Standard CT Accuracy Ratings in Metal-Clad Switchgear

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I. Introduction

In general, our industry appears unaware of how high current interrupting ratings and CT accuracy ratings affect the performance of protective relays. This is evident from the standard accuracy ratings list in Table 4 of the IEEE Standard for Metal-Clad Switchgear C37.20.2-1999. The inconsistency is that the switchgear interrupting rating is 50 kA and the Standard lists the lowest possible accuracy ratings available.

The table of ratings from the Standard is reproduced below. It may be that too few power engineers can visualize saturated current waveforms caused by high fault currents or how they are processed in modern protective relays. This paper shows the consequences of low accuracy ratings and analyzes the relay response for fault currents in the range of 25 kA to 50 kA, using the CT accuracy rating from the table relay data acquisition.

Table 4—Standard accuracy class ratings[a] for current transformers in MC switchgear

Ratio	B0.1	B0.2	B0.5	B0.9[b]	B1.8[b]	Relaying accuracy[c]
50:5	1.2	2.4[d]	—	—	—	C or T10
75:5	1.2	2.4[d]	—	—	—	C or T10
100:5	1.2	2.4[d]	—	—	—	C or T10
150:5	0.6	1.2	2.4[d]	—	—	C or T20
200:5	0.6	1.2	2.4[d]	—	—	C or T20
300:5	0.6	1.2	2.4[d]	2.4[d]	—	C or T20
400:5	0.3	0.6	1.2	1.2	2.4[d]	C or T50
600:5	0.3	0.3	0.3	1.2	2.4[d]	C or T50
800:5	0.3	0.3	0.3	0.6	1.2	C or T50
1200:5	0.3	0.3	0.3	0.3	0.3	C100
1500:5	0.3	0.3	0.3	0.3	0.3	C100
2000:5	0.3	0.3	0.3	0.3	0.3	C100
3000:5	0.3	0.3	0.3	0.3	0.3	C100
4000:5	0.3	0.3	0.3	0.3	0.3	C100

[a]See IEEE Std C57.13-1993.
[b]Note that these were formerly standard burdens of B1.0 and B2.0, respectively, which now are classified as relaying burdens in IEEE Std C57.13-1993.
[c]These accuracies may not be sufficient for proper relaying performance under all conditions. To ensure proper relaying performance, the user should make a careful analysis of CT performance considering the relaying requirements for the specific short circuit currents and secondary circuit impedances (see 8.7.1).
[d]This metering accuracy is not in IEEE Std C57.13-1993.

Fig. 1 is a generic data acquisition system common to most microprocessor-based relays and shows the location of the measured signals. In Fig. 1, the relay auxiliary transformer converts the CT secondary current to a scaled voltage signal.

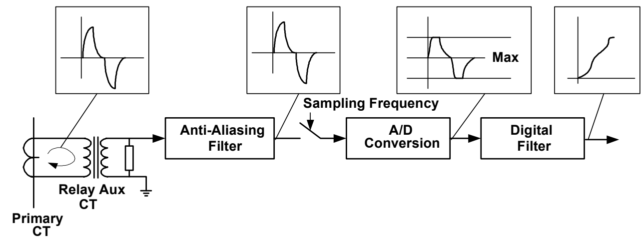

Fig. 1 Relay Schematic Showing Measured Signals

The anti-aliasing filter removes any high frequency present in the waveform, and the A/D converter converts the signal to the digital value of the current at a typical sampling rate of 16 samples per cycle. The function of the digital filter is to reject all harmonics and to extract the magnitude of the fundamental content of the signal. Fig. 2 shows the extracted fundamental magnitude resulting from a 10 kA primary current in the C50, 800:5 CT. The sine wave current and the extracted fundamental magnitude shown in Fig. 2 are the expected waveforms. What waveform can be expected for the 50 kA fault?

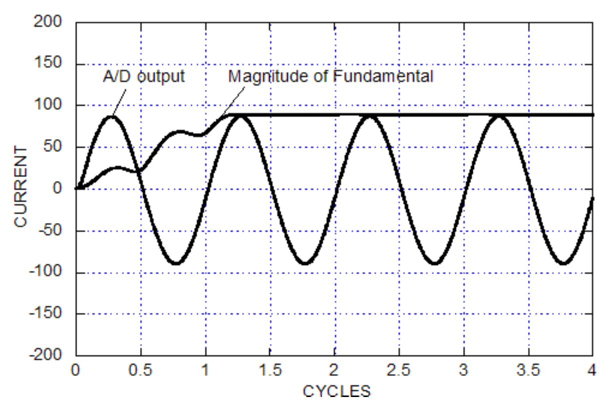

Fig. 2 Secondary CT Signal Extracted From a C50, 800:5 CT With 10 kA Primary

Fig. 3 shows the severely saturated CT secondary current and the limited magnitude A/D output. What is more, the fundamental extracted from the A/D output falls short of the 80 A trip threshold.

The waveforms in Fig. 3 show the signature pattern produced by CT saturation. The saturated waveform is limited to a fixed volt-time area. As its peak increases with increasing current, its pulse duration decreases. Although the peak increases, the relay measuring range is limited to 20 times the rated secondary current and the maximum measured signal is limited to 150 amps as shown in Fig. 3. The relay receives only a signal consisting of square wave pulses that decrease in duration as current increases. As a result, the fundamental extracted decreases, the signal fails to reach the maximum, and no trip signal is issued. This analysis applies to each of the CT ratings in Table 4 of the Standard.

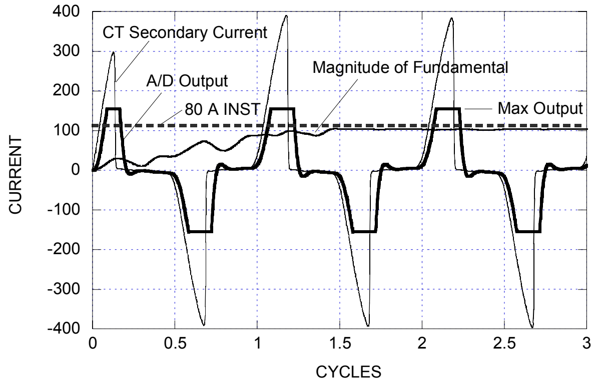

Fig. 3 Secondary CT Signal Extracted From a C50, 800:5 CT With 50 kA Primary

The following Fig. 4 through Fig. 15 show the current waveforms with response for switchgear faults using CT accuracy ratings selected from Table 4 of the IEEE Standard.

II. CT 300:5, C20

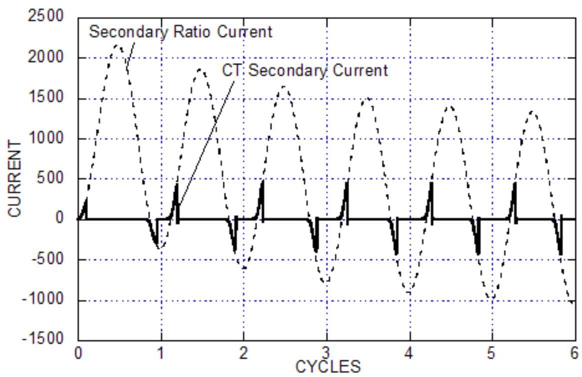

Fig. 4 Current Waveforms of a C20, 300:5 CT, Burden 0.5 ohms, 50 kA, X/R = 17

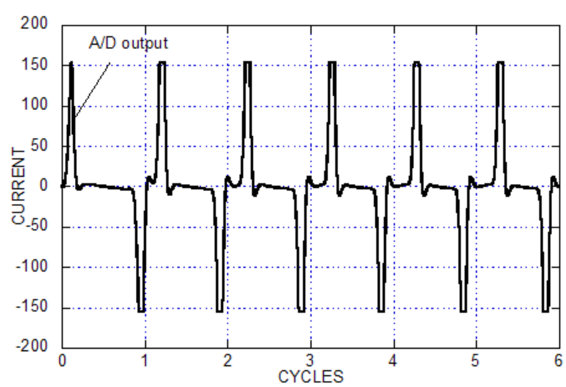

Fig. 5 A/D Output With a C20, 300:5 CT With 50 kA, X/R = 17

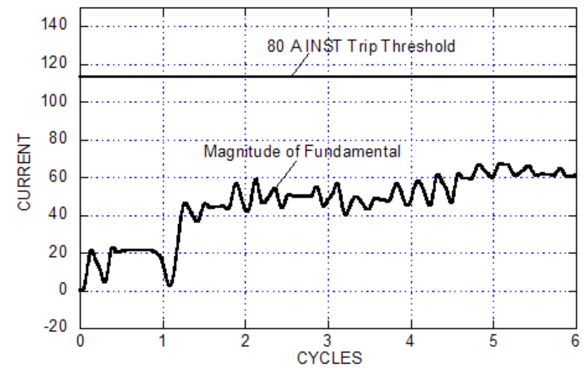

Fig. 6 Response of Fundamental Filter With a C20, 300:5 CT With 50 kA, X/R = 17

III. CT 600:5, C50

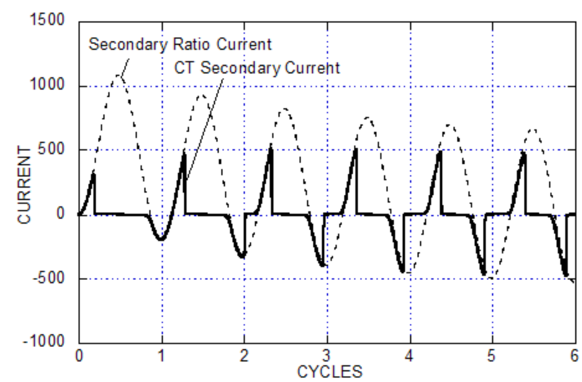

Fig. 7 Current Waveforms of a C50, 600:5 CT, Burden 0.5 ohms, 5 kA, X/R = 17

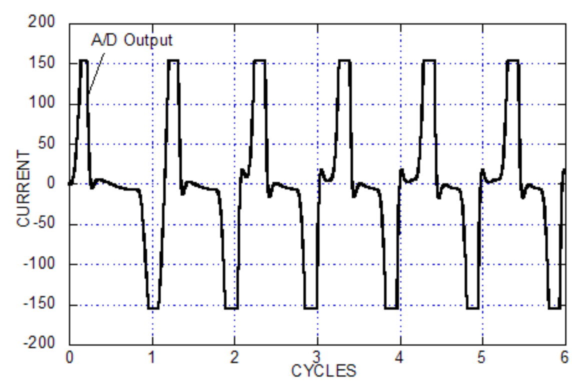

Fig. 8 A/D Output With a C50, 600:5 CT With 50 kA, X/R = 17

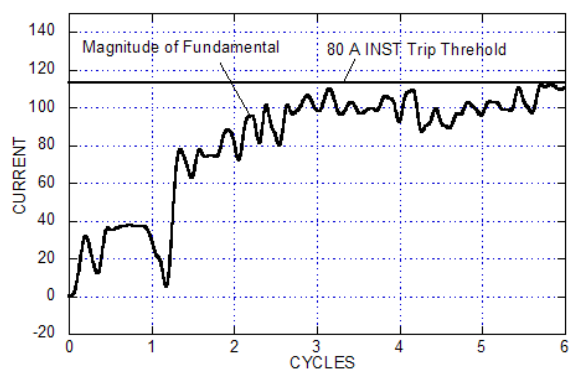

Fig. 9 Response of Fundamental Filter With a C50, 600:5 CT With 50 kA, X/R = 17

IV. CT 1200:5, C100

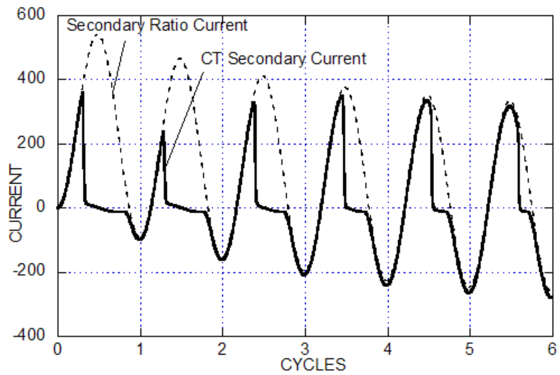

Fig. 10 Current Waveforms of a C100, 1200:5 CT, Burden 0.5 ohms, 50 kA, X/R = 17

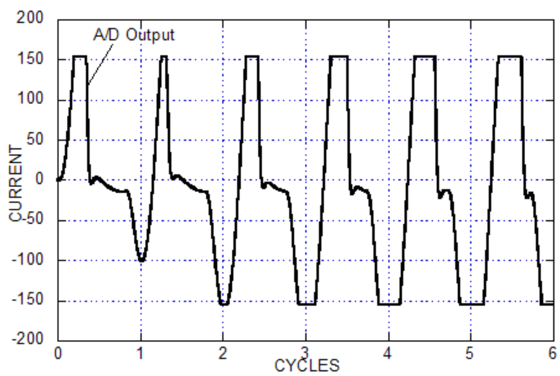

Fig. 11 A/D Output With a C100, 1200:5 CT With 50 kA, X/R = 17

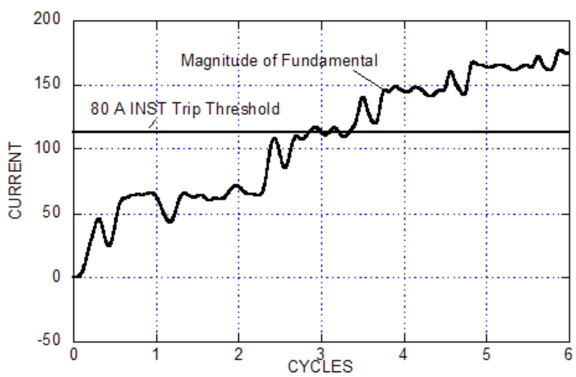

Fig. 12 Response of Fundamental Filter With A C100, 1200:5 CT With 50 kA, X/R = 17

V. CT 1200:5 C400

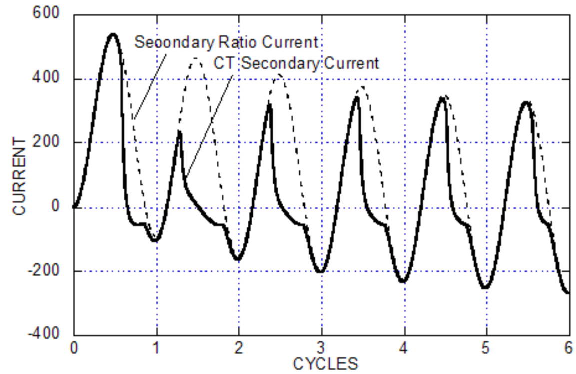

Fig. 13 Current Waveforms of a C400, 1200:5 CT, Burden 0.5 ohms, 50 kA, X/R = 17

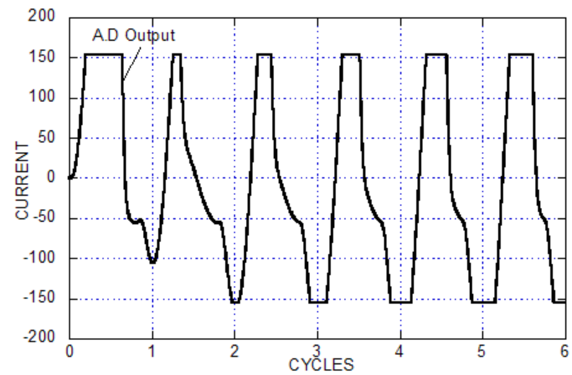

Fig. 14 A/D Output With a C400, 1200:5 CT With 50 kA, X/R = 17

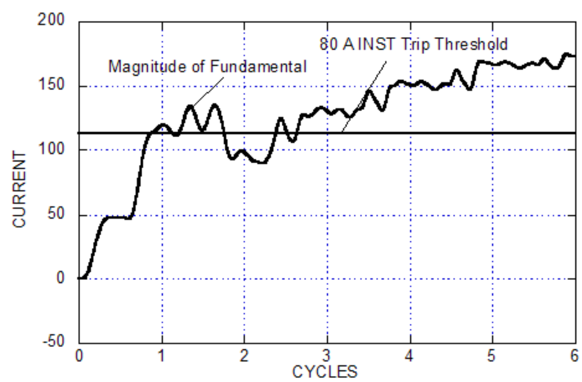

Fig. 15 Response of Fundamental Filter With a C400, 1200:5 CT With 50 kA, X/R = 17

VI. Annex A: Response of Relays With 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 Fig. 16 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, 2nd and 3rd harmonic and switches the input to the Bipolar Peak Detector when the distortion reaches a predetermined value. The filter is described in reference [2] using Matlab® simulations to describe its response to severely saturated waveforms. Fig. 17 through Fig. 22 below show the ability of the Cosine-Peak Adaptive filter to produce a valid trip signal for all the cases previously studied.

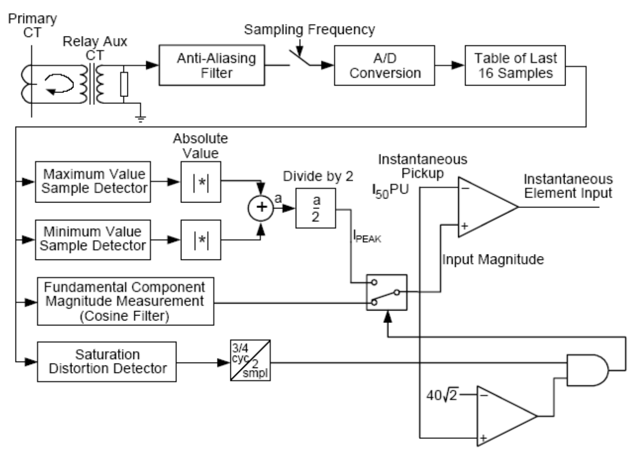

Fig. 16 Cosine-Peak Adaptive Filter

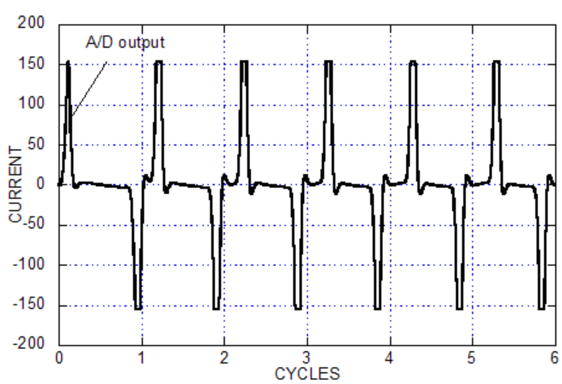

Fig. 17 A/D Output With a C20, 300:5 CT, Burden 0.5 ohms, 50 kA, X/R = 17

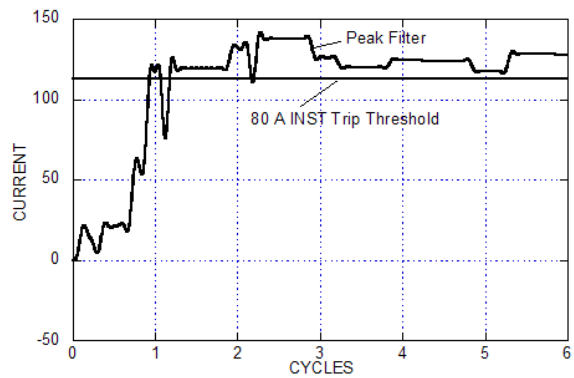

Fig. 18 C20, 300:5 CT With 50 kA, X/R = 17 with Peak Detector

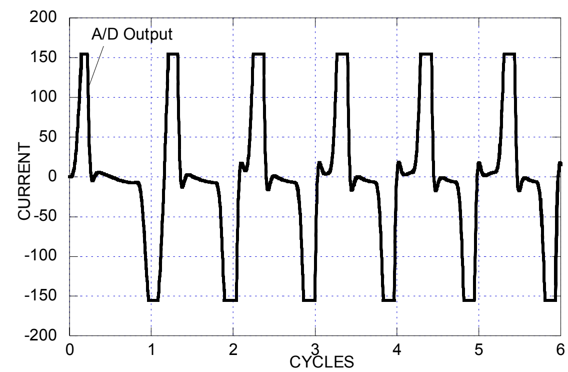

Fig. 19 A/D Output with C50, 600:5 CT, Burden 0.5 ohms, 50 kA, X/R = 17

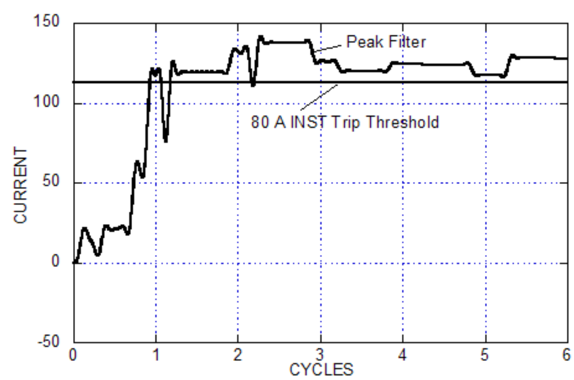

Fig. 20 C50, 600:5 CT With 50 kA, X/R = 17 with Peak Detector

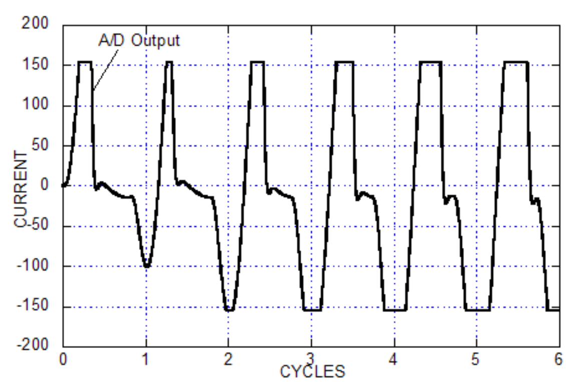

Fig. 21 Current Waveforms of a C100, 1200:5 CT, Burden 0.5 ohms, 50 kA, X/R = 17

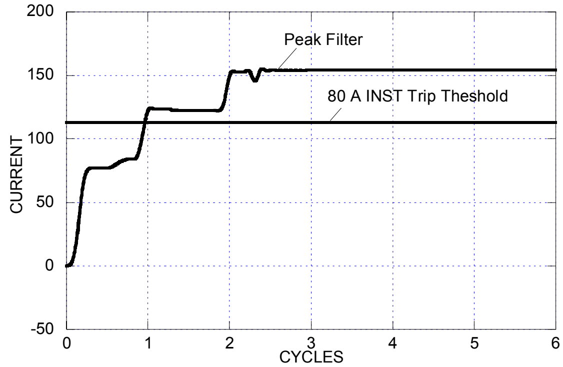

Fig. 22 C100, 1200:5 CT With 50 kA, X/R = 17 with Peak Detector

VII. Conclusions

1. Footnote c of Table 4 in the Standard states: “These accuracies may not be sufficient for proper relaying performance under all conditions. To ensure proper relaying performance, the user should make a careful analysis of CT performance considering the relaying requirements for the specific short circuit current and the secondary circuit impedances.” In fact, none of the accuracies in Table 4 are sufficient for proper relay performance with realistic secondary impedance and X/R ratio within the range allowed by the Standard.
2. The careful analysis of CT performance for high magnitude offset fault requires computer simulation of the relay, as well as the CT, and cannot be carried out by manual calculation.
3. The Standard should be revised to list CT accuracy ratings that are adequate for rated fault currents. No less than a C400, 1200:5 CT rating proves adequate for fast clearing of a 50 kA fault with an X/R ratio of 17 (see Fig. 15).

VIII. References

[1] IEEE Std. C37.20.2-1999 IEEE Standard for Metal-Clad Switchgear.

[2] G. Benmouyal, S. E. Zocholl, “Impact of High Fault Current and CT Rating Limits on Overcurrent Protection,” 29th Annual Western Protective Relay Conference, Spokane, WA, October 23-25, 2002.

[3] S. E. Zocholl, J. Mooney, “Primary High Current Testing of Relays With Low Ratio Current Transformers,” 30th Annual Western Protective Relay Conference, Spokane, WA, October 21–23, 2003.

IX. Biography

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.

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