End-to-End Relay Testing
Using MULTI-AMP® PULSAR Test Systems
Synchronized through a Global Positioning Satellite

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Introduction
Recent laboratory tests promise to take power system relay testing to a new level. Tests have been completed using two Global Positioning System (GPS) satellite receivers and two *MULTI-AMP® PULSAR* Universal Test Systems, simulating a simultaneous fault at different ends of a transmission line.

Protecting the Power System

Electromechanical protection relays have reliably provided adequate power system protection for many decades. However, higher line loads and more complex power system configurations, such as parallel transmission lines, multi-terminal lines and series-compensated lines, require a more sophisticated level of protection.

The newer microprocessor-based relays offer greater protection, flexibility and speed. They respond to a greater variety of situations and choose operating sequences based upon the state of the power system. At the same time, they also create a testing challenge for the test technician and the relay engineer.

Testing Relays

The testing and calibration of protective relays plays a crucial role in the proper operation and protection of the power system. In the past, testing and calibration normally have been performed upon commissioning and periodically as part of routine maintenance.
These tests consisted of applying steady-state values of voltage and/or current and measuring the response of the relay. In 1984, **AVO** Multi-Amp Corporation introduced the *MULTI-AMP® EPOCH®* family of microprocessor-based relay test sets capable of performing dynamic tests, sometimes referred to as multi-state tests. Under dynamic conditions, the relay is tested by applying a pre-fault condition and then applying a simulated fault condition using a pure sine wave (no dc offset or harmonics).

New Hardware and Software

In October 1992, AVO Multi-Amp introduced its newest achievement in relay testing hardware and software. The hardware incorporates the latest
in digital signal processors (DSP) and amplifier technologies. The unit, *MULTI-AMP® PULSAR* can do the work of five *EPOCH®* units, yet weighs less than the original EPOCH-I,. With the *Microsoft® Windows®* - based *MULTI-AMP PulseMasterTM* software, *PULSAR* can perform the steady-state and dynamic (multi-state) tests the *EPOCH®* units could perform, plus transient tests.

PULSAR takes relay testing to the ultimate level with actual reproduction of faults, including dc offset and harmonics. Transient waveforms can be produced by *PULSAR* in several ways: mathematically using Fourier Expansion with Exponential Offset and Decay, through the replay of actual recorded faults from a Digital Fault Recorder (DFR) and through simulation using EMTP/ATP files converted to the COMTRADE ASCII format. COMTRADE is an acronym for COMmon format for TRAnsient Data Exchange (see IEEE Standard C37.11 - 1991)[1]

The purpose of the COMTRADE standard format is to provide a means to exchange or share recorded fault, test or simulation data. Relay manufacturers can now share and reproduce fault records for the evaluation of new relays. This will reduce the time to market for newer and improved microprocessor-based relays. At the same time, it will add a higher degree of reliability to the power system by allowing power companies to evaluate protection relays under actual fault conditions.

In addition, *PULSAR* has the capability to be initiated from a GPS satellite receiver. This allows multiple *PULSAR* units to be triggered at various relay terminals, miles apart, within micro-seconds of each other. Therefore, not only can *PULSAR* replay the recorded fault in the field, but it can do it at various points in the system for an even better coordination evaluation.

Timing Accuracy

To accurately verify proper coordinated operation between terminals and different zones of protection, it is important that the relays and their associated communication link be tested as an integrated system. This requires extremely accurate initiation of the test systems at both ends of the transmission line.

Investigation in 1986 into using the GOES satellite proved an undesirable error of more than 1 millisecond. Considering the speed of the newer relays and communications, AVO Multi-Amp designed *PULSAR* to initiate on an external trigger from a GPS satellite receiver (many of the newer GPS receivers are accurate to 1 micro-second.)

The initiation of two *PULSAR* systems was anticipated to be separated in time by only the accumulated error of the two GPS receivers (±2 microseconds); however, a number of variables existed. Realistically, AVO Multi-Amp designed for high-speed operation and expected no more than a +0.2° separation (at 60 Hertz, 9.26 microseconds) at initiation.

Test System

The recent laboratory tests were conducted to verify the ability of the *PULSAR* units to be triggered by a programmable GPS receiver and determine the overall synchronization error (between two *PULSAR* units) associated with the initiation of the fault.

The tests were performed using two separate test systems. Each system consisted of a PULSAR unit (Cat. No. 10E3T3G-1/60) with a standard GPS receiver, Model GPStar, manufactured by Odetics Precision Time Division of Anaheim, California. The receiver was controlled by an NEC UltraLite notebook computer SL/20 (80386SX).

The notebook docking station was used to take advantage of the IEEE-488 interface, which was installed in one of the expansion slots. The PULSAR units used in the experiment have the optional IEEE-488 interface, which speeds up the process of downloading DFR waveforms.

The standard built-in RS-232 interface could have been used instead of the IEEE-488, in which case the docking station would not have been needed. The advantage to using the IEEE-488 is that the COM1 port on the notebook PC can be used for programming the GPS receiver for the desired event trigger, or to communicate with the relay under test. To verify the synchronization, a Soltec Model TA200-938MF recorder was used to record the waveforms from the two *PULSAR* test systems.

Test Results

The tests were conducted in two steps. The first step was to program the *PULSAR* units, using a modified version of PulseMaster software, to provide a 0- to 25-volt dc step. This was done for two reasons: the Soltec recorder only accepts signals up to 25 volts ac/dc, and better definition could be achieved on the rising edge of the waveform (to determine exactly when each output channel turned on, in time.)
The Soltec recorder provides resolution down to 2 microseconds, which is accurate enough to determine any synchronization error of initiation.

The GPS receivers were synchronized to GPS satellites that were available (20° above the horizon, and time-of-day) to a Time Figure of Merit (TFOM) of 4. The TFOM indicates the estimated accuracy of the GPStar timing outputs. A TFOM = 4 indicates the timing error is <1 micro-second.[2]

To get this accuracy, we placed the GPS antenna / down converters outside the building (they can be operated inside, but at higher timing error.) The GPStar Event Trigger connectors were connected to the "SYNC IN" BNC connector on the back of their respective *PULSAR* units. The GPS receivers were programmed to trigger their respective *PULSAR* units at a specific point in time (to within 1 microsecond.) The first test results were better than expected, with a simultaneous initiation of less than 10 microseconds.

The second test was to download identical digital fault recordings into each *PULSAR* test system, initiate from the GPS receivers and measure the results.

Several differences existed between this test and the first. The first test involved programming the individual outputs using the *PULSAR* command set. The second test was to download transient waveforms into RAM storage of individual output modules.

Using the modified PulseMaster software, two macro files were made. One file downloaded the DFR file into the *PULSAR* unit, and the other was used with the GPStar to trigger the test systems. The DFR record was of a three-phase fault, caused by a lightning strike. The prefault amplitudes of the voltage channels averaged about 67 volts f - N, with the fault values somewhat lower.

The voltage outputs were recorded for each phase of each *PULSAR* unit because the Soltec recorder only has six analog channels. A voltage divider was used to drop the voltage to acceptable recorder-input levels (<25 volts). No modifications were made to the DFR COMTRADE file. A test file was made using the DFR playback feature of the PulseMaster software, downloaded using the modified macro and executed (see Figures 2 and 3). The results were the same as with the dc step voltage.

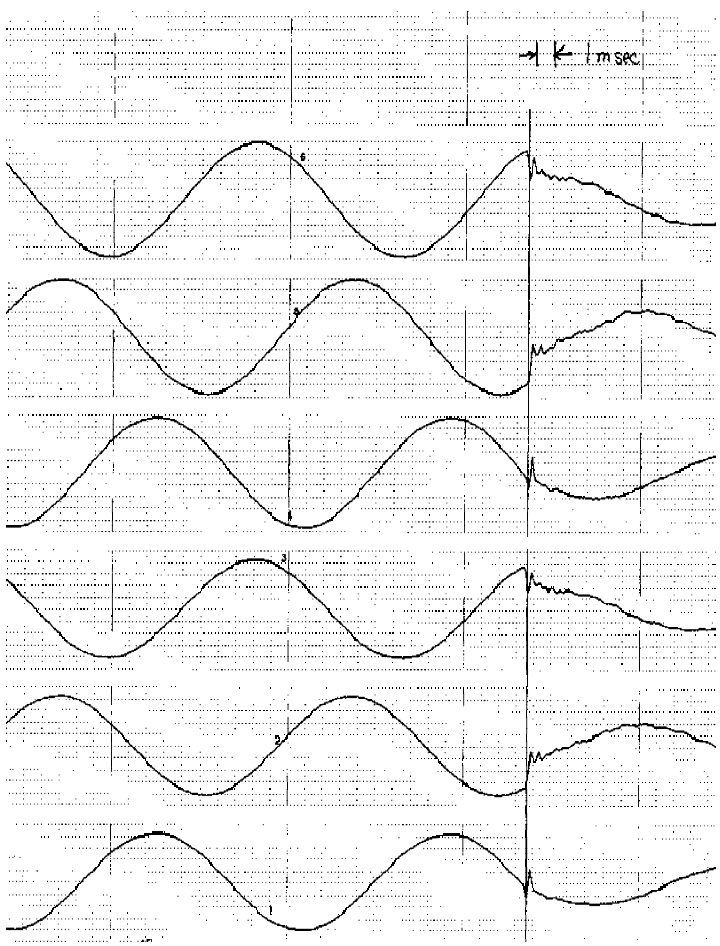

Figure 2. Recorded DFR waveforms using GPS synchronization

Figure 3. Laboratory simulation with two test systems

Field Testing

Field testing currently is underway to determine accuracy under actual operating conditions (temperature and EHV). Theoretically speaking, even though the test systems were only a few feet apart in the lab, they could have been 100 miles apart with no difference in results.

Summary

AVO Multi-Amp Corporation has made significant strides in the ability to synchronize the outputs of two or more *PULSAR* test systems which are not physically connected to each other.

When used with *PULSAR 's* ability to reproduce three-phase transient faults, which include dc offset and harmonics, this remote synchronous capability provides the means to perform a more comprehensive evaluation of relay schemes and their associated communications link.

Laboratory tests have been conducted showing that two *PULSAR* Universal Test Systems can be triggered externally using the GPS satellite system. Field testing is being conducted to determine accuracy under actual field conditions.

References

[1]"IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems," IEEE C37.111-1991.

[2]GPStar Users Manual, Version 1.0 (Odetics Precision Time Division, Anaheim, California, Dec. 21, 1992), p. 10-9.

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About The Author

Stanley I. Thompson is Senior Applications Engineer with AVO International, headquartered in Dallas, Texas, USA. He joined AVO International in 1977 and has worked extensively in protective relay testing and maintenance. Mr. Thompson has a BSEE degree from The University of Texas at Arlington and is a member of the IEEE. He has written numerous papers on the testing and maintenance of protective relays.