the basis for Trouble Shooting such events.
- GPS technology is mature and easier than ever to implement.
- Works on all PAC technologies and systems using the right tools.
- Applicable on distributed protection schemes (SIPS, PMU, RAS, etc.)

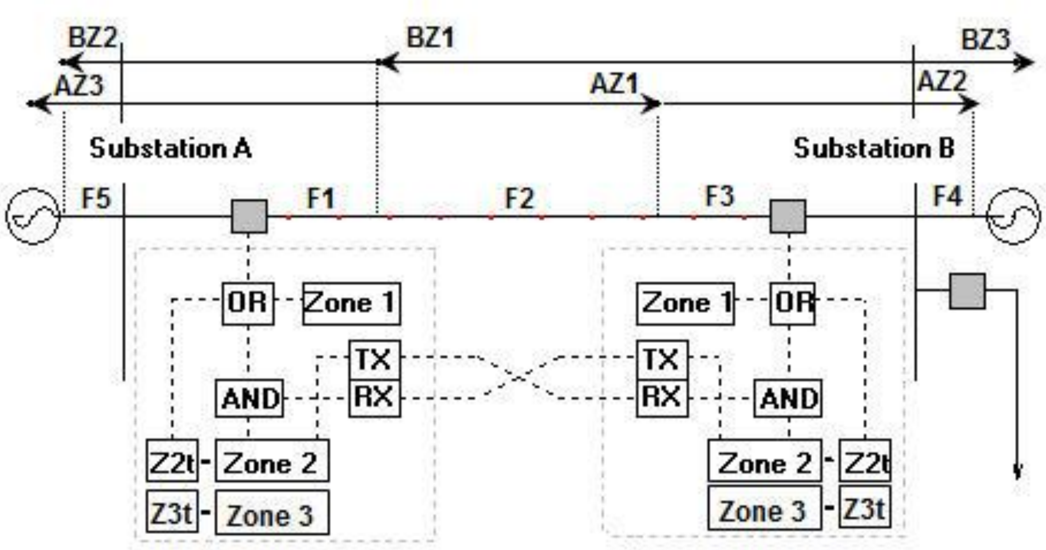
Why End to End Testing?

- It can detect:
  - a bad or failing relay output contact,
  - a failed 52B contact (52A contact too),
  - failing wire insulation or loose connections,
  - bad turns of an interposing CT,
  - inadvertent change of settings,
  - if an event log or report fails to generate,
  - proper interlocking with another device,
  - correct operation of a remote device,
  - or measurement inaccuracies.

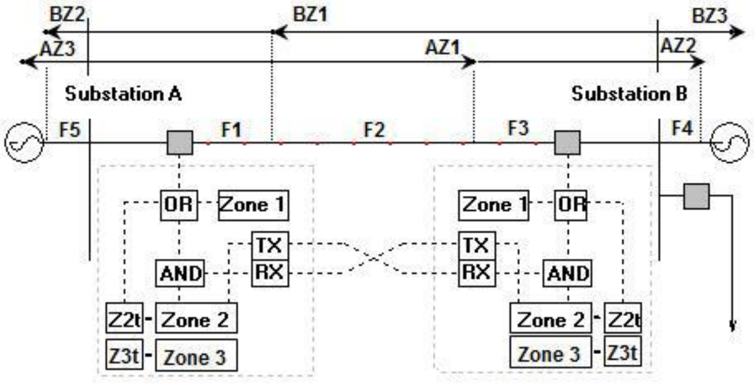
Engineering Preparation

Example: 3-Zone Step Distance w/POTT scheme

The “Problem Domain” is defining the test cases to prove the overall scheme operation/coordination with proper fault detection. By definition, we should know and understand the operational limits of the protection scheme and that defines the test set performance and accuracies we will need to perform the tests.



Engineering Preparation



Example: 3-Zone w/POTT scheme

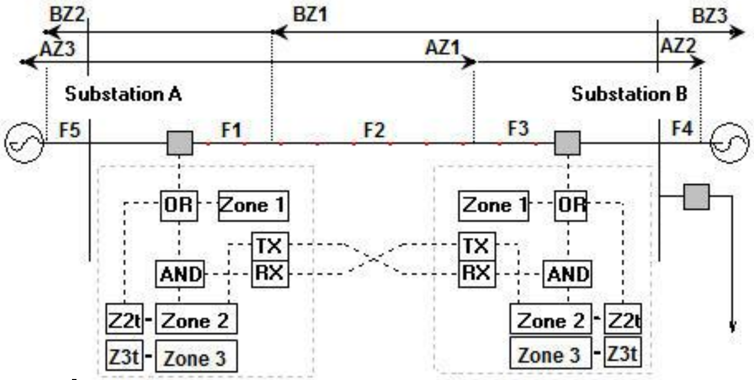
To make the best test cases we need:

- Correct secondary voltage used
- Nominal CB operation times
- Proper 52a/52b simulation
- Line Impedance Z1 and Z0 (Pos/Zero Seq) values
- Zone 1, 2, 3 reach and delay times
- Typical propagation delay of the Comm channel
- Synchronized start of the test sets within our application limits, especially at fault inception
- Fault Model Tool compatible with Test SW

Common Attributes
VT sec = 67V
CT sec = 5A
CB time = 2,3,5 cy
PLC delay = 14mS
Fiber delay = 3mS
Microwave = 8mS
Time Sync = <0.5mS

Relay Settings Have:
Z1, Z2, Z3 Mag/Ang
Zone Delay Times
Directional Behaviour
Line Z1/Z0 Values

Engineering Preparation



Example: 3-Zone w/POTT scheme

With a Fault Model Tool, we can use the Positive Sequence Line Impedance, create simple PreFault/Fault/PostFault states for each test case we need.

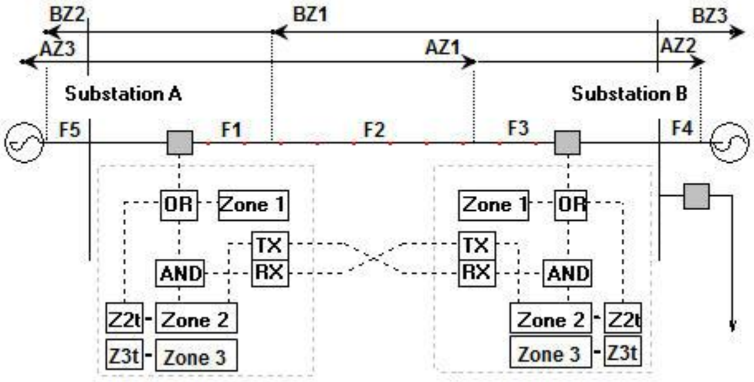
Test Cases are shown in the Figure (F1-F5)
Use Substation A as reference, Substation B Test Cases are Mirrored

Table shows the logical test cases as defined and expected results.

Fault Case	% of LL (A)	Sub A Op	Sub A Time	% of LL (B)	Sub B Op	Sub B Time
F1	10	Z1+PTT-Send	<30mS	90	Z2+PTT-Recv	<50mS
F2	50	Z1+PTT-Send	<30mS	50	Z1+PTT-Send	<30mS
F3	90	Z2+PTT-Recv	<50mS	10	Z1+PTT-Send	<30mS
F4	120	Z2+No PTT	No trip	-20	Z3+No PTT	No Trip
F5	-20	Z3+No PTT	No trip	120	Z2+No PTT	No Trip
SPECIAL CASES - PTT Failure / Out of Segment Failure						
F1-No PTT	10	Z1+PTT-Send	<30mS	90	Z2T	<330mS
F3-No PTT	90	Z2T	<330mS	10	Z1+PTT-Send	<30mS
F4-No Blk	120	Z2T	<330mS	-20	Z3T	<630mS
F5-No Blk	-20	Z3T	<630mS	120	Z2T	<330mS

Engineering Preparation

Example: 3-Zone w/POTT scheme



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F3	90	Z2+PTT-Recv	<50mS	10	Z1+PTT-Send	<30mS
F4	120	Z2+No PTT	No trip	-20	Z3+No PTT	No Trip
F5	-20	Z3+No PTT	No trip	120	Z2+No PTT	No Trip
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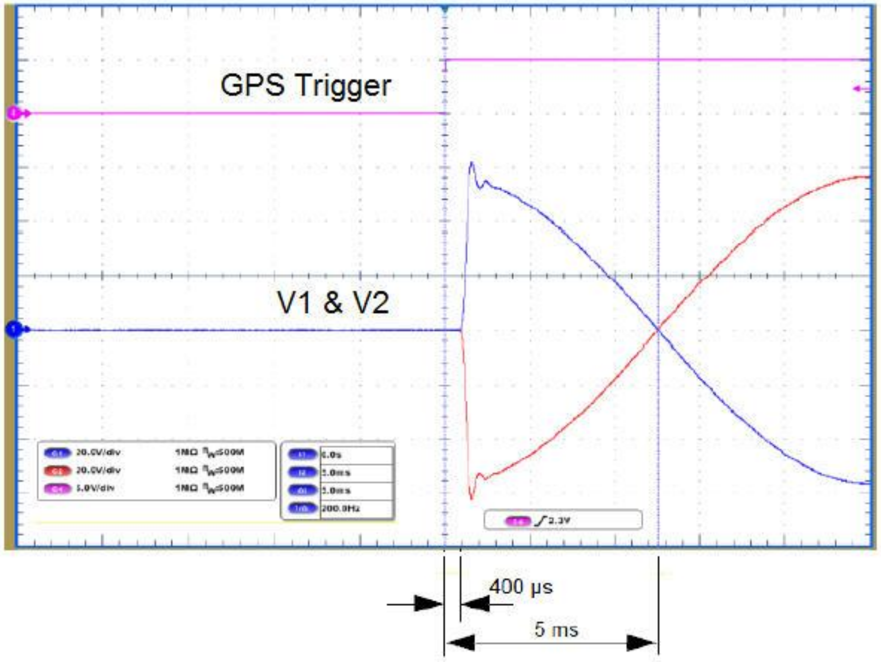
Better Testing Tools

Ans: We must know critical timing data of the test kits used.

Re: Two test kits of the same make and model and we generally assume that their internal triggering, circuitry, and timing compensations are identical – so the only variable is the timing pulse detection. (T or F?)

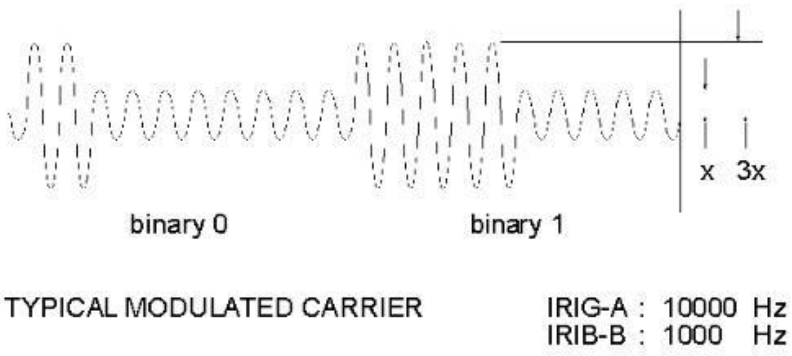
Problem: What if the test kits are from two different manufacturers? (Test it!)

- Test of two 100V injections, 0°/180°, start @ +/-90 deg.
- Measured from two identical test kits, showing internal start delay from GPS trigger. (~400uS)
- Phase sync @ their zero crossing verified. (@50Hz)

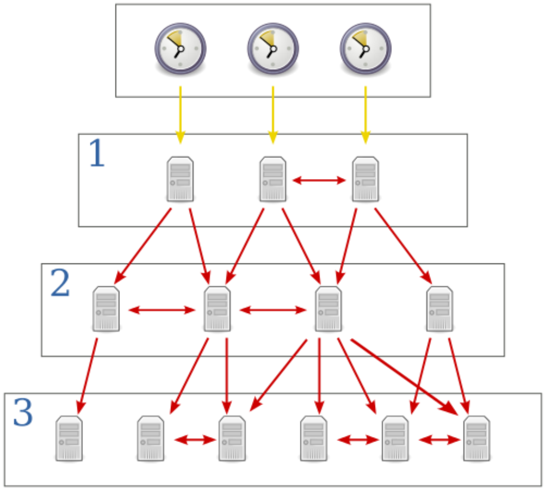


Sync Sources and Time Codes

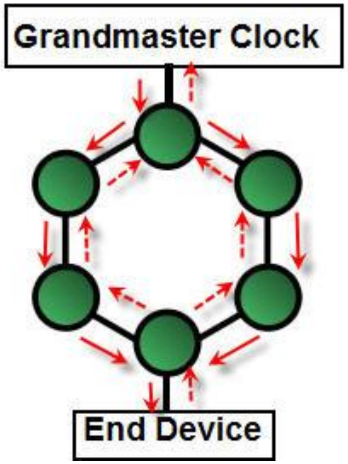
IRIG-B (+/-1uS) (+/-5-100uS Typ)



NTP/SNTP (+/-10mS)



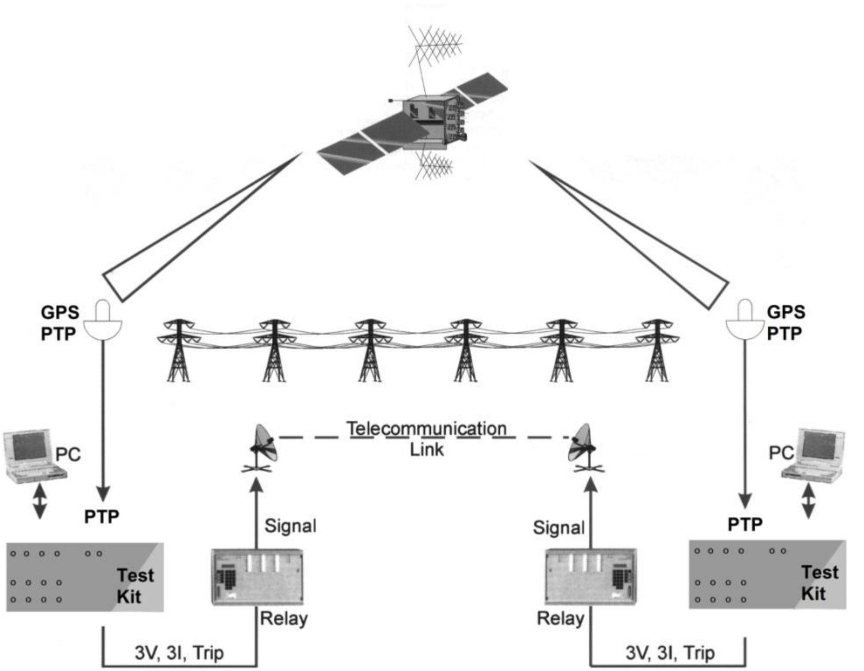
IEEE 1588-2008 * (PTP)



Use of the IEEE 1588-2008 and IEEE C37.238-2011 standards with compliant devices, we can achieve synchronization of +/- 1 microsecond over most networks.

(* - under revision)

Improving End-to-End Testing



A typical test kit has an internal propagation delay
(i.e. ~400uS = 9.0° @ 60Hz).

The delay is a sum of:

- OS/Firmware constant: n*100uS
- DAC-synchronization
- Time code/pulse decoding
- Time delay of the reconstruction filter (biggest variable in devices)

Key Advantages of Portable PTP/GPS clock:

- Direct Ethernet connection
- Time lock to +/- 200 nanoseconds
- No power supply needed (PoE)
- Auto boot and Sync
- 100m capable lead length

Using PTP directly in the test kit embedded system allows several key advantages:

- Elimination of extra hardware (both external and internal)
- Precise clock synch (+/- 0.2uS)
- Simplified application software

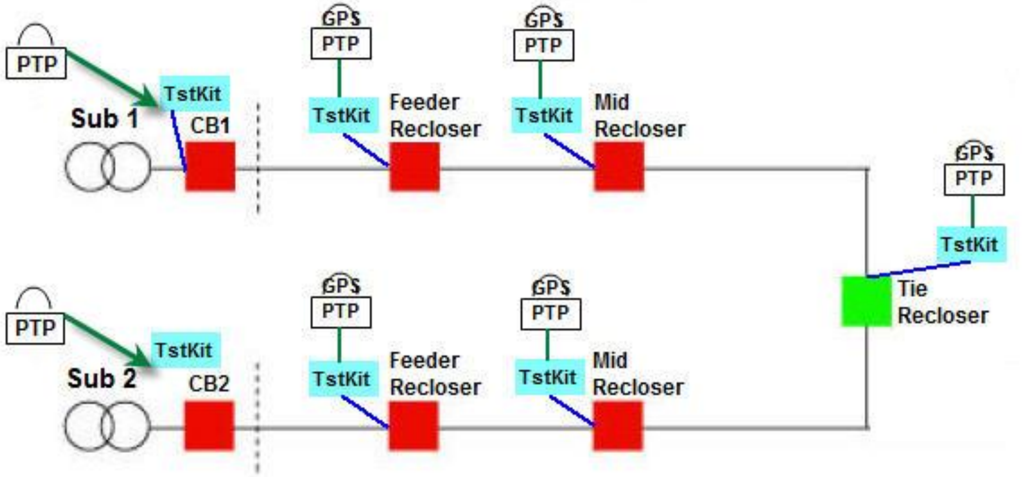
Better Testing Tools

Distribution Automation Field Tests

The ability to perform synchronized testing of multiple CB's and reclosers that are part of a loop scheme or Distribution Automation network is a new but necessary requirement.

For distributed testing, the ability to time sync each location and test kit to +/- 1 microsecond would make the test execution and result analysis simple since time alignment of the various test results would be near automatic.

If all locations have the same local time within +/- 1 microsecond – then even slow but reliable commuincations and a common test software can control and execute the entire scheme test from one location.

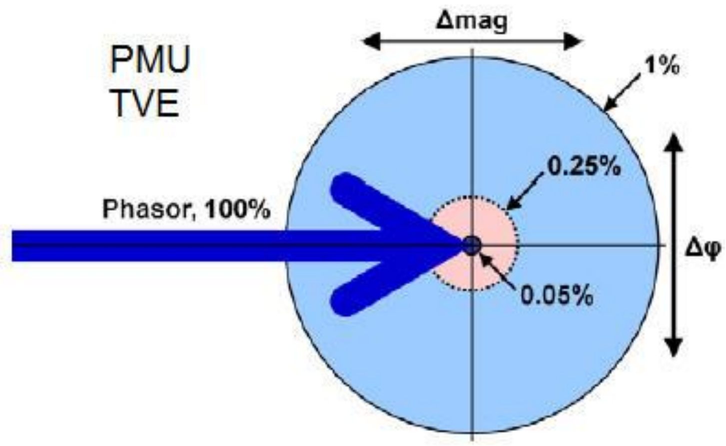


Better Testing Tools

Time Critical Protection Schemes

An application (@ 60Hz) that requires 1mS accuracy equates to a phase error of 21.6 degrees. (not really good enough for Line Differential testing) For an application requiring 0.5mS, it is 10.8 degrees and if it is 0.1mS then it is 2.16 degrees phase error.

Synchrophasor (PMU) Accuracy Requirement



IEEE C37.118.1 requires a 1 microsecond timestamp accuracy to achieve the defined Total Vector Error.

Future standards will likely follow suit as sampled values become the norm.

Portable
PTP Grandmaster

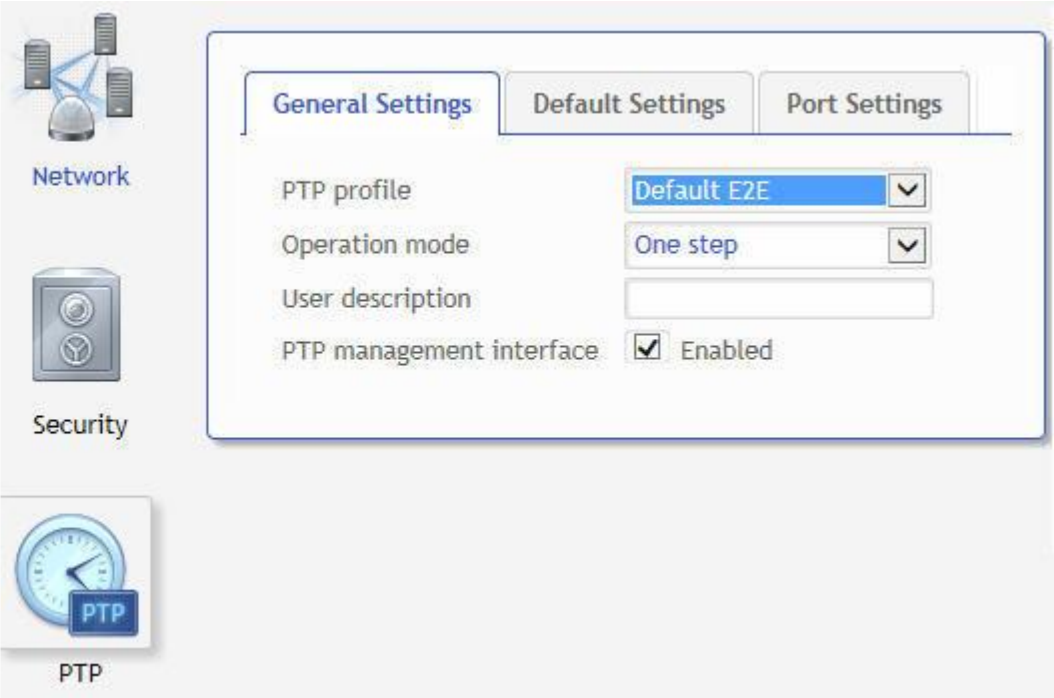
IEEE 1588-2008 brings numerous advantages:

Mutiple time codes can be simulataneously supported

Profiles can be used to create simple operational configurations (i.e. EtoE Test)

Critical status easily checked

Setup, aquire, lock and sync to GM can be automated.

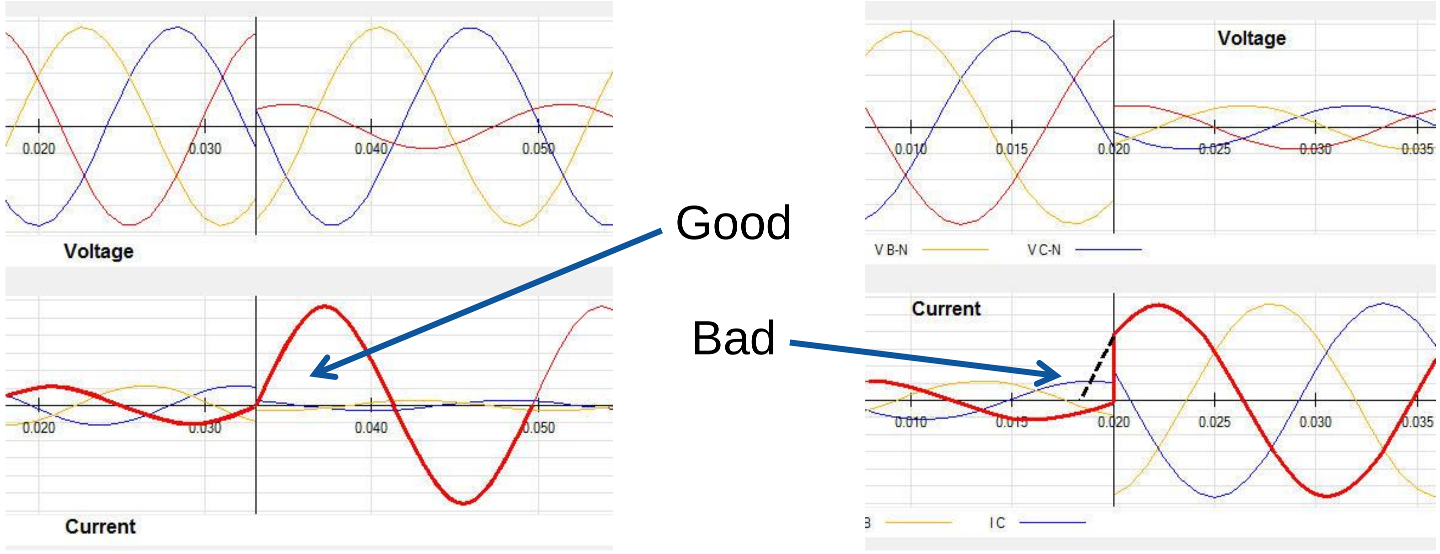


End to End – Hints!

- Some relay algorithms may be sensitive to both a phase and magnitude step change in the currents, to avoid this keep the current's phase unchanged between Prefault/Fault states only changing the magnitude. Instead change the voltage phase reference for the specific fault impedance phase angle.

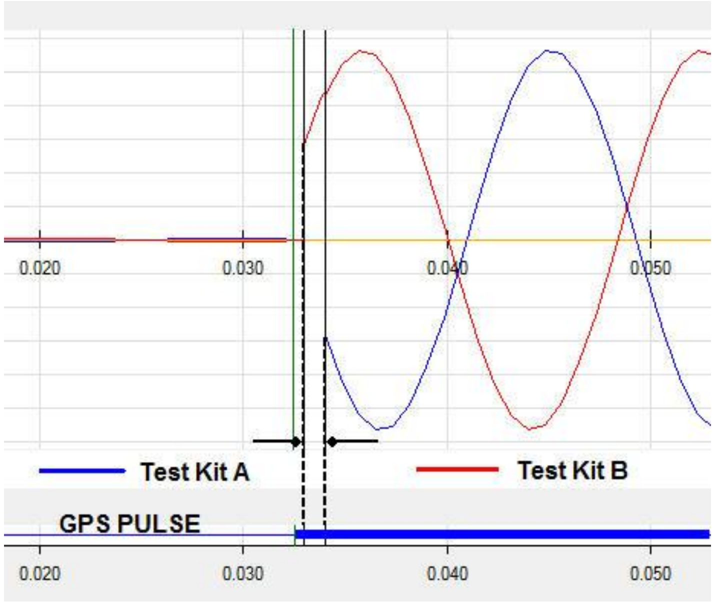
CTC – Zero Deg Phase Shift

CTC – Mag & Ph Shift



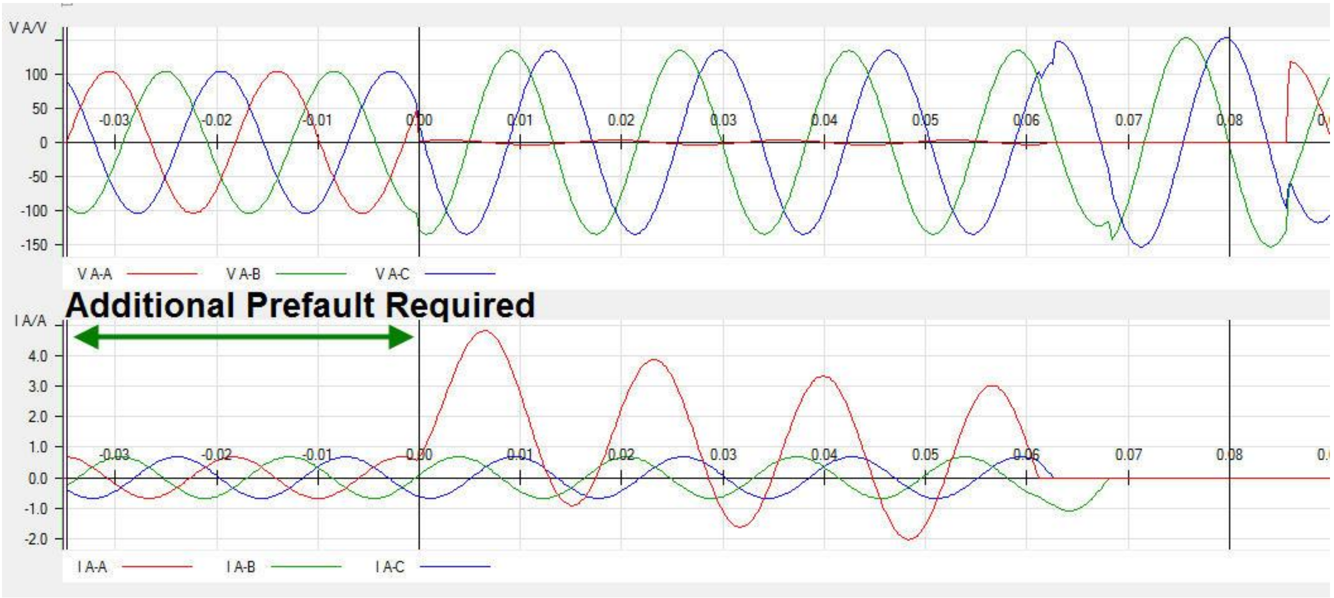
End to End – Hints!

- It is always best practice to use matched test set hardware when executing any synchronized test method. Each technology employed has different limitations and benefits. It is possible to use mixed hardware and even mixed test set manufacturers, but it is always advised to make a bench test, configured exactly as they will be used, to document the start delays and phase offsets in order to properly compensate for them in the test software and test cases used.



End to End – Hints!

- When using COMTRADE files as test cases, be sure to have a COMTRADE editor tool. The two ends making the injection must ensure that the relays at each end see the fault inception at the same time. For many relays, they must see enough PreFault in order to initialize their routines and logic before the fault occurs. And adjustments for CT/VT ratios, adding/mapping 52a/b simulations, or other I/O keying is required to make these test files work correctly.



End to End - Critical Success Factors

1. Put your E2E test method into the Engineering Process, training is a requirement, not an option.
2. Perform Acceptance tests on all discrete components in a lab or controlled environment. This eliminates the need for further functional testing unless it is E/M.
3. Use the same system test cases regularly on new or existing relays of the same application for both commissioning and routine testing.
4. Verify the health and availability of the digital protection relay/system in situ without violating its commissioned status or performing excessive testing.
5. When possible, use matched test equipment and the best accuracy clocks available, and match the test equipment capabilities to the protection application requirements.
6. Coordinate the test case sequences for each end and ensure the power system will be properly modeled.
7. Use a Network Simulation tool for best system test cases.
8. Automate as much of the data exchange into the test software and/or test cases.

Conclusions

To properly maintain a modern protection system one must begin at the planning and engineering phase in order to provide the proper design, support, build and configuration of the protection system. (Design friendly to System Testing)

New standards and technology coupled with proper system test methods like End-to-End testing allow a significant reduction in manhours and intrusive functional testing. (Better results with less risk)

PTP can be deployed as a portable time clock solution to revolutionize field testing of PAC schemes and systems. (Implement New Technology)

Using 1970's test methods and technology is a dis-service to the industry, the utility, the workforce, and more important the customer. Training, Education, and the Right Tools are key for an efficient Power System.