CASE STUDY

SEL Adaptive Overcurrent Element Technology Raises Performance Standards of Microprocessor-Based Protective Relays

SEL Technology Improves Relay Response Under High Fault-Current Conditions

The use of low-ratio CTs can expose power systems to catastrophic damage from high fault currents—a perilous situation that may go undetected. SEL's exclusive "Adaptive Overcurrent Element" technology improves the protective response under high fault-current conditions when CT saturation is present.

Pullman, WA—The use of low-ratio current transformers (CTs) can add significant exposure to CT saturation that results in the distortion of secondary transformer signals (waveforms). CT saturation causes severe waveform distortion, which prevents the accurate measurement of current by the digital filters used in microprocessor-based relays. Without adequate current information, a relay's overcurrent element can be slow or inoperative. This condition can become problematic in the presence of high fault currents, because the relays protecting the system may not react to the fault.

"In such a situation, there could be many thousands of amperes flowing into the power system busbars," says Gabriel Benmouyal, Research Engineer at Schweitzer Engineering Laboratories, Inc. (SEL). "The protective relay is supposed to respond to these faults in a matter of one cycle—16.66 milliseconds. If the relay's overcurrent element fails to measure the fault accurately and trip, the level of short circuit could result in a system-wide disaster."

"Microprocessor-based relays usually depend on the *cosine* type of digital filters to interpret CT waveforms," explains Stanley Zocholl, an SEL Distinguished Engineer who frequently collaborates with Benmouyal. "These cosine filters extract the fundamental out of whatever waveform the CT and A/D converter can measure. Although they offer excellent performance in the elimination of dc offset and harmonics, cosine filters cannot accurately measure a fault current once CT saturation occurs—especially when the fault current magnitude is high."

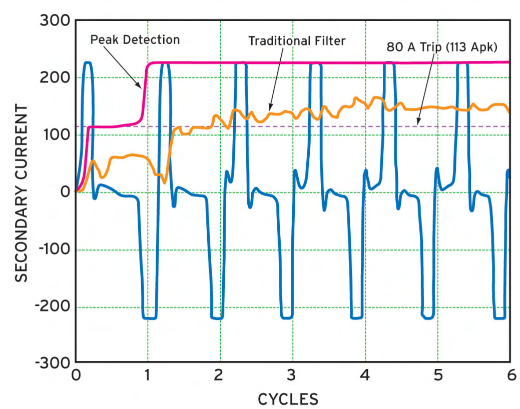

Figure 1—Engineers at SEL developed a patented filter technology that SEL calls Adaptive Overcurrent Element filtering. Combining the dc offset and harmonic immunity of the cosine filter, and the accurate magnitude acquisition of the peak filter, SEL's Adaptive Overcurrent Element provides "the winning combination" of both filters working at any given time.

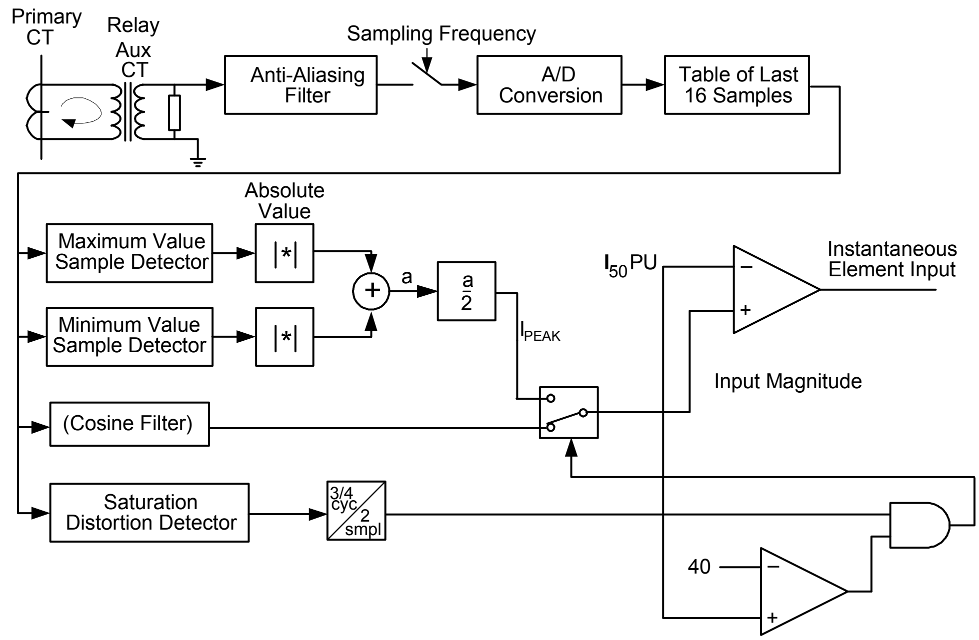

Figure 2—Combining two classes of signal filters provides an elegant solution for ensuring reliable overcurrent element operation

Zocholl explains that in situations where CTs are heavily saturated by a high fault current—the resulting waveforms are "off the map" to cosine filters—the bipolar peak detector provides the best current magnitude detection. "Yet, conversely, peak detectors are less responsive than cosine filters when CTs are not heavily saturated," he adds.

Benmouyal and Zocholl decided that what was needed was a dual filter that provided both cosine and peak detection capabilities. They developed a patented filter technology that SEL calls Adaptive Overcurrent Element filtering. Combining the dc offset and harmonic immunity of the cosine filter, and the accurate magnitude acquisition of the peak filter, SEL's Adaptive Overcurrent Element provides "the winning combination" of both filters working at any given time.

SEL's Adaptive Overcurrent Element normally operates using the output of a cosine filter algorithm. During heavy fault currents, the overcurrent element detects severe CT saturation and begins to operate on the output of the bipolar peak detector.

SEL has incorporated the Adaptive Overcurrent Element into the SEL-351 (-0 through -7), SEL-351A, SEL-351S, SEL-501, SEL-551, SEL-551C, SEL-587, SEL-701, SEL-749M, and SEL-710 Relays.

Faults occurring during CT saturation are generally the most severe, and need to be cleared quickly to improve safety and limit equipment damage. While CT saturation can occur at any location in a power system, some places are more susceptible than others. CT saturation-susceptible locations include:

- Generation stations—especially in large facilities with multiple units and lines connected.
- Industrial facilities with multiple sources or in heavily built-up areas.
- Medium-voltage feeders originating from large substations.

Combining two classes of signal filters provides an elegant solution for ensuring reliable overcurrent element operation. Based on the level of a “harmonic distortion index,” Adaptive Overcurrent Elements operate on either the output of the cosine filter or the output of the bipolar peak detector. When the harmonic distortion index exceeds the fixed threshold that indicates severe CT saturation, the overcurrent element “adapts” accordingly, and operates on the output of the peak detector. When the harmonic distortion index is below the fixed threshold, the Adaptive Overcurrent Element operates on the output of the cosine filter.

“In the big picture, the ‘bad guy’ is the low-ratio CT,” Benmouyal reminds. “A few years ago, the IEEE Power System Relay Committee wrote a paper in which it warned about the practice of using low-ratio CTs. The committee recommended that, in addition to low-ratio CTs, power plants should install secondary high-ratio CTs to take care of the high fault currents. Unfortunately, many power system designers, relay engineers and relay manufacturers don’t fully appreciate the potential for CT saturation occurrences, and have ignored this precautionary measure.”

Zocholl says that the problem is insidious. “Power plants don’t experience high bus loads every day of the week. But when one does occur, the result can be a catastrophe; they may not even realize what happened. All they find afterward is a clump of charred metal, so they might blame it on a stuck circuit breaker.”

Zocholl says that in many instances, CT saturation occurs in an auxiliary generator bus, where low-ratio CTs are usually considered perfectly adequate to support subsystems, such as arrays of small motors running turbines, heat pumps, and water pumps. “In cases like these, the grounded generator is supposed to limit fault current on line-to-ground faults. One of the generator leads gets attached to ground and puts out 400 A. So, for line-to-ground faults you get 400 A on a 100-A CT, which is not so bad. What *is* very bad is that a line-to-line fault can happen. For example, if two wires were to make contact in a cable between a breaker and a motor, you would not involve ground. The generator would feed that fault with 40 kA, but the cosine filter wouldn’t see it.”

Zocholl says that in a case like this, another relay up in the system would trip and shut down the auxiliary bus, leaving the rest of the plant up and running. “But in some cases auxiliary buses are running critical equipment,” Zocholl explains. “In that case, a fault that didn’t clear could result in a terrible incident.”

“Saturated waveforms are a study in themselves,” Zocholl adds. “The tools needed for that study are simply not available to relay engineers. They may read about them in papers, but have no analytic tools to actually see the waveforms. They make linear calculations of Ohm’s Law, which doesn’t apply to this problem. When a high fault current hits a saturated CT, the A/D converter tops out—can’t put out any more bits. So, in effect, all the relay sees is a small square waveform even though high current is actually flowing. Only a peak detector or our Adaptive Overcurrent Element will actually see the true waveform and cause the relay to respond.”

For more details on the SEL Adaptive Overcurrent Element technology, refer to the paper, "The Impact of High Fault Current and CT Rating Limits on Overcurrent Protection," by Gabriel Benmouyal and Stanley Zocholl. It can be downloaded from the SEL website at www.selinc.com/techpprs/6142.pdf.

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About Stanley Zocholl

Stanley E. 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 a member of the Power System Relaying Committee and past chair of the Relay Input Sources Subcommittee. 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. He was with ABB Power T&D (formerly ITE, Gould, BBC) since 1947, where he held various engineering positions, including Director of Protection Technology. He joined Schweitzer Engineering Laboratories, Inc. as Distinguished Engineer in 1991.

About Gabriel Benmouyal

Gabriel Benmouyal received his B.A.Sc. in Electrical Engineering and his M.A.Sc. in Control Engineering from Ecole Polytechnique, Université de Montréal, Canada. In 1969, he joined Hydro-Québec, where he worked as an instrumentation and control specialist on projects involving substation control systems and dispatching centers. In 1978, he joined IREQ, where his main field of activity was the application of microprocessors and digital techniques to substation and generating-station control and protection systems. In 1997, he joined Schweitzer Engineering Laboratories, Inc. in the position of Research Engineer. He has served on the Power System Relaying Committee of IEEE since May 1989.

About SEL

Schweitzer Engineering Laboratories, Inc. (SEL) has been making electric power safer, more reliable, and more economical since 1984. This ISO 9001:2000-certified company serves the electric power industry worldwide through the design, manufacture, supply, and support of products and services for power system protection, control, and monitoring. For more information, contact SEL, 2350 NE Hopkins Court, Pullman, WA 99163-5603; phone: (509) 332-1890; fax: (509) 332-7990; email: info@selinc.com; website: www.selinc.com.

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