# IMPROVING SELECTIVITY & ARC-FLASH PROTECTION THROUGH OPTIMIZED INSTANTANEOUS PROTECTION SETTINGS


Paper No. ESW



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***Abstract*** –In today's power distribution systems, existing protection methods do not provide full selectivity and instantaneous fault clearing for expected fault current, including lower magnitude arcing currents simultaneously. This paper will discuss two methods that may change that. The first method is a selectivity analytical technique useful with many circuit breaker trips currently available in the industry. The second method is a new circuit breaker trip technology. Both methods allow switchgear Circuit Breakers (CB) to use sensitive instantaneous settings and maintain selectivity when used upstream current-limiting molded case circuit breakers, current-limiting motor circuit protectors or current-limiting fuses in downstream equipment such as motor control centers.

*Index Terms* — Arc-flash, Incident Energy, Selectivity, Instantaneous protection, Current-limiting Circuit Breakers, Current-limiting Fuses.

## I. INTRODUCTION

### *A. Shortcomings of existing methods*

Many power distribution systems in industrial facilities consist of low voltage switchgear, feeding motor control centers with various sized motor loads and small distribution loads. In many cases the majority of the protective devices in the motor control centers and small distribution loads are current-limiting (CL) circuit breakers, motor circuit protectors or current-limiting fuses. Traditional coordination studies use Time Current Curve overlays limited to graphical models of overcurrent device behavior above 10 milliseconds. The traditional graphical method ignores the current-limiting performance of the overcurrent-protective-devices (OCPD) in the motor control centers and other downstream distribution equipment. The use of traditional time current curves (TCC) as the sole basis to assess selectivity, often results in the switchgear feeders omitting instantaneous protection or implementing very high, hence insensitive, instantaneous pickup settings. Furthermore, the main circuit breaker in the switchgear often omits instantaneous protection completely, relying on delayed short time protection to maintain selectivity above the feeder circuit breakers in the switchgear. Even when implementing Zone-Selective-Interlocking (ZSI) this method of designing a low voltage power system can result in relatively high arc-flash incident energy at the main bus of major equipment.

### *B. Recent improvements*

In recent years circuit breaker manufacturers have published selectivity tables identifying the selectivity that may be available between circuit breaker of different sizes even if the upstream circuit breaker includes an instantaneous trip. However, the published tables usually assume that the instantaneous setting in the upstream circuit breaker is at the maximum allowable for the circuit breaker. A maximum instantaneous setting in a large circuit breaker may be too high to sense arcing currents associated with an arc-flash event.

### *C. Opportunities for improvement*

Understanding how the trip units in the switchgear circuit breakers interpret the current-limiting behavior of the downstream protectors can allow more finely tuned instantaneous pickup settings for many electronic trip circuit breakers. Furthermore, trip systems may be designed to optimize performance based on the interpretation of energy-limiting behavior in downstream protectors. For the purposes of this paper the authors shall refer to the interpretation of the energy-limiting behavior by an electronic trip, with a specially designed algorithm for that purpose, as “waveform recognition” (WFR). Modern advances in zone selective interlocking combined with the improved waveform recognition algorithm allows selectivity at sensitive instantaneous settings for multiple layers of large circuit breakers. The combination of the two technologies allows full systems to be designed in such a manner that full selectivity and 100% instantaneous protection at calculated arcing current is possible. For most industrial systems, these capabilities, when used together, will result in incident energy under 8 cal/cm$^2$ at 18”.

## II. ARCING CURRENT SENSITIVITY AND TIME

### *A. The Importance of time in arc-flash incident energy*

A protective device's clearing time at expected arcing current is a key determinant in how much incident energy will result during an arc-flash event. Arc-flash analysis using the IEEE 1584 guide (Guide For Performing Arc-flash Incident Energy Calculations) equations shows that interrupting arcing faults in the instantaneous range, even for a large Low-Voltage-Power Circuit Breaker, allows incident energy to remain below 8 cal/cm$^2$ for a broad range of conditions that may be found in an industrial system.

Fig. 1 demonstrates the effect of clearing time on incident energy for a fixed working distance and for a specific set of system assumptions. This demonstrates that circuit breakers may provide reasonable levels of incident energy protection as long as they operate with clearing times of 6 cycles or less. Six cycles is a very fast short time band and close to an instantaneous clearing time.

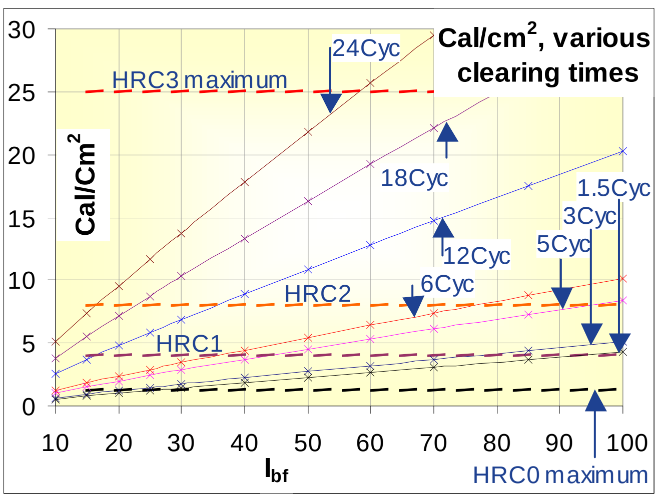


**Fig. 1** Incident energy for a 480V, solidly grounded systems with a 32mm arcing gap and 24" working distance.

### *B. The risk caused by variance in arcing current*

Figure one (Fig. 2) demonstrates the variance that IEEE 1584 calculations define for a 480V solidly grounded system for various arcing gap assumptions. The 100% and 85% range defined in the IEEE guide predicts the variance observed by the IEEE 1584 working group for the test protocol used to derive arcing current data. This suggested variance does not take into account other variance that may be in the system due to incorrect estimates or fluctuations in system impedance, short circuit calculation errors, estimated data, the difference in the arcing gap from the IEEE 1584 recommendations or any other sources of variance. Fig. 1 shows that, without taking into account bolted fault current variance, the IEEE predicted variance and arc gap variance might cause almost 2:1 variation in arcing current. Also, variance could be in the direction of lower arcing current than nominally predicted.

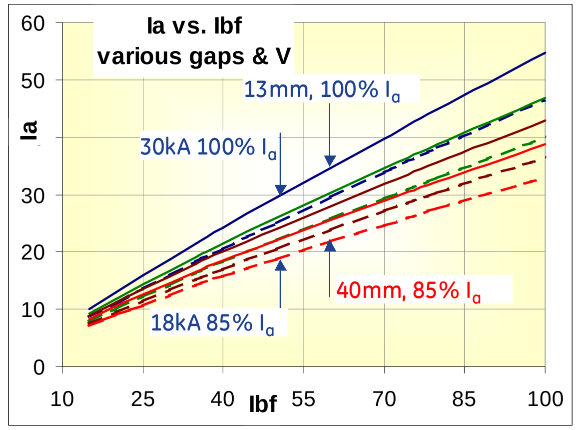


**Fig. 2** 100% & 85% Arcing Current Vs. time for 480V, solidly grounded system per IEEE 1584. ($I_a$=arcing current, $I_{bf}$ = bolted fault current)

### *C. The need for fast protection at "low" arcing current*

The two figures combined illustrate the importance of fast clearing and sensitive settings for overcurrent devices relied upon to provide optimal incident energy protection. Generally, to achieve protection at 4cal/cm$^2$ (HRC1 maximum) 3 cycles or faster clearing is required. However, in many power systems selectivity needs often drive circuit breaker trips toward greater insensitivity and slower operation in the circuits where faster and more sensitive protection is most needed.

## III. CURRENT-LIMITING OCPD

### *A. Understanding current-limiting behavior is required*

Current-limiting (CL) overcurrent protective devices (OCPD), either circuit breakers or fuses, once operating beyond their current-limiting-threshold, can have their let-through-current described in instantaneous peak current ($I_{pk}$). Manufacturers publish Peak-Let-Through graphs. Either derived from the graph, or furnished directly from the manufacturer, a mathematical transfer function can be created that describes the peak let-through current in terms of the available prospective fault current. Equations 1 and 2 are examples of such functions for a molded case circuit breaker and a current-limiting fuse.

$$y = a + bI + c\ln(I) + d\frac{\ln(I)}{I} \qquad \text{Eq. 1}$$

Peak Let-Through current for Current-limiting Circuit Breaker

Where:

$y$ = let-through peak current
$a, b, c$ & $d$ = coefficients for a particular circuit breaker.
$I$ = prospective bolted fault current

$$y = I_{PT}\left(I_{AS}/I_{AT}\right)^{1/3} \qquad \text{Eq. 2}$$

Peak Let-Through current for Current-limiting Fuse

Where:

$y$ = Peak Let-Through current at prospective bolted fault current
$I_{PT}$ = Peak let-through current at test prospective fault current ($I_{AT}$)

$I_{AS}$ = Prospective current for which Peak-let-through current is desired (Equivalent of $I$ in Eq. 1).

$I_{AT}$ = Test prospective fault current that defines fuse let-through characteristic determined from published curve or provided by manufacturer.

The peak let-through current of an OCPD operating in its current and energy limiting range has a characteristic waveform shape typically described as a portion of a half cycle sine wave as shown in Fig 3. The wave shape has a lower peak current than the prospective and a shorter period than the full prospective half cycle fault current. The exact shape will vary slightly depending on whether the current limiting device is a fuse or a circuit breaker. However both may be described by this general characterization. Regardless of type of OCPD the limited fault current will have limited energy and limited peak current even if the wave shape is not exactly as the traditional model predicts. It is this limited characteristic waveform that can be used by an upstream trip system to differentiate a fault current being interrupted by a current-limiting OCPD from an arcing or bolted fault that is not being interrupted by a fast current-limiting OCPD.

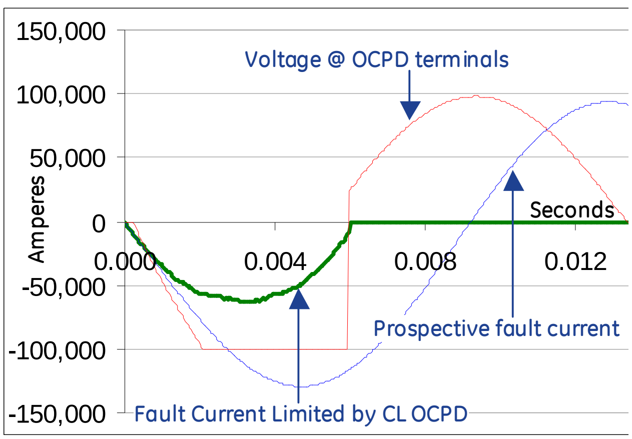


**Fig. 3** Modeled peak let-through waveform for a single pole of a CL circuit breaker operating in its current-limiting range.

## IV. TAKING ADVANTAGE OF ELECTRONIC TRIP SYSTEMS

Two methods for optimizing electronic trip instantaneous pickup settings in circuit breakers are discussed in this paper. One defined as the "peak let-through selectivity method is described in greater detail in references 3 & 4. The other based on a specific implementation of an electronic sensing algorithm the authors shall refer to as the "waveform-recognition" method.

### *A. Peak Let-through selectivity method [3,4]*

The instantaneous function in electronic trips often is a simple sample and compare algorithm or circuit. This type of implementation may also be called a peak sensing algorithm or circuit. Though the trip settings are calibrated in rms amperes and the associated time current curve is drawn in rms amperes, the trip operates on instantaneous peak amperes. The conservative assumption is that the trip is calibrated to operate at 1.41 times the rms value shown on the time current curve. Hence a trip nominally set at 10 000A rms is sampling current and comparing it to a threshold of 14 100A . Allowing for a 10% tolerance the 10 000A rms setting means the trip will not actuate if the peak current is below 12,690 A (10,000X1.41X0.9). Using the knowledge that the upstream electronic trip is sensitive to peak current will allow the circuit breaker to have its instantaneous algorithm on and set above the prospective "peak-let-through" fault current as let through by the current limiting device below. Figure 4 shows the value the instantaneous would need to be set to if set based on traditional time current curves (minimum TCC setting). The lower value identified as "minimum $I_{pk}$ setting" would maintain selectivity due to the known "peak-let-through" of the current limiting branch downstream. A correctly set circuit breaker may achieve a significant level of selectivity due to the current-limiting action of the downstream CL OCPD while using a much lower pickup setting than the traditional TCC based method would allow.

### *B. Waveform recognition (WFR) selectivity method*

An electronic trip implementing WFR can consider a combination of peak current and time to determine if the fault current shows the characteristic wave shape of a current and energy limiting fault current interruption. Since peak currents and time are being considered the trip may be described as capable of waveform recognition (WFR). Waveform recognition could also be considered as sensing energy let-through. A trip able to detect that the waveform is energy limited can be set more sensitively (lower pickup) than one that only considers peak current. Figure 4 illustrates the difference between the different trip sensing methods. In Fig. 4 the line identified as "Minimum TCC setting", is the setting in peak amperes (ignoring trip sensing and processing tolerance) that a line side CB would need to be selective at the prospective fault current when determined via a traditional TCC based coordination study. The "Minimum $I_{pk}$ setting" is the setting the same trip could employ if the peak let-through of the downstream current-limiting OCPD is considered. The "WFR setting" is what the trip setting at the same upstream device could be if the trip employs a WFR, or energy, sensing algorithm. Actual setting would vary based on the "quality" of the algorithm and the CL performance of the current-limiting device.

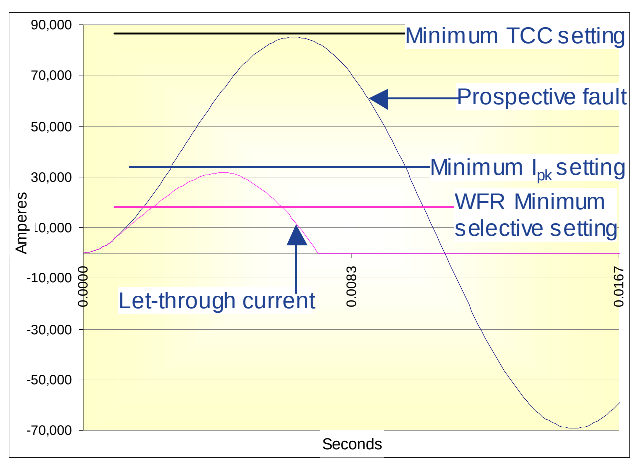


**Fig. 4** Comparison of different selective circuit breaker settings for a specific prospective fault condition depending on trip algorithm type and coordination study assessment method

## V. DETERMINING RANGE OF FAULT CURRENTS, MINIMUM SETTING & MAXIMUM POSSIBLE SELECTIVITY

*A. Useful current-limiting threshold*

For each type of current limiting device and for each selectivity assessment method a useful current-limiting threshold must be derived. For the peak-let-through analysis the derived threshold represents the minimum value of prospective fault current at which the analysis may be used. If prospective fault current is lower than this value the traditional TCC based coordination must be used. The actual pickup setting will vary depending on the maximum prospective fault current expected and may be higher than the current limiting threshold. For the waveform recognition based analysis the minimum threshold is the setting value used by the upstream circuit breaker trip for all prospective fault currents higher than the threshold. Hence, for the WFR method the threshold ends up being the only value needed.

*B. Fault conditions vary, but the threshold must be valid regardless*

Both thresholds must be valid regardless of fault power factor, closing angle or the number of phases faulted. For the peak method the valid threshold, or minimum point at which the method may be applied, is where the peak let-through current will not exceed manufacturer's published curves for all possible fault conditions. For the waveform recognition method the valid starting point is where neither the peak let-through current exceeds published values and where current interruption occurs in less than ½ cycle.

For fuses, the published current-limiting characteristic is derived from a single-phase test at low power factor. Hence some additional allowance must be made for more resistive power factors and three phase faults. For circuit breakers the published curve represents the worst single phase let-through during a three-phase test at a low power factor. To calculate the threshold for circuit breaker an allowance must be made for more resistive power factors. In the case of circuit breakers the waveform recognition method also requires some additional margin due to variation in the length of the let-through current waveform. This variation is identified via inspection of test oscillography.

The peak method's related threshold defines the beginning of a range. The upstream circuit breakers optimal setting will be determined by the degree of current limitation provided by the downstream device and the prospective fault current. For the waveform recognition method the related threshold defines the required setting for the upstream trip irrespective of the prospective fault current available.

*C. Threshold for $I_{pk}$ based selectivity determination*

The lower current-limiting threshold (CLT) used for the $I_{pk}$ method is derived the same way for both types of devices. The CLT can be derived from the published let-through curve by drawing a diagonal line on the $I_{pk}$ let-through curve representing √2 times the prospective fault current. The intersection of the √2-line and the $I_{pk}$ let-through line is the CLT used for the $I_{pk}$ analysis for both current-limiting fuses and circuit breakers. The CLT may also be derived by setting Eq. 1 and Eq. 2 equal to √2 times prospective rms fault current and solving for the prospective fault current. Eq. 3a-3c shows the mathematical calculation of a fuse's current-limiting threshold used for the peak selectivity method, derived from Eq. 2.

$$I_{CLTpeak1} = \sqrt{\frac{I^3{}_{PT} / I_{AT}}{\sqrt{2}^3}} \qquad \text{Eq. 3a}$$

$$I_{CLTpeak1} = I_{PT}^{3/2} \Big/ I_{AT}^{1/2} (\sqrt{2}^3)^{1/2} \qquad \text{Eq. 3b}$$

$$I_{CLTpeak1} = .595 \times I_{PT}^{3/2} \Big/ I_{AT}^{1/2} \qquad \text{Eq. 3c}$$

Where:

$I_{CLTpeak1}$ = Lowest prospective rms fault current for which the peak let-through selectivity analysis is applicable for the specific downstream fuse.

$I_{AT}$ = Test prospective fault current that defines fuse let-through characteristic determined from published curve or provided by manufacturer.

$I_{PT}$ = Peak let-through current at test prospective fault current ($I_{AT}$)

*D. Threshold for Waveform recognition (WFR) based selectivity determination*

For the waveform recognition analysis a more conservative higher threshold is required to ensure that the current interruption is fully current and energy limiting on all phases regardless of fault asymmetry or number of phases involved. From experience the authors determined that multiplying the first threshold used for the peak-let-through method by 140% provides a conservative estimate of the suitable threshold for implementing the WFR method. Eq. 4 shows the calculation of the higher current-limiting threshold required for the waveform recognition algorithm.

$$I_{CLTpeak2} = 1.4 \times .595 \times I_{PT}^{3/2} \Big/ I_{AT}^{1/2} \qquad \text{Eq. 4}$$

Where:

$I_{CLTpeak2}$ = Lowest prospective rms fault current for which the waveform recognition selectivity analysis is applicable for the specific downstream fuse.

For current-limiting circuit breakers the manufacturer must provide the higher threshold required for valid analysis based on testing. The manufacturer may provide threshold values based on testing, inspection of fault interruption oscillographic data, or both, as needed to match the trip algorithm used in the upstream circuit breaker trip. These values would be branch circuit breaker manufacturer and line side circuit breaker algorithm specific.

*E. Maximum selectivity and setting variation*

Fig. 5 graphically demonstrates the current-limiting thresholds used for fuses. Note that the higher threshold that the waveform recognition algorithm recognizes for fuses may be calculated, but for circuit breakers it must be provided by the manufacturer. The three current-limiting thresholds can be seen more easily on the fuse let-through curve. The top most diagonal line shown on the graph in fig. 5 is the published single-phase low power factor peak current line not used for selectivity analysis. The fuse's typical current-limiting threshold is the intersection of this line with the fuse's let-through peak current line. In fig. 5 this occurs outside of the graph, to the left. The middle threshold created by the intersection of the peak for a symmetrical waveform (peak at unity power factor) and the fuse's let-through line is used for the peak analysis. The highest threshold, further to the right, is used for the waveform recognition based analysis. This is the fault current value for which the particular fuse reliably produces a recognizable current-limiting let-through waveform for a three phase fault regardless of fault power factor.

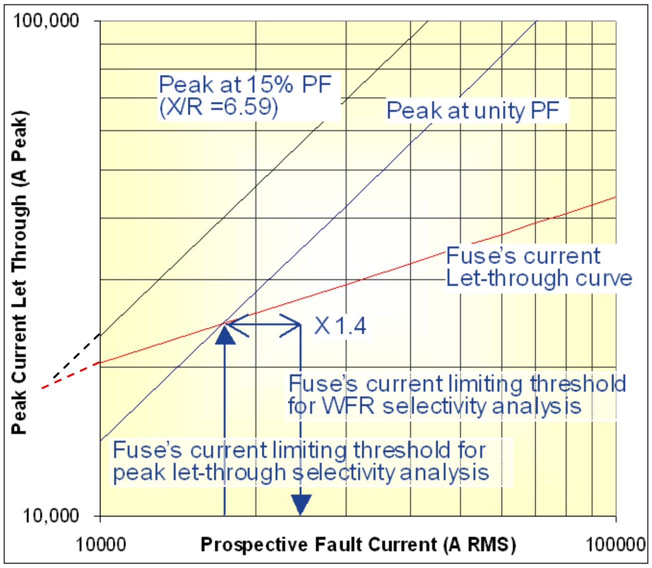


**Fig. 5** Fuse I peak let-through functions and derivations of current-limiting threshold used for selectivity analysis

The setting for the upstream trip derived via the peak method must be increased as determined by the $I_{pk}$ let-through transfer function as available fault current increases. Unfortunately, this reduces protection sensitivity as prospective fault current increases.

*F. Comparison of methods in a sample MCP application*

Figure 6 is a graphical device intended to demonstrate the various current value important to the analysis. The graph shows the optimized selective settings for a 480V switchgear feeder feeding a motor control center (MCC) with Motor Circuit Protectors (MCP) no larger than 30 amperes. The long vertical lines are the nominal trip instantaneous pickup settings. The bands at the bottom of the vertical lines account for trip tolerance. Bolted fault current at the MCC available from the switchgear is 55kA shown by the short vertical line at the upper right. Motor contribution at the MCC is 4kA and is not individually identified in the diagram. The plot shows the current-limiting Peak Let-Through curve for the MCP (curved line top right quadrant). The 100 and 85% arcing currents, based on IEEE 1584 calculations for a 25mm gap at the MCC, are shown as a rectangle just above the horizontal axis. As can be seen in Fig. 6 both methods yield switchgear feeder settings that should allow the feeder to trip instantaneously for the expected arcing current at the MCC main bus, while maintaining selectivity with a fault below the 30A MCP.

Fig. 7 shows the same analysis for a 250A MCP or current-limiting molded case circuit breaker. To be selective with the larger device the switchgear feeder setting using peak-let-through analysis must be increased such that it overlaps the expected arcing current. If this setting is used arcing fault protection timing must be determined from the short time delay band, not the instantaneous clearing. However, in both the case of the 30 MCP and the 250A MCP the WFR setting is selective and is significantly lower than the arcing fault level thereby clearing instantaneously for expected arcing currents. In this case the incident energy at 18" operating distance from the MCC bus is expected to be 5.4 cal/cm$^2$ on this sample 480/277 V system.

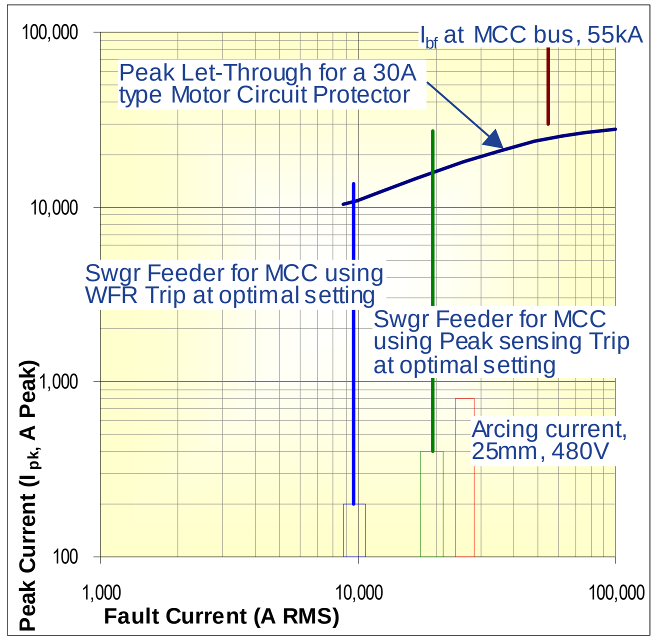


**Fig. 6** Peak and WFR settings above a 30A MCP with 55kA available, showing arcing current for 25mm gap at 55kA $I_{bf}$

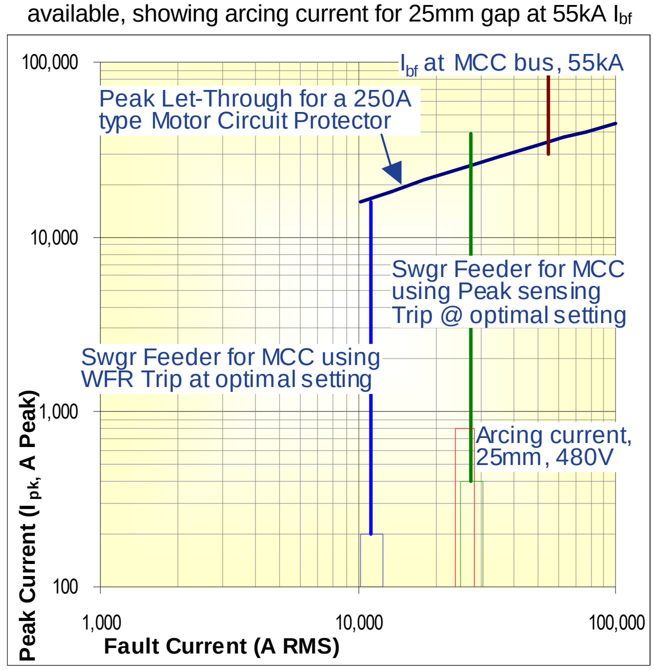


**Fig. 7** Peak & WFR settings above a 250A MCP with 55kA available, showing arcing current for 25mm gap at 55kA $I_{bf}$

*G. Comparison of methods in a sample fuse application*

Figure 8 demonstrates similar analysis for a 400A Class J time delay fuse at 480V. The fuse's low current-limiting threshold allows selective settings while maintaining the upstream MCC feeder sensitive enough to trip on expected arcing fault current on the MCC bus. It should be noted that the settings are suitable for application at 600V when derived for fuses as all published current-limiting data for fuses is typically at 600V.

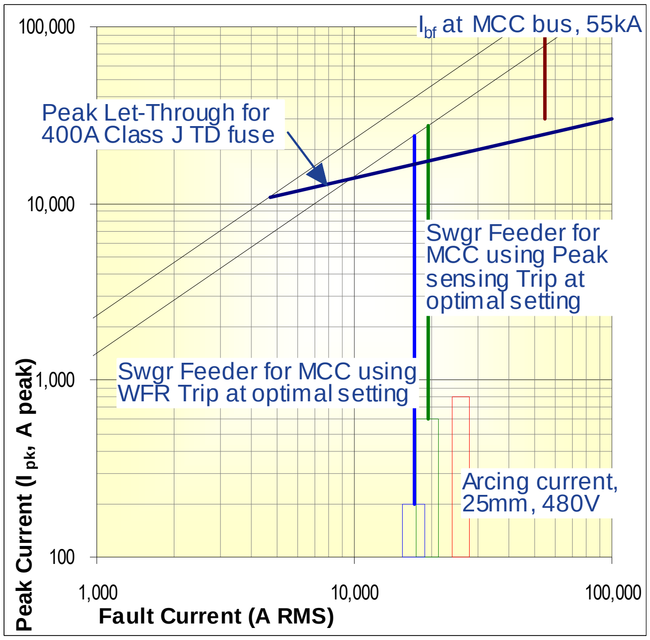


**Fig. 8** Peak and WFR settings above a 400A Class J Time Delay fuse with 55kA available, showing arcing current for 25mm gap at 55kA $I_{bf}$

*H. Motor contribution*

A comment on motor contribution currents: When analyzing a system for selectivity and arc-flash hazard it is important to properly account for motor contribution current. For selectivity analysis only the current that flows through the upstream feeder circuit breaker should be considered. For arc-flash hazard analysis on a bus all possible currents must be considered.

## VI. ADVANCED TRIP ALGORITHMS AND ZONE SELECTIVE INTERLOCKING (ZSI)

An advanced instantaneous trip algorithm may provide sufficient time for ZSI to function in the instantaneous range. This capability allows the benefits of a feeder's sensitive instantaneous pickup to extend to a tie and main circuit breaker. The combination of the capabilities can allow main circuit breakers to provide main bus protection at sensitive instantaneous pickup settings while providing selectivity up to high fault currents such as 100kA. Figure 9 shows a pair of circuit breakers such as a main and a feeder above a CL molded case circuit breaker (MCCB) that are set to be selective up to 65kA at the feeder, and 85kA at the main circuit breaker, while providing instantaneous protection at a nominal 10,400A at the feeder and 14,400A at the main circuit breaker. Arcing current for a 32mm gap at 480V is estimated at 24-20.5kA per IEEE 1584 recommended practice. The diagonal constant energy line in Fig. 9 demonstrates that both the feeder and the main are able to protect allowing less than 8cal/cm$^2$ for a broad available bolted fault range, while maintaining selectivity via the Instantaneous Zone Selective Interlocking scheme.

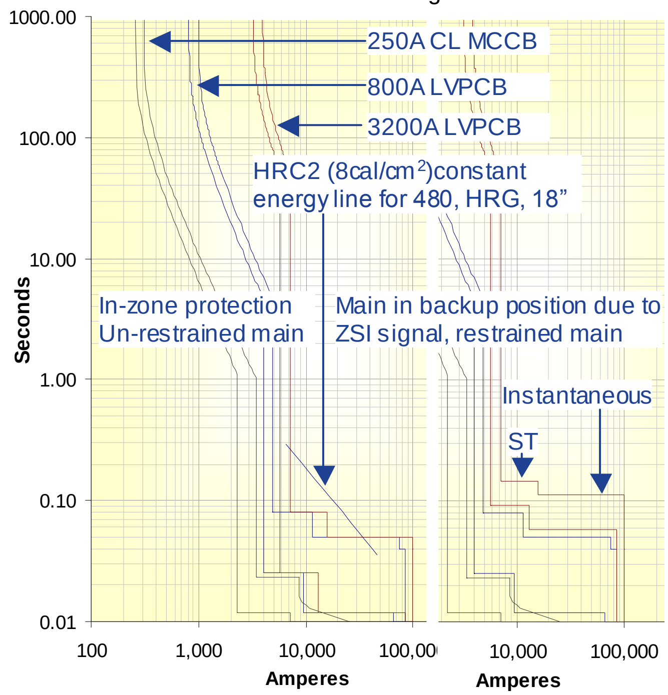


**Fig. 9** Three circuit breakers (250A MCCB, 800A LVPCB & 3200A LVPCB) set selectively up to 65kA & 85kA & with Instantaneous clearing for low in-zone fault currents. Rightmost TCC shows effect of ZSI shift on main CB

## VII. CONCLUSIONS & SUMMARY

The combination of current-limiting branch circuit protectors, fuses or circuit breakers, and line side circuit breakers with adjustable electronic trips may yield instantaneous trip pickup settings that provide both the required selectivity and desirable arc-flash hazard mitigation if the proper coordination analysis techniques are used. A significant protection improvement may be achieved using traditional electronic trips and even greater improvements may be possible using more modern advanced waveform recognition or energy sensing algorithms.

Either trip sensing technology requires that traditional time current curve analysis be supplanted with more sophisticated methods that recognize the downstream device's current-limiting characteristics and the upstream device's exact trip algorithm operating characteristics. Some of the analysis may be performed with published information and other may require cooperation with the upstream trip device's manufacturer to optimize settings.

Advances in Zone-Selective-Interlocking, in conjunction with the newer sophisticated instantaneous algorithms can extend the benefits of the sensitive instantaneous pickup to upper tier circuit breakers. Using both capabilities together increases the probability that large main circuit breakers will provide instantaneous protection for main buses and lower arc-flash hazard where implementation of circuit breakers without instantaneous trips due to selectivity requirements causes high arc-flash hazard to be expected.

Table 1 lists typical trip setting settings for two types of trips above various current-limiting over-current devices that may be found in a motor control center. One column identifies the settings that a trip with waveform capture capability would use for all prospective fault currents above the setting. The 2nd column identifies the setting that a peak sensing trip would need above the same devices to achieve selectivity up to 55kA. Exact settings would vary based on the exact manufacturer and model of the downstream device, and, possibly, the upstream device as well.

**Table 1**
**Typical "Minimum Instantaneous Thresholds" for upstream feeders above CL OCPDs (3)**

| CL OCPD Device Type | CL OCPD Device Size | WFR Trip Min. Setting @ Feeder Trip (1) (2) | Peak Sensing Min setting for 55kA Selectivity |
|---|---|---|---|
| MCP with current limiters | 3A | 310 A | 1,820 A |
| MCP with current limiters | 7A | 310 A | 1,820 A |
| MCP with current limiters | 15A | 840 A | 3,570 A |
| MCP with current limiters | 30A | 1,770 A | 5,800 A |
| MCP with current limiters | 50A | 3,800 A | 9,740 A |
| MCP with current limiters | 100A | 7,210 A | 14,770 A |
| MCP with current limiters | 150A | 10,750 A | 19,200 A |
| Molded Case MCP | 150AF | 9,600 A | 27,610 A |
| Molded Case MCP | 250AF | 11,200 A | 27,640 A |
| Lighting CL MCCB | 100AF | 6,540 A | 16,000 A |
| Molded Case MCB | 150AF | 9,600 A | 27,610 A |
| Molded Case MCB | 250AF | 9,900 A | 22,407 A |
| Molded Case MCB | 600AF | 20,350 A | 33,810 A |
| Class J, time delay | 30A | 970 A | 3,090 A |
| Class J, time delay | 100A | 3,810 A | 7,730 A |
| Class J, time delay | 200A | 7,590 A | 12,240 A |
| Class J, time delay | 400A | 15,050 A | 19,320 A |
| Class J, time delay | 600A | 26,730 A | 28,330 A |
| Class RK1, time delay | 30A | 1,030 A | 3,220 A |
| Class RK1, time delay | 100A | 4,300 A | 8,370 A |
| Class RK1, time delay | 200A | 9,450 A | 14,170 A |
| Class RK1, time delay | 400A | 18,970 A | 22,540 A |
| Class RK1, time delay | 600A | 32,380 A | 32,190 A |
| Class RK5, time delay | 30A | 2,900 A | 6,440 A |
| Class RK5, time delay | 100A | 8,820 A | 13,520 A |
| Class RK5, time delay | 200A | 15,050 A | 19,320 A |
| Class RK5, time delay | 400A | 34,340 A | 33,480 A |
| Class RK5, time delay | 600A | 57,120 A | 47,000 A |

**Notes: (1)** Selectivity will range up to the short circuit rating of the lowest rated device in pair, or the withstand of the line side device, whichever is lowest. **(2)** Minimum setting assumes 10% tolerance. Not all trips will be able to provide exact setting, next higher setting should be used. **(3)** Settings above circuit breakers applicable at 480V & below, settings above fused devices applicable at 600V & below.

## VIII. ACKNOWLEDGEMENT

The authors wish to thank Miss Cindy Cline from Ferraz Shawmut for her generous assistance with fuse application.

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## X. VITAE

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Industrial Applications Engineering chapter in San Jose, CA, and the Industrial Applications chapter in San Francisco, CA. He is a registered Professional Electrical Engineer in California. Mr. Valdes has authored and co-authored over a dozen papers for IEEE and other engineering forums, and has 10 patents in the field of power systems protection and circuit breaker trip systems. Currently Mr. Valdes is a member of several IEEE standard working groups, including the working group editing the revision of the IEEE Color Books into a new format, a new recommended practice for safe power distribution system design. He is currently vice chair of IEEE P1683, Standard for Safe Motor Control Centers and leader of the project to write the "Recommended Practice for Bus and Switchgear Protection" (P3004.11).