PRIMARY HIGH-CURRENT TESTING OF RELAYS WITH LOW RATIO CURRENT TRANSFORMERS

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INTRODUCTION

This paper will serve as one of few references describing primary high-current testing of protective relays using low ratio current transformers. Maximum fault currents on power plant auxiliary buses are routinely 40 kA and can be as high as 80 kA. Accurate measurement of high-current magnitudes requires high ratio current transformers. However, it is the practice to apply low ratio CTs based on small motor loads. The protection engineer then relies on the motor relay to trip for the enormous current of a phase-to-phase fault in the motor cable. The assumption is that fault current exceeding 300 times the CT rating can produce a secondary current large enough for a fast instantaneous trip. This leap of faith is based on the lack of knowledge of the highly distorted secondary waveform and how it is processed in the relay.

The tests show the limitations of Fourier and Cosine filters used in microprocessor relays that extract the fundamental phasors and eliminate harmonics. The tests validate the operation of a Cosine-Peak Adaptive Filter designed to cope with the highly distorted saturated waveforms produced by the low ratio CTs subjected to high current. The details of relay operation are shown in unfiltered event records of the test cases.

This paper reports on the results of primary high-current tests of overcurrent, motor, and distance relays using low ratio CTs. The test currents ranging from 6 kA to 50 kA were used with current transformers with ratios of 50:5, 300:5, and 600:5. The paper compares the internal unfiltered event records with MATLAB® simulations of the same cases.

TEST PLAN

Figure 1 is a schematic diagram of the A-phase input of four relays wired to the test current transformer with 50 feet of #10 wire.

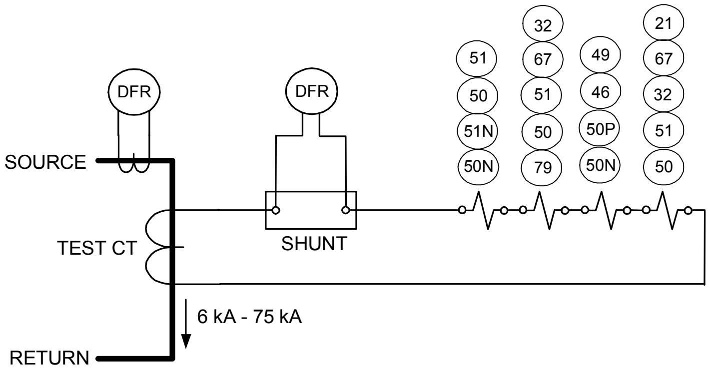

Figure 1 Schematic Diagram of Test Circuit

Each multifunction relay has an instantaneous element set to the maximum pickup of 80 A. The representative test relays are a general-purpose overcurrent relay, a multifunction distribution relay, a motor protection relay, and a line protection relay. With the exception of the line relay, the phase instantaneous elements employ a Cosine-Peak Adaptive Filter to provide a fast trip during highly saturated current waveforms. The test currents ranging from 6 kA to 50 kA were used with current transformers with ratios of 50:5, 300:5, and 600:5.

THE COSINE-PEAK ADAPTIVE FILTER

The Cosine filter has an excellent performance with respect to dc offset and removal of harmonics. The Bipolar Peak Detector has the best magnitude acquisition in situations of extreme CT saturation. Combining the two filters provides an efficient solution for the ideal instantaneous element. This instantaneous element shown in Figure 2 is called a Cosine-Peak Adaptive Filter since it incorporates both filters. The Cosine filter supplies the magnitude for normal sine wave operation. The Bipolar Peak Detector provides magnitude for saturated waveforms. A detector measures the degree of saturation by evaluating the level of fundamental and 2nd and 3rd harmonics, then switches the input to the Bipolar Peak Detector when the distortion reaches a predetermined value. The filter is described in reference [1] using MATLAB simulations to describe its response to severely saturated waveforms. The objective of the high-current test is to verify the accuracy of the simulations and record the response time of the instantaneous element.

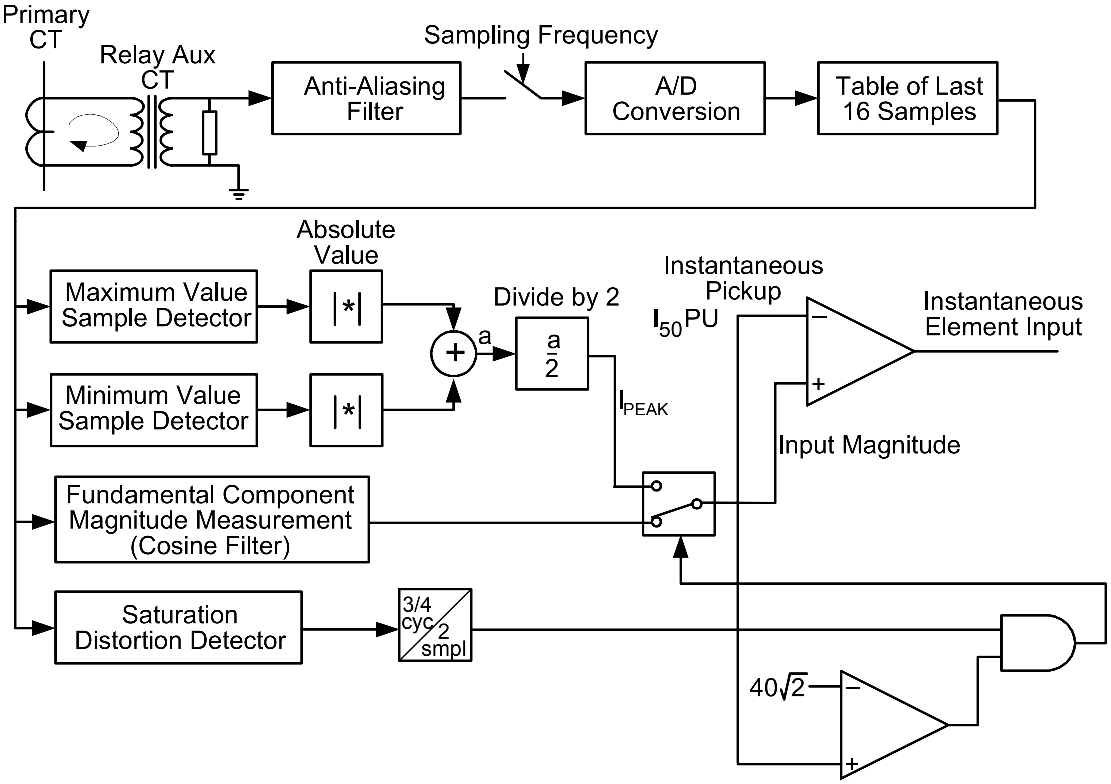

Figure 2 The Peak-Cosine Adaptive Filter

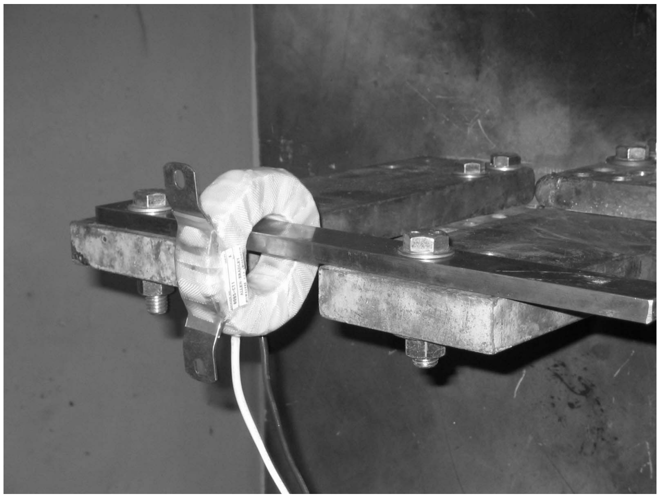

Figure 3 Bus Mounting of the 50:5 CT

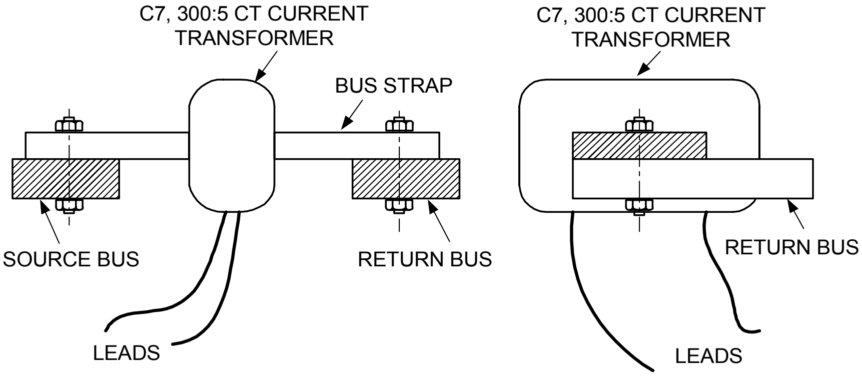

Figure 4 Bus Mounting of the 300:5 CT

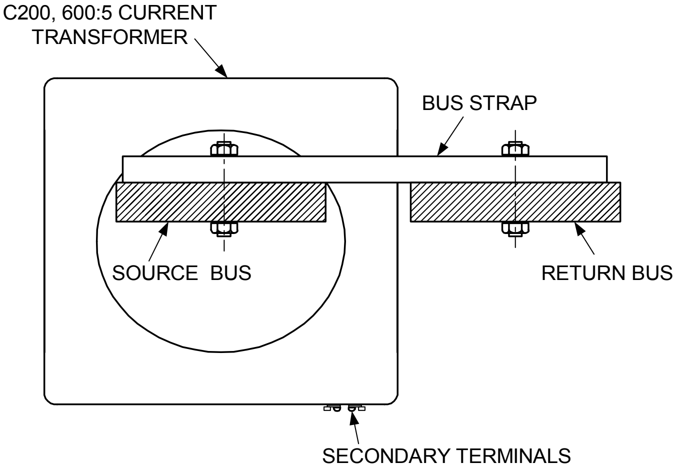

Figure 5 Bus Mounting of the 600:5 CT

50:5 CT HIGH-CURRENT TEST

One might well question the purpose of a 50:5 CT with the small core pictured in Figure 3. Our purpose is to use it as an extreme case with which to compare the MATLAB CT and relay filter simulation. The CT was subjected to a 6.09 kA primary current. The plots of the relay filter signals and the primary and secondary current are shown in Figures 6 and 7. The primary current has been divided by the turns ratio. Where the signal falls far short of an 80 A instantaneous setting, the peak detector trips when the setting is reduced to 30 A. Figure 8 shows the actual secondary. Figure 9 shows the MATLAB simulation of the case for comparison.

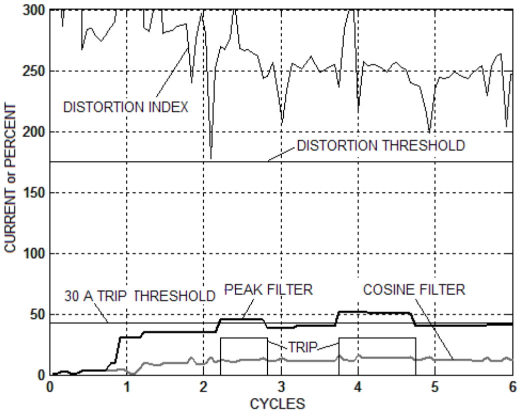

Figure 6 Cosine-Peak Adaptive Filter Signals for the 6.09 kA Test of a 50:5 CT

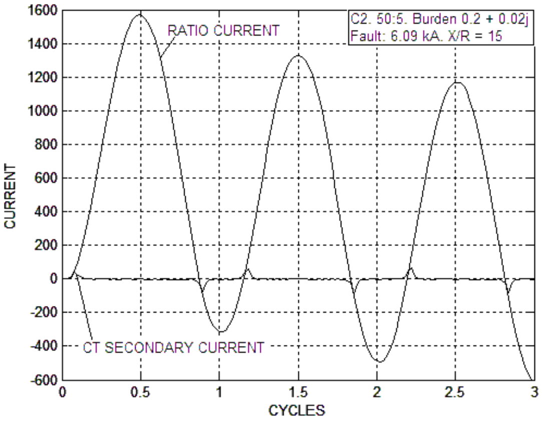

Figure 7 Ratio and Secondary Current in the 50:5 CT with 6.09 kA

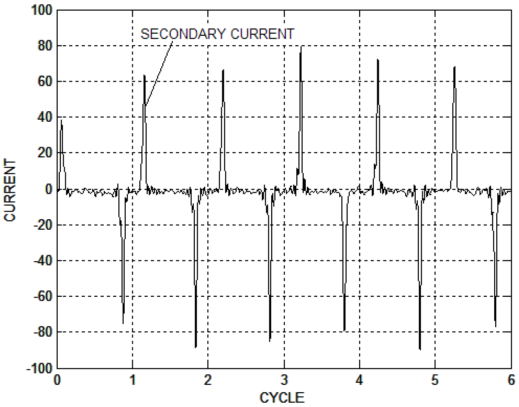

Figure 8 Secondary Current for 6.09 kA Test of a 50:5 CT

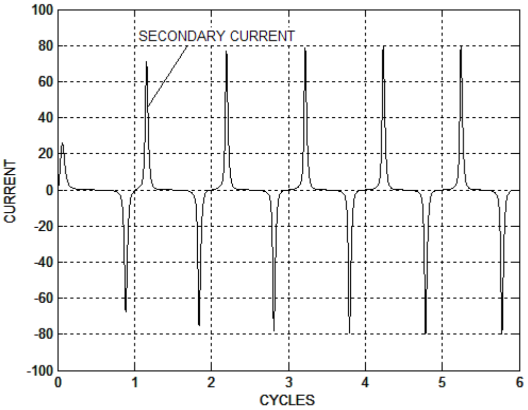

Figure 9 CT Simulation for 6.09 kA test of a 50:5 CT(Burden 0.2 +0.02j)

300:5 CT HIGH-CURRENT TEST

Figure 4 shows the bus work of a small 300:5 CT that was tested for a fault of 6.09 kA with an X/R ratio of 15. The plot of the primary and secondary current is shown in Figure 10 where the primary current has been divided by the turns ratio. Figure 11 shows a plot of the CT simulation superimposed on the plot of the secondary current. The simulation matches the test current exactly using a 0.2 + 0.02j ohm burden. What rating is the CT? This marginal CT supports only 7 volts at 100 A secondary with a 0.7 ohm burden.

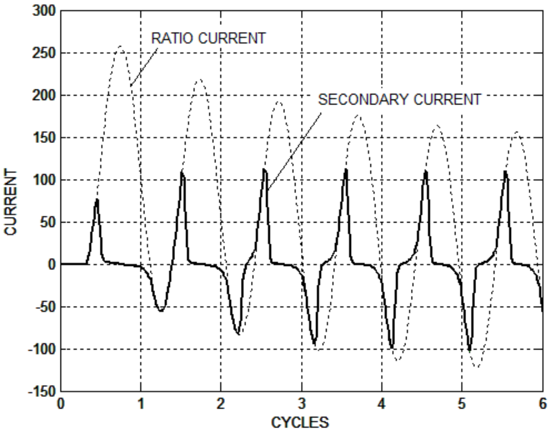

Figure 10 Ratio and Secondary current in the 300:5 CT with 6.09 kA

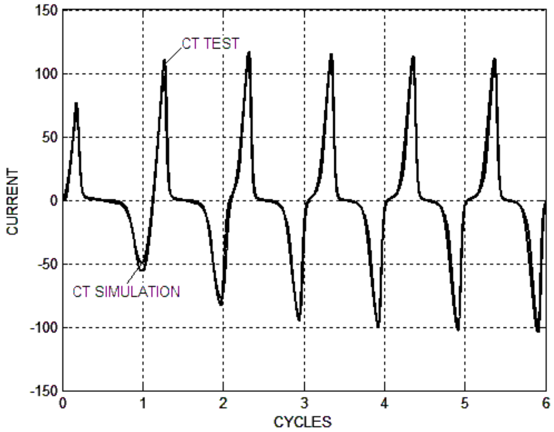

Figure 11 CT Simulation shown Superimposed on a plot of the Secondary Current

Plots of the relay filter signals and current for the 6.09 kA test are shown in Figures 12 and 13 where even the peak detector signal fails to reach the 80 A threshold. Figure 13 shows the trip threshold lowered to 40 A to produce an instantaneous trip.

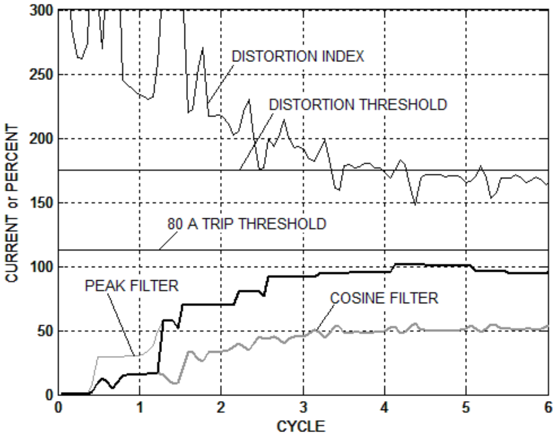

Figure 12 Cosine-Peak Adaptive Filter Signals the 6.09 kA Test of a 300:5 CT

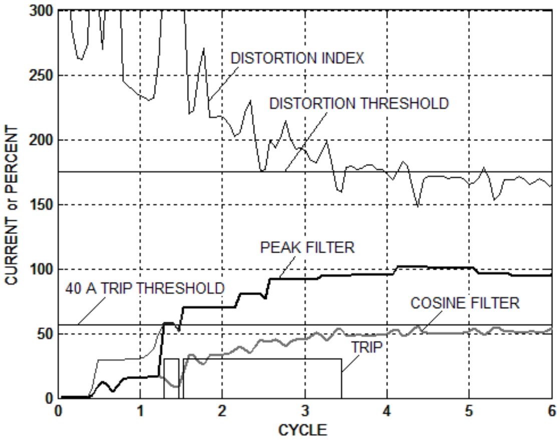

Figure 13 Relay Trip with Trip Threshold Lowered to 40A Primary

600:5 CT HIGH-CURRENT TESTS

The C200, 600:5 CT mounted on the bus shown on Figure 5 was tested using primary currents of 12.1 kA, 20.2 kA, and 50 kA all with an X/R ratio of 15. Mounting the toroid CT on a rectangular bus bar in close proximity of the return conductor allows for leakage flux (see reference [8]). Flux linkages not cancelled by the mutual flux adds an inductive burden and causes the inductive saturation shown in Figure 15. Consequently, neither the Peak nor the Cosine filter signal reaches the trip threshold until the fourth cycle.

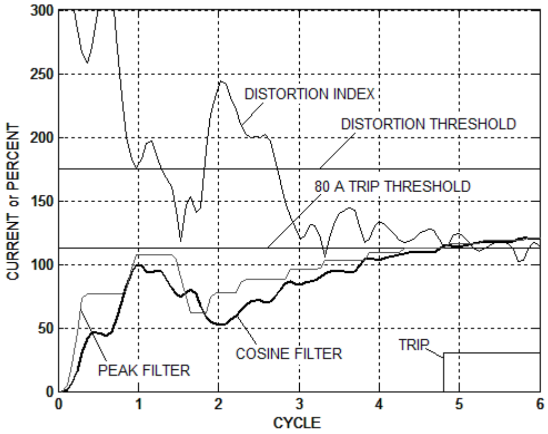

Figure 14 Cosine-Peak Adaptive Filter Signals the 12.1 kA Test of a 600:5 CT

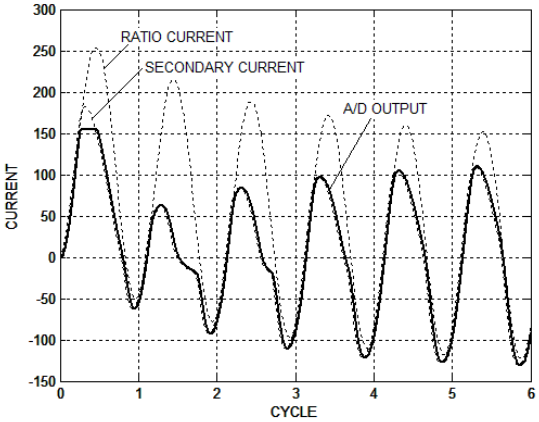

Figure 15 Ratio and Secondary Current in the 600:5 CT with 12.1 kA Primary

The waveform resulting from inductive saturation produces less magnitude of 2nd and 3rd harmonic and a lower Distortion Index. Plots of the relay filter signals and current for the 20.2 kA test are shown in Figures 16 and 17. In this case, the Distortion Index falls below the Distortion Threshold and prevents a trip in the first cycle.

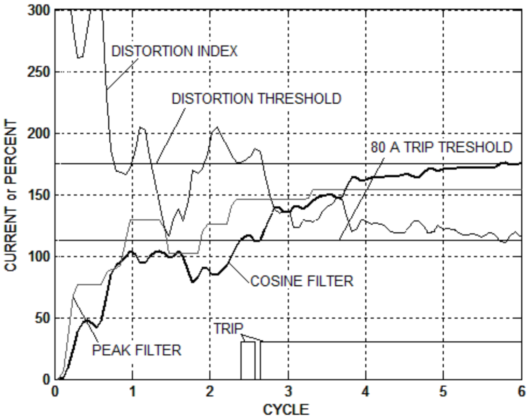

Figure 16 Cosine-peak Adaptive Filter Signals the 20.2 kA Test of a 600:5 CT

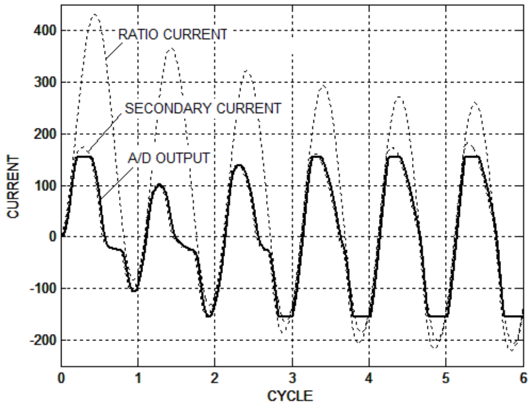

Figure 17 Ratio and Secondary Current in the 600:5 CT with 20.2 kA Primary

Plots of the relay filter signals and current for the 50 kA test are shown in Figures 18 and 19. The truncated A/D signal in Figure 18 indicate that the secondary current is beyond the measuring range of the A/D converter. However, both the Peak and Cosine filter reach the trip threshold to provide a trip in the first cycle.

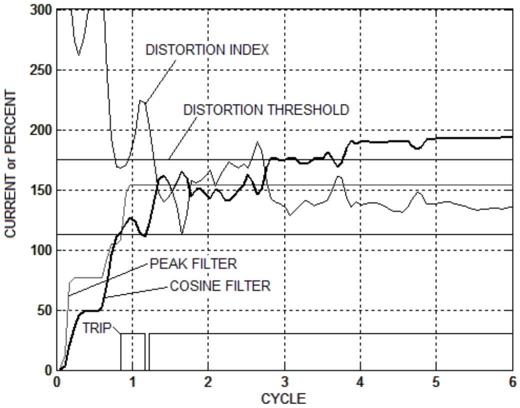

Figure 18 Cosine-Peak Adaptive Filter Signals the 50 kA Test of a 600:5 CT

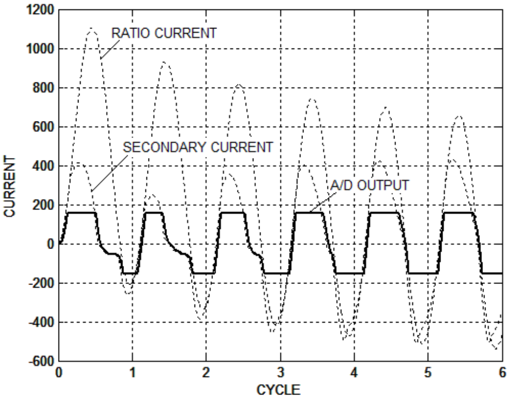

Figure 19 Ratio and Secondary current in the 600:5 CT with 50 kA Primary

CONCLUSIONS

1. The high primary current tests validate the operation of a Cosine-Peak Adaptive Filter designed to cope with the highly distorted saturated waveforms produced by the low ratio CTs subjected to high current.
2. The 6.09 kA primary tests using 50:5 and 300:5 CT prove the accuracy of the MATLAB CT and relay filter simulations used to predict relay performance.
3. The high-current tests show that the bus configuration affects the saturation secondary current waveform. The tests also show that CT saturation with inductive burden produces a lower distortion index and causes trip delays.
4. The tests verify that the peak of a saturated waveform is more representative of the fault magnitude. However, the high primary tests also reveal the limitations of inadequately rated low ratio CTs.

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BIOGRAPHIES

Stanley (Stan) Zocholl has a B.S. and M.S. in Electrical Engineering from Drexel University. He is an IEEE Life Fellow and a member of the Power Engineering Society and the Industrial Application Society. He is also a member of the Power System Relaying Committee and past chair of the Relay Input Sources Subcommittee. He joined Schweitzer Engineering Laboratories in 1991 in the position of Distinguished Engineer. He was with ABB Power T&D Company Allentown (formerly ITE, Gould, BBC) since 1947, where he held various engineering positions, including Director of Protection Technology.

His biography appears in Who's Who in America. He holds over a dozen patents associated with power system protection using solid state and microprocessor technology and is the author of numerous IEEE and Protective Relay Conference papers. He received the Best Paper Award of the 1988 Petroleum and Chemical Industry Conference and the Power System Relaying Committee's Distinguished Service Award in 1991.

Joseph B. Mooney, P.E. received his B.Sc. in Electrical Engineering from Washington State University in 1985. He joined Pacific Gas and Electric Company upon graduation as a System Protection Engineer. In 1989, he left Pacific Gas and Electric and was employed by Bonneville Power Administration as a System Protection Maintenance District Supervisor. In 1991, he left Bonneville Power Administration and joined Schweitzer Engineering Laboratories as an Application Engineer. Shortly after starting with SEL, he was promoted to Application Engineering Manager where he remained for nearly three years. He is currently the manager of the Power Engineering Group of the Research and Development department at Schweitzer Engineering Laboratories. He is a registered Professional Engineer in the State of California and Washington.

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