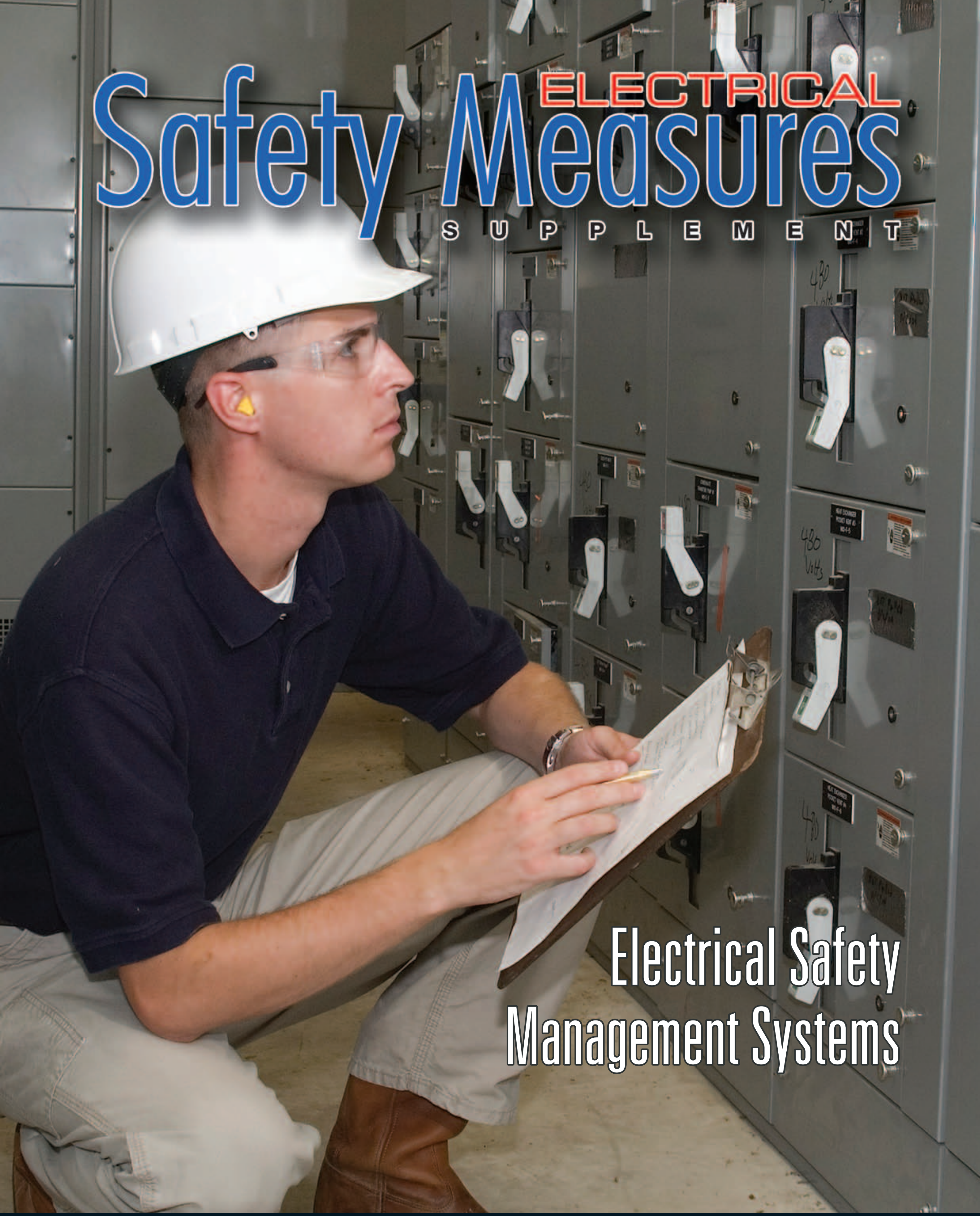
ELECTRICAL Safety Measures SUPPLEMENT



Electrical Safety Management Systems

Assessing The Hazards Of High and Low Voltage

Single-Phase Arc-Flash

By Albert Marroquin

One common question being asked is how to determine the hazard level associated with 1-Phase (1-P) Arc Flash (AF) incidents. There is very little information about this type of circuit in the available guidelines such as CSA Z462-08, NFPA 70E 2009 & IEEE 1584 2002. If the right risk level is not properly determined, we run the risk of over-protecting or under-protecting personnel that are working on this type of electrical system. The objective of this article is to present different methods for assessing the hazards of high and low voltage 1-P equipment, and to justify the results taking into consideration the behaviour of arc faults at different voltage levels.

1-P circuits are used mostly for low scale power distribution. Most of the 1-P circuits are located in residential and

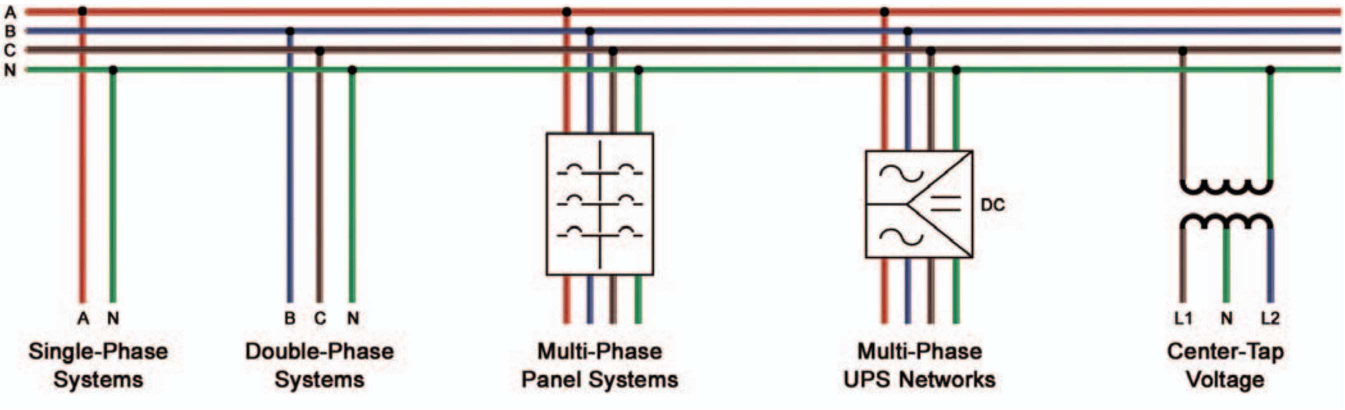


Figure 1. *Typical 1-P circuit connections*

small commercial zones, but they are also commonly found in industrial plants being used for lighting loads and other types of circuits such as service drops for temporary equipment around the facility (loadcentres). Personnel come in contact with these types of equipment on a daily basis.

Typical 1-Phase Circuits

The most common types of 1-P circuits can be classified as Line to Neutral (i.e. AN, BN, CN), Line to Line (AB, BC, CA) and centre tap (L1 & L2). Figure 1 shows typical 1-P circuit connections which can occur at different voltage levels. Examples of LV (< 1.0 kV) 1-P applications include centre tap 240/120 Volt pole mounted distribution connections (See Figure 2) and phase to phase or line to neutral circuits (i.e. 347 Volt lighting circuits). Examples of HV 1-P circuits include traction power distribution for railway transportation systems where 1-P voltages between the pole and center tap are as high as 55 kV (V1, V2) or 110 kV (V1+V2).

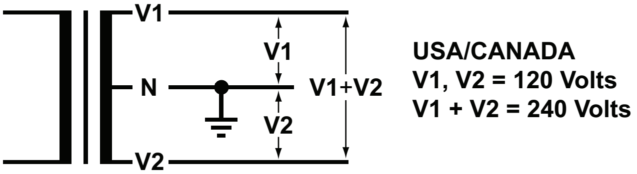


Figure 2. *1-P centre tap transformer*

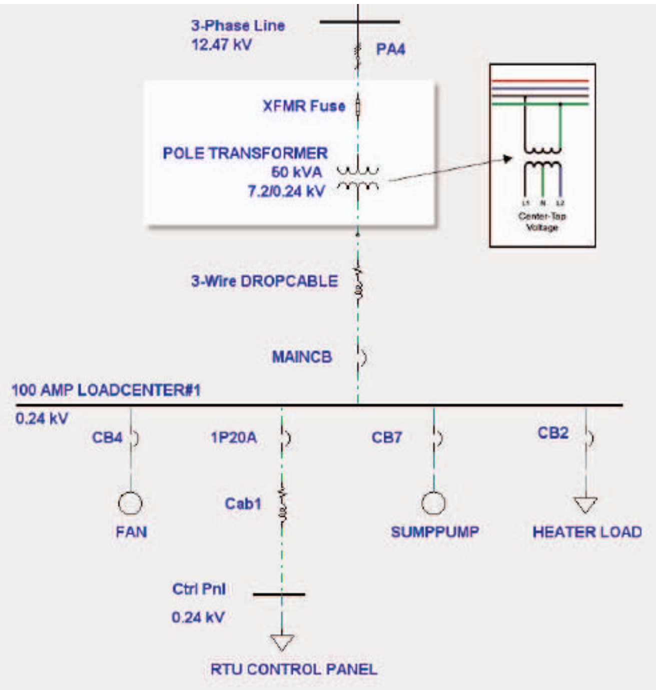


Figure 3. *One-line diagram for a 1-P 240/120 V circuit.*

Figure 3 shows a diagram for a pole mounted 1-P 50 kVA transformer service for a 240/120 Volt small loadcentre inside an industrial facility. The size of the transformers is typically 100 kVA or less (400 Amps at 240 Volts); however in some cases larger transformers need to be used.

An AF on this load center could easily occur between a Phase to Ground or between the L1 and L2 poles to constitute a 240 Volt fault.

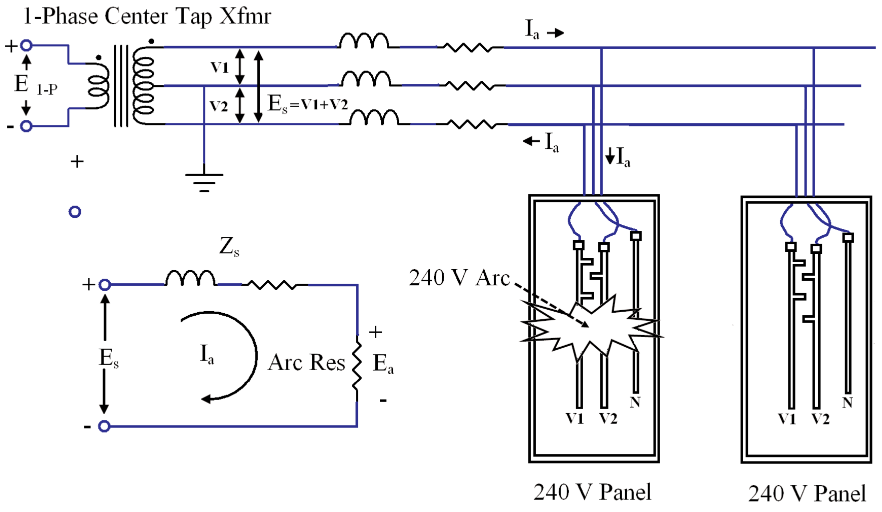


Figure 4. *AF across a LV 1-P transformer with centre tap connections.*

1-Phase Arc Flash Behaviour

Before we can pursue a solution to the problem of how to determine the energy released by 1-P circuits, we have to understand some fundamental behaviours of electrical arcs at different voltage levels.

The energy released by the arc is determined from the product of arc voltage drop E_a and the arc current I_a, (Lee, Ralph H. "The Other Electrical Hazard: Electric Arc Blast Burns" IEEE *Transactions on Industry Applications Vol. IA-18 No. 3*, 1982). Figure 4 illustrates the equivalent arc resistance which is introduced by the arc plasma. The effect of this fictitious arc resistance is to limit the arc current to a value smaller than the available bolted (metal to metal) fault current of the circuit. The heat delivered by the arc is generated by the rapid expansion of plasma composed of vapourized metal. The extreme temperatures in this metal vapour plasma increase the overall impedance of the circuit which in turn increases the magnitude of E_a. This is why in bolted faults there is very little heat generation since the bolted metal conductors offer very little resistance and thus the arc voltage drop is not present.

In high voltage 1-P and 3-P (>1.0 kV) circuits, the gap between conductors can be easily bridged. This behaviour tends to reduce the effect of the fictitious arc resistance and to yield higher arc currents which are smaller than the bolted current by only 5 to 10%. This is the reason why conservative approximations are made to set the arc current to be limited only by the system source impedance Z_s (>15.0 kV). The biggest concern with this behaviour is that for 1-P faults we must consider the additional impedance of the zero sequence components (high resistance ground paths) which further reduce the magnitude of I_a and inversely affect the fault clearing time (time needed for protective devices to open and extinguish the fault). This lower arc current magnitude behaviour is not necessarily present in a 3-P system since the arc may initiate between a Phase to Ground (neutral), but it will quickly escalate to a higher current 3-P Arc. For 1-P circuits, the path through grounded conductors with higher impedance may be the only route for the flow of I_a.

The behaviour of Line to Line 1-P circuits is not expected to be much different from that of 3-P arcs because we should not have higher resistance paths involved. Of course the appropriate magnitude of the Line to Line bolted fault currents must be estimated before determining the arc current.

Low voltage arcs have different behaviour. Depending on the kVA rating of the equipment, the LV arc may or may not have enough voltage difference between the source voltage E_s and the arc voltage drop E_a to power up the arc and bridge the gap between conductors. The arc voltage drop is about 75 to 100Volts/inch and the source voltage E_s is relatively small. For a 2 inch gap, we are already looking at 150 to 200 Volt arc voltage drop and this value would be very near the source voltage E_s.

Depending on the source voltage E_s and the available fault current, the LV arcs may or may not be self- sustaining. A typical threshold for self-sustaining arcs can be set at around 208 to 240 VAC and fault current of about 10 kA (at 240 Volts). For our 1-P system in Figure 4, you may expect an arc to be possibly generated on the 240 Volt circuit, but not on the 120 Volt circuit. Regardless, we can still estimate the heat and power which are present in the 120 Volt circuits using the bolted fault current I_{bf} and source voltage Es however it would not be really necessary since we do not expect any significant heat to be generated from this circuit.

How To Obtain 1-Phase Arc Flash Results

With the understanding of the behaviour of arc faults at different voltage levels, we can proceed to determine how to obtain analysis results for different types of 1-P equipment. The 3-P equations can be used to obtain conservative results on 1-P applications and are likely to yield conservative results (CSA Z462-08 Annex D.7.3 and IEEE 1584 2002 Section 5.1). Therefore, the equations of CSA Z462-08 Annex D.7.3 and D.7.4 (IEEE 1584 2002 Empirical equations) can be used as long as the voltage of the 1-P circuits is between 0.208 kV and 15 kV.

The equation of CSA Z462-08 Annex D.7.5 may be used for 1-P circuits (AB, BC, CA, and LL) with nominal voltage above 15kV. The results should be conservative. For possible AN, BN and CN circuits above 15 kV, but it is also possible to use CSA Z462-8 Tables D.6 and D.7 to obtain a less conservative (but maybe more accurate) estimate of the released arc energy. Please keep in mind that the voltages in these tables are given as the Phase to Phase circuit voltage and you will need to divide by √3 to find the values for the 1-P to Neutral or Ground faults.

For low voltage equipment, it is recommended that 1-P AF results be obtained from the equations given in

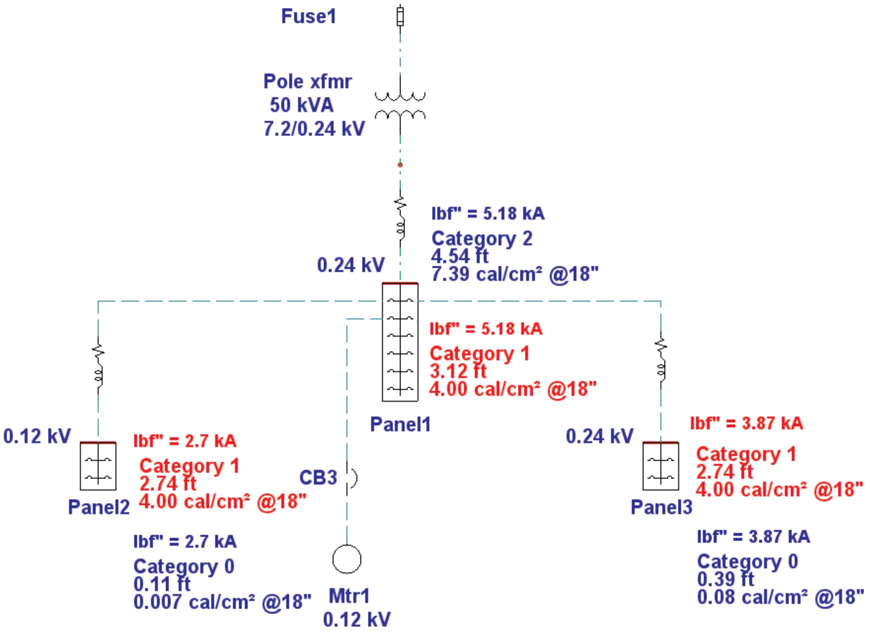


Figure 5. *AF calculated results (blue) vs. Category assumptions (red).*

CSA Z462-08 Annex D.7.3 and D.7.4 as long as the 1-P pole voltage is above 0.208 kV and the available bolted 1-P fault current is between 0.7 kA and 106 kA. These equations may yield over conservative results especially as the voltage levels go below 0.240 kV. Alternative to the empirical equations, we can use the equations of CSA Z462-08 Annex D.7.5 for 1-P circuits which fall outside of this range.

Exceptions For 1-Phase Circuit Arc Flash Analysis

CSA Z462-08 Section 4.3.3.1 contains an exception for not providing a detailed AF hazard analysis if the circuit voltage is less than 240 Volts AC and the circuit is supplied by a single transformer rated < 125 kVA. Taking credit for this exception limits the amount of 1-P circuits which need to be analyzed. However, taking credit for this exception does not imply that a Hazard/Risk Category does not need to be applied using the Table Method of arc flash hazard analysis. The requirements of CSA Z462-08 Section 4.3.7.3.9 Table 4 must still be met and the tasks require Hazard/Risk Category 0 or 1 PPE. Circuits fed from 1-P transformers rated < 125 kVA fall into this Hazard/Risk Category. If a Hazard/Risk Category 1 level is assigned to any circuit within this range, then we are making the assumption that the circuit's released energy is not higher than 4.0 cal/cm^2. The arc flash protection boundary (AFPB ft) can be determined based on this energy limit.

Figure 5 shows the difference in the energy and AFPB obtained from two simulations. The results in the blue colour were obtained from the equations of CSA Z462-08 Annex D.7.3and D.7.4. The results in the red colour were automatically assigned a Hazard/Risk Category 1 level. The calculation results determined the Hazard/Risk Category 2 results for the 240 V Panel 1. The AF results at Panel 1 depend exclusively on the total fault clearing time of Fuse 1 on the primary side of the pole transformer (7.2 kV Line to Neutral). The selected fuse is size 8A, but it would not be uncommon to see a size 12A fuse being used to protect this transformer (high overloads are sometimes used to maintain higher service continuity). If this were the case, the predicted energy obtained from the equations would be as high as 13 cal/cm^2 with a fault clearing time of almost 1.5 seconds. The conclusion from this example is that the equations can be safely used to determine 3-P and 1-P AF results and will yield conservative results. However, as long as the circuits fall within the guidelines of CSA Z462-08 Section 4.3.3, then it is safely assumed that Hazard/Risk Category 1 or 0 PPE requirements are good for these locations.

Conclusion

CSA Z462-08 and NFPA 70E 2009 do not provide specific 1-P circuit calculation methods, however, it can be generalized that the behaviour of 1-P faults is very similar to that of 3-P faults since the same fundamental physical principles of system impedance and voltage apply to both. It would be of great benefit to the public in general for the technical committees to extend the research of arcs to specifically common 1-P applications. This will remove some of the ambiguity in the available guideline so that individuals can assess the hazard of this type of circuit more easily. There are deficiencies in the available equations and they may not account for all the parameters involved in unbalanced arc faults; however, we still have to arrive at conservative conclusions based on the current methods.

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