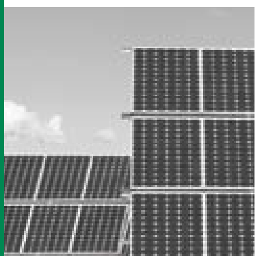

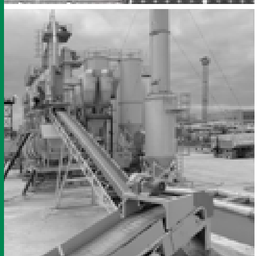

WHITE PAPER

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GROUND FAULT

Lowering the Limits for Ground Fault Detection

Current flowing to ground has only two paths—it can flow to ground through a ground fault, or it can flow to ground through distributed capacitance. Current flowing to ground through distributed capacitance can cause sympathetic tripping during a ground fault and it can cause nuisance tripping during normal operation. If the ground-fault trip level is high enough to eliminate sympathetic tripping, nuisance tripping due to unbalanced and harmonic capacitive current is usually not a problem.

However, if sympathetic tripping is not a concern and ground-fault trip levels are lowered, nuisance tripping can become a problem that worsens with the increased use of adjustable-speed drives. This paper discusses the sources of current flowing to ground that are not the result of a ground fault, and shows how a digital filter tuned to the fundamental component of ground-fault current can provide lower trip levels without nuisance tripping.

The limit to practical low-level ground-fault protection in industrial electrical systems is a function of physical parameters. Current sensing is the best method to detect and locate ground faults; however, system capacitance, unbalanced loads, current-sensor limitations, and harmonics affect current measurement and limit the lower level of practical ground-fault detection. This paper discusses limiting factors and solutions that can be implemented to mitigate them. Grounded systems are presumed.

Figure 1 illustrates that each phase in a distribution system has capacitance to ground. Phase-to-ground capacitance is distributed throughout the electrical system, but it can be modeled as a "lumped" value, as shown in the figure. When the system is energized, a capacitive current will flow from each phase to ground. The extent to which this capacitive current affects ground-fault detection will be discussed in some detail.

Charging current is defined as the current that flows to ground when one phase of an ungrounded system is faulted to ground, as measured by the ammeter causing the fault in *Figure 2*. Charging current can cause sympathetic ground-fault tripping in the unfaulted feeders of a multiple-feeder system. As *Figure 3* shows, core-balance current transformers (CTs) on the unfaulted feeders detect the charging current of the respective feeder. The CT on the faulted feeder detects the vector sum of the charging currents of the unfaulted feeders and the current in the impedance-grounding device. To avoid sympathetic tripping, the ground-fault current pickup level must be set above the largest feeder's charging current. To detect high-impedance faults and provide machine-winding protection, the ground-fault current pickup level should be less than 20% of the prospective ground-fault current. The pickup level of all system ground-fault protection devices should be the same, and coordination should be accomplished by varying trip delay times.

Unbalance in the phase-to-ground capacitances ($X_c \neq X_b \neq X_a$) illustrated in *Figure 1* will result in a steadystate zero-sequence current. One source of unbalance is geometric asymmetry with respect to the phase conductors and ground. In a balanced system, phase capacitive currents add to zero. In an unbalanced system, the sum of the capacitive currents is not zero and can be detected by a core-balance CT. This current to ground is not the result of a ground fault but can cause nuisance ground-fault tripping. Transposing phases in long feeders can reduce capacitance unbalance.

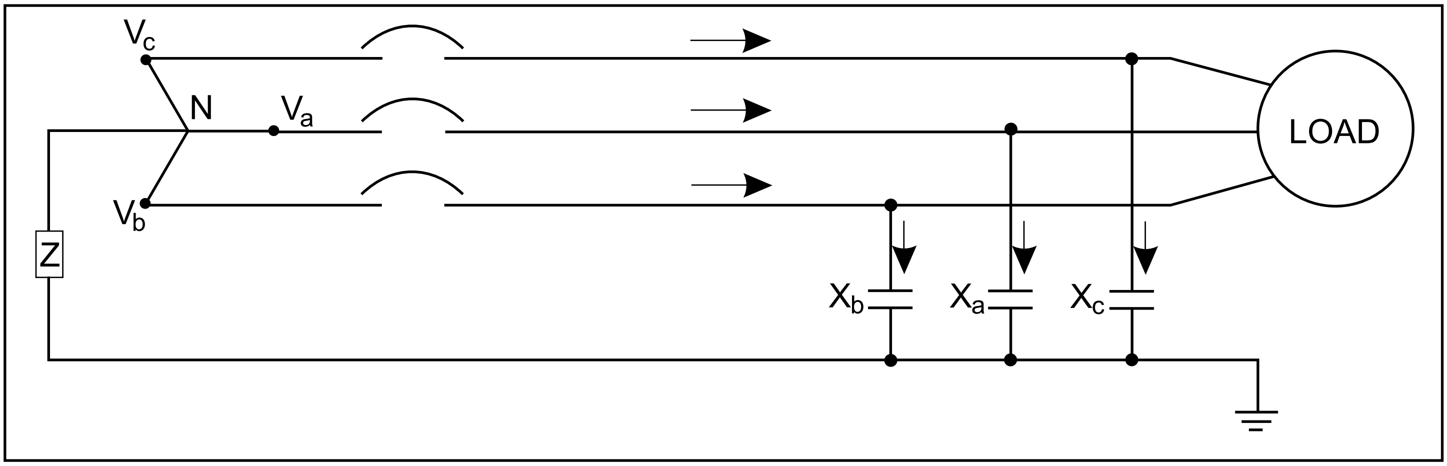

FIGURE 1

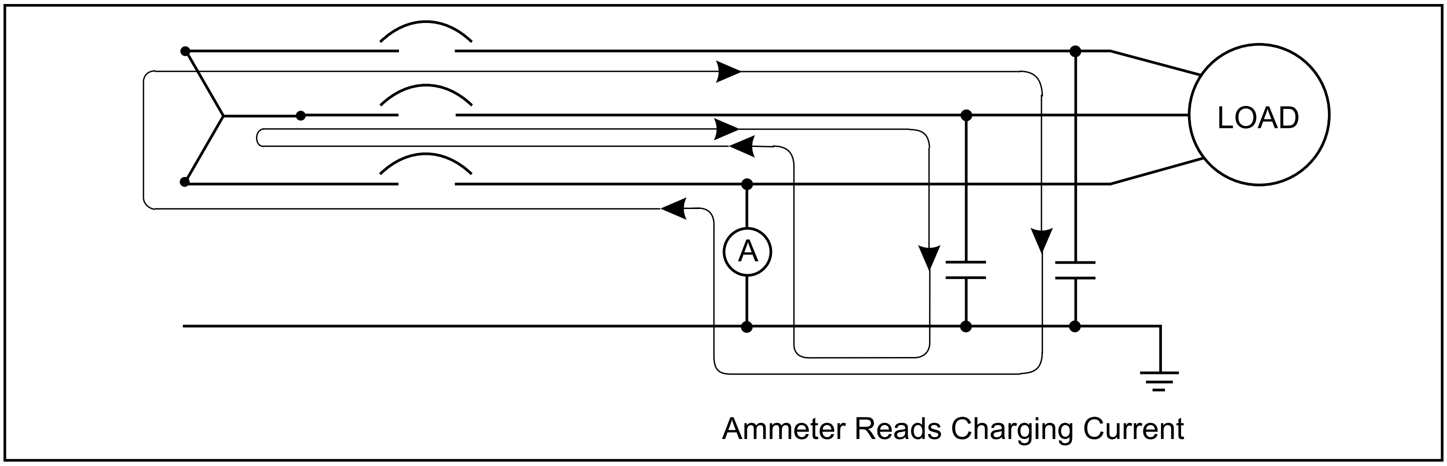

FIGURE 2

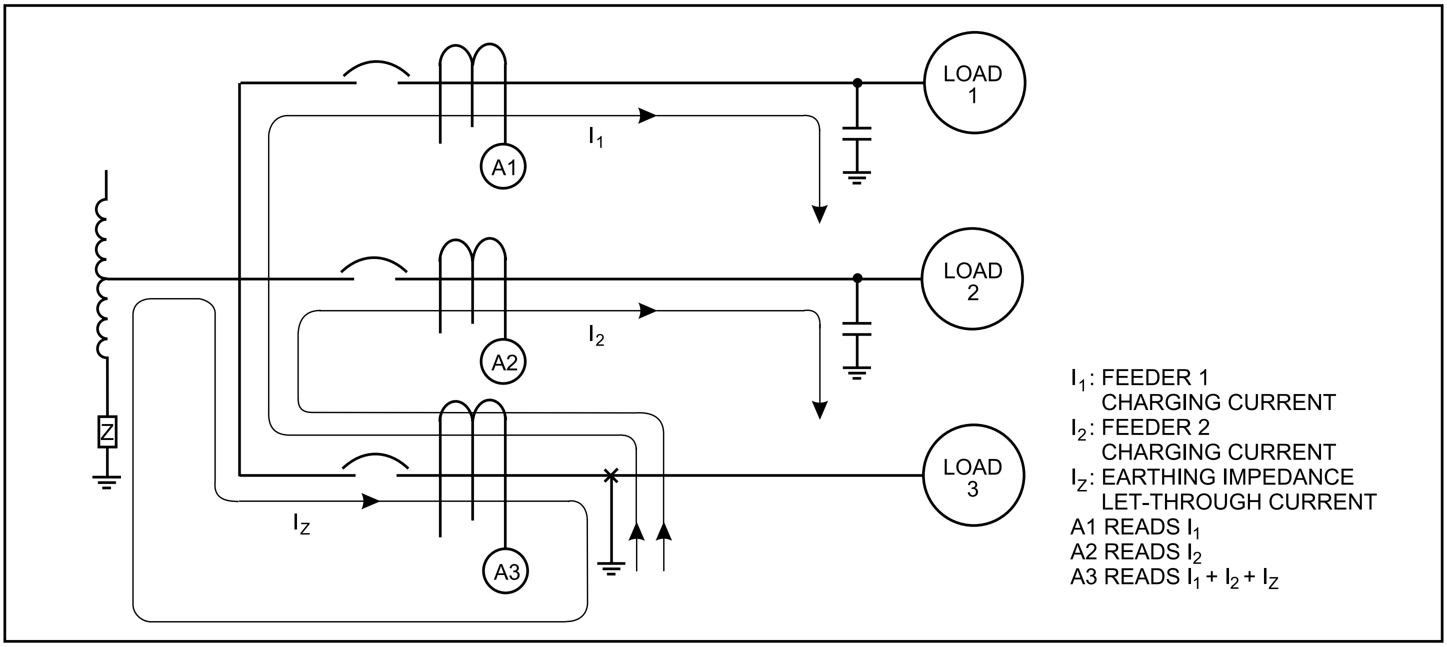

FIGURE 3

Phase-voltage unbalance (*Figure 1*: $V_{an} \neq V_{bn} \neq V_{cn}$) has the same effect as unbalanced phase capacitances. Voltage unbalance forces capacitive current to be unbalanced, and the resultant can be detected by a core-balance CT. Unbalanced voltage from the electrical utility may be the result of unbalanced single-phase loads. Voltage unbalance combined with capacitance unbalance may increase capacitive current unbalance, and this current can cause nuisance ground-fault protection trips.

It is important to note that unbalanced load currents do not cause nuisance ground-fault trips. If there is no leakage to ground, unbalanced load currents add to zero and do not cause an output from a core-balance CT.

When a motor is started across-the-line, the inrush current can have a dc-offset component that can cause an output from a core-balance CT. Transient characteristics are unpredictable because the switch can close at any point in the electrical cycle. Transient conditions typically last less than 100 ms and nuisance ground-fault trips can be avoided by setting a longer trip delay time or by using a digital filter to reject the dc component.

All current transformers, including the window-type core-balance CT's used to detect ground-fault (zero-sequence) current have practical limitations. A minimum excitation current is required in the primary before there can be a proportional output current. Excitation current is a function of burden, CT construction, and size. Primary currents smaller than the excitation current will not be detected. Sensitive ground-fault detection requires excitation current to be small.

A large fault current, such as a phase-to-phase fault or a ground fault on a solidly grounded system, can saturate a current transformer. Saturation occurs when a CT cannot maintain a secondary current waveform proportional to a large primary current. Secondary current characteristics in this case are unpredictable and ground-fault protection may not operate.

Surge currents and conductor placement can lead to local saturation in a core-balance CT. Local saturation can cause a core-balance CT secondary output when no zero-sequence current exists, leading to a nuisance trip. Surge currents are typically 160% locked-rotor current for motors. As shown in *Figure 4* phase conductors should be centered in the CT window, and multi-conductor circuits should be bundled ABC, ABC, etc., not AA, BB, CC, etc. The use of a flux conditioner, a ring of magnetically conductive material inserted in the CT window, can reduce local saturation.

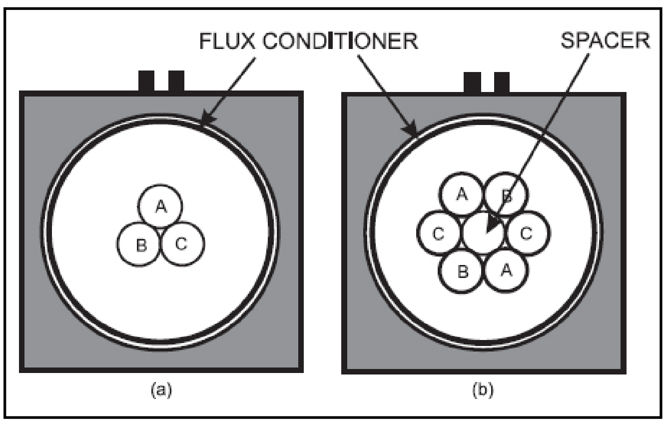

FIGURE 4

The presence of harmonic-frequency voltages (integer multiples of the fundamental frequency) in an electrical system cause harmonic-frequency currents that can affect ground-fault detection and minimum trip set points. Harmonics can be the result of the use of adjustable-speed drives (ASD) and solid-state starters. Static switching of line currents cause harmonic voltages that drive harmonic-capacitive current from the phases to ground. Capacitive impedance is inversely proportional to frequency ($X_c = 1/(2\pi fC)$ where f = frequency in Hertz). The higher the frequency, the lower the capacitive impedance, and the greater the current per volt. Except for the triplens, harmonic currents to ground add in the same manner as the fundamental components of capacitive current to ground. That is, only the unbalance in each harmonic contributes to neutral current.

Triplen harmonic-frequency currents present a special case. In a three-phase system, triplen harmonics are in phase and their sum is three times the individual magnitude. See *Figure 5*. In a 50-Hz system, 150-Hz, 300-Hz, 450-Hz, etc. components add to the 50 Hz fundamental component and can cause nuisance ground-fault trips.

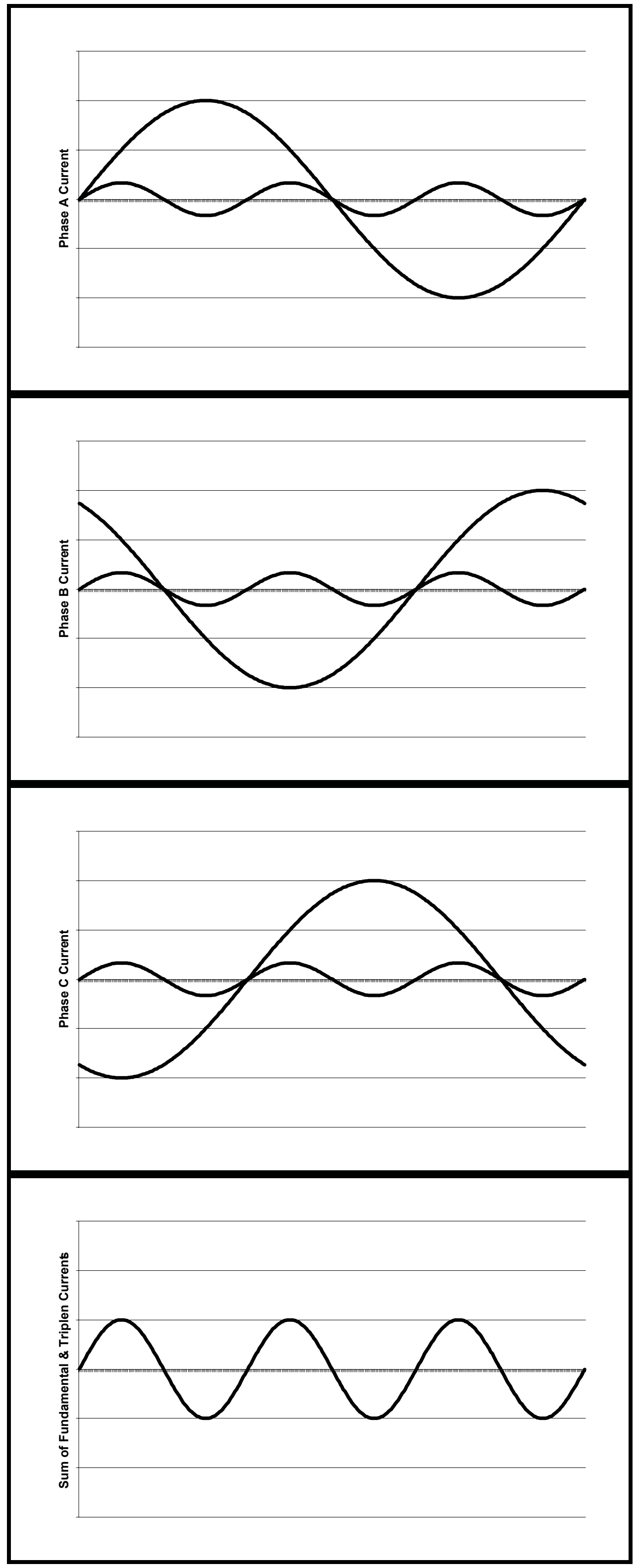

FIGURE 5

Harmonic-frequency current components can necessitate undesirably high ground-fault current-protection pickup levels to avoid nuisance tripping. To mitigate the undesired affects, use a ground-fault protection device that ignores dc-offset and harmonic-frequency current, and responds only to the fundamental-frequency component of current. The filtering characteristic must be fast to allow a short ground-fault trip time.

Digital filtering of the zero-sequence-current waveform provides a fast and accurate solution to many low-level ground-fault detection problems. Digital sampling and digital signal processing techniques can be used to construct a band-pass filter that responds to only the fundamental-frequency component; dc-offset and harmonic components are ignored. The discrete Fourier transform (DFT) algorithm is a mathematical tool that can quickly extract a specific-frequency signal from a multiple-frequency signal. The example shown in *Figure 6* is a 50-Hz signal with a 150-Hz third-harmonic component. The simplified DFT algorithm is:

$$Ip = \frac{2}{m}\sum_{n=0}^{m-1} I(n) \times \sin(\frac{2\pi n}{m})$$

Where:

I_p = peak current

m = number of samples per cycle

n = sample number

I(n) = measured sample

The sampler is set to take a known number of samples per cycle of the desired frequency. In this example, the filter is tuned to 50 Hz by selecting a sample frequency of 1 kHz (20 samples per cycle). The example summation is:

$$Ip = \frac{2}{20}\sum_{n=0}^{19} I(n) \times \sin(\frac{2\pi n}{20})$$

$$Ip = 1.414$$

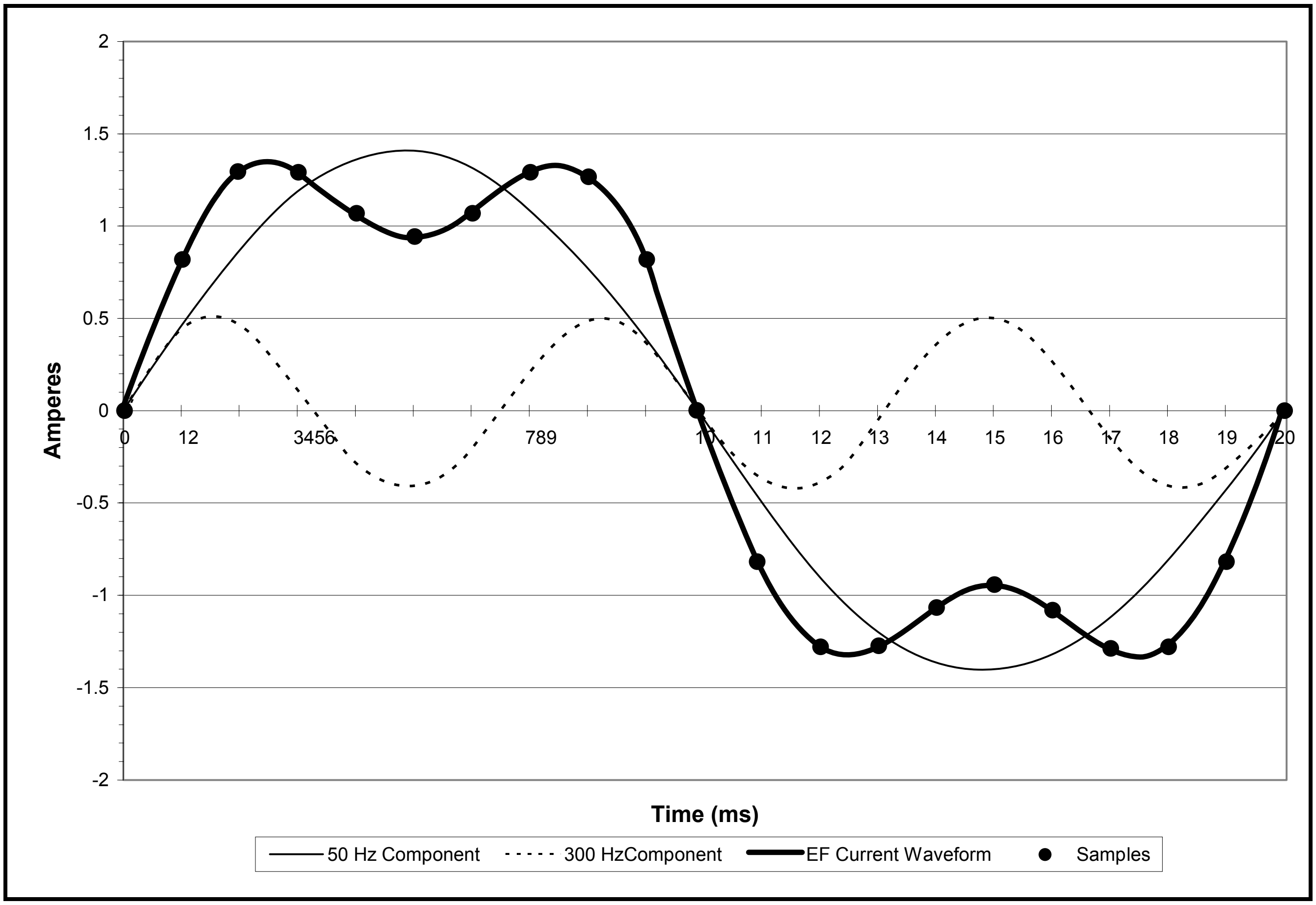

FIGURE 6

Table 1 shows the values, based on the example in *Figure 6*, of the 50 Hz component, the 150 Hz component, and the ground-fault current that is the sum of the two, at each of the sample times, n. It also shows the sample-time DFT-component value of both the 50 Hz component and of the sample, and the sum of each over the sample period of n=0 to n=19. Note that the sum for the fundamental component is the same as the sum for the sampled waveform, showing that this sampling technique has provided an accurate measurement of the fundamental component in spite of the presence of the 150 Hz third harmonic.

Note that only a single cycle of the fundamental component is required for the calculation, here 1/50th second, or 20 ms. Thereafter, the value is updated every millisecond and the value is accurate, based on the previous 20 samples.

Ground-fault protection relays that use digital filtering techniques can reduce nuisance tripping associated with low-level protection. Such devices ignore the dc component when a motor starts, and allow lower trip current and trip time set points. Protection that uses DFT filtering ignores harmonic components of zero-sequence current that results from capacitive unbalance, again allowing a lower trip set point. Triplen harmonic components, whose phase values are additive, are filtered by the DFT algorithm both in terms of capacitance unbalance current and earth-fault current. This permits the selection of a lower current trip level, with the one-cycle DFT calculation time allowing for a rapid trip time.

SAMPLE NUMBER (n)	50 Hz COMP. $I_f(n)$	150 Hz COMP.	SAMPLED VALUE I(n)	$I_f(n)$sin(2*pi*n/20)I	(n)sin(2*pi*n/20)
00	.000	0.0000	.000	0.000	0.000
10	.437	0.3810	.818	0.135	0.253
20	.831	0.4481	.280	0.489	0.752
31	.144	0.1461	.290	0.926	1.043
41	.345	-0.277	1.068	1.279	1.016
51	.414	-0.471	0.943	1.414	0.943
61	.345	-0.277	1.068	1.279	1.016
71	.144	0.1461	.290	0.926	1.043
80	.831	0.4481	.280	0.489	0.752
90	.437	0.3810	.818	0.135	0.253
10	0.0000	.000	0.000	0.000	0.000
11	-0.437	-0.381	-0.818	0.135	0.253
12	-0.831	-0.448	-1.280	0.489	0.752
13	-1.144	-0.146	-1.290	0.926	1.043
14	-1.345	0.277-	1.068	1.279	1.016
15	-1.414	0.471-	0.943	1.414	0.943
16	-1.345	0.277-	1.068	1.279	1.016
17	-1.144	-0.146	-1.290	0.926	1.043
18	-0.831	-0.448	-1.280	0.489	0.752
19	-0.437	-0.381	-0.818	0.135	0.253
				14.142	14.142

TABLE 1

Additional technical information and application data for Littelfuse POWR-GARD® protection relays, fuses and other circuit protection and safety products can be found on **www.littelfuse.com**. For questions, contact our Technical Support Group **(800-832-3873)**. Definitions of terms used in this white paper can be found in the Technical Application Guide section of the POWR-GARD Catalog. To download a copy visit **www.littelfuse.com/catalogs**.