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ArcCalc at Dominion Energy

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SUMMARY

Field personnel perform daily overhead energized work on bare conductors. Field workers trust their protective personal equipment (PPE) flame resistant clothing calorie ratings provide adequate protection in the event of an unanticipated arc flash. Protection Engineers calculate the maximum arc flash incident energies (cal/cm^2) available within a zone of protection. These calculations sometimes determine the need for additional protective devices or mitigation. Traditionally, arc flash calculations have been performed on single source, radial lines. The topology of the distribution infrastructure is changing due the advent of feeder automation, circuit tie automation, and distributed energy resources (DER). It is critical that protection engineers adapt their methods of calculating arc-flash incident energies to the evolving grid of the future.

Dominion Energy (headquartered in Richmond, VA) owns and operates about 1,600 feeders containing approximately 57,000 miles of distribution lines. Dominion Energy's electric distribution's grid is mainly composed of 34.5 kV system level voltages. It is not uncommon for line workers to 'glove' these voltages. Due to these high voltages, it of upmost importance we limit the available arc flash energy. At Dominion Energy, we strive to have arc flash incident energies less than, 4 cal/cm^2 and no greater than 8 cal/cm^2. This level of energy is achieved by controlling the speed of clearing a phase-ground fault for its' respective zone of protection.

This paper provides an introduction to methods and assumptions used for calculating arc flash incident energies for radial single source radial lines and lines with DER.

KEYWORDS

Arc Flash, DER, Distribution, Hot-Line Tag, Gloving

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Introduction:

An arc flash occurs when a fault current moves across a gap of air, releasing dangerous levels of energy mainly in the form of heat (cal/cm^2). Field personnel trust their protective personal flame retardant clothing's calorie ratings are greater than the available arc flash energy. It is the protection engineers' job to make sure the field personnel is protected. Ideally, the zone of protection should have intensity values no greater than 4 cal/cm^2, however, energies up to 8 cal/cm^2 are tolerated. There are several variables that affect the incident energy; most notably the arc gap spacing (defined by the National Electric Safety Code – 2012[1]), the available fault magnitude, and the fault duration to total clear. The fault duration is the one component that protection engineers have the most control. The fault duration, or clearing time, is the operating time plus the relay delay and breaker interruption time. When called to perform line work, the field personnel will go through a 'Hot Line Tag-Out' process. Part of this process involves enabling 'Hot Line' on the feeder relay when available. This 'Hot Tag' logic will enable a lower instantaneous (INST.) overcurrent pick up value, thus clipping the incident arc flash energy.

Dominion Energy's distribution grid is comprised of system level voltages from 4kV to 34.5 kV, with 34.5 kV as the dominate system level voltage. Dominion's standard line work practice is to work on only one phase at a time by covering up (insulating) the remaining two phases. By covering up the other two phases, we assume an incidental contact will only provide a phase-to-ground fault. This a common practice with other utilities for the purpose of arc-flash calculations. This eliminates calculating the arc flash incident energy for other types of faults (i.e. three-phase or phase-phase faults).

For radial lines with no downline generation, two fault current values define the boundaries of arc flash consideration. A feeder close-in bus fault defines the upper limit of fault current, whereas the zone of protections' reach point defines the lower limit of fault current. The instantaneous overcurrent pick up value defines the point of transition between instantaneous breaker operation and a timed breaker operation. It is important to note the fault current at the point of the fault can be different than the fault current through the zone's protective device CT. To be covered later, this is important to note when applied to lines with downline DER. The lower and upper fault current limits are defined by the source and impedance model. Distribution impedance models are represented by simple homogeneous impedances. The NESC is used to approximate the arc flash values by utilizing four points from table 410-2, the 25.1-36 kV system voltage, 4-calorie level: (5kA, 20.9cyc.), (10kA, 8.8cyc.), (15kA, 5.2cyc.), and (20kA, 3.5cyc). The ratio of the 4-cal/cm^2 system and the corresponding maximum clearing time (cycles) calculates a Cal/cm2/sec value at the corresponding fault current (kA) value. For example, 4 cal/cm^2 divided by 20.9 cycles (0.34 sec.) to obtain a value of 11.8 $cal/cm^2/sec$, associated with the 5kA fault current value. Using the four data points, a 2^{nd} order polynomial equation is calculated (Figure 1 shows these four data points). NESC states the four data points were derived using a commercially available computer software program. This equation is then used with fault current as the input (x) and $cal/cm^2/sec$ as the output (y).

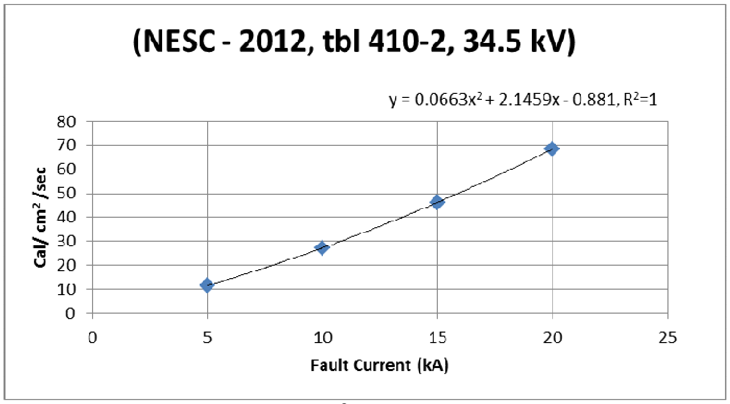

Figure 1: Cal/cm^2/sec per NESC 2012

Multiplying the protecting devices' fault duration (seconds) by the cal/cm^2/sec value (given its' respective fault current) derives an arc flash energy density (cal/cm^2). Figure 2 shows all the possible arc flash values for an overcurrent protective device using an U3 Very Inverse time curve[2], with a time dial of 1, and a pickup of 1000 Amps. In addition, Figure 2 shows the arc flash values of consideration provided an upper limit of 8 kA (fault at close-in bus) and the lower limit of 4 kA (fault at RP). A lower and upper limit, defined by the source and impedance model, is a practice approach to developing practical results. It is not unreasonable to include a positive percentage tolerance on the upper limit and negative percentage tolerance on the lower limit. In this case, without an instantaneous value, the maximum arc flash value in the area of consideration is approximately 5.2 cal/ cm^2. This method of calculating is acceptable with radial single source lines.

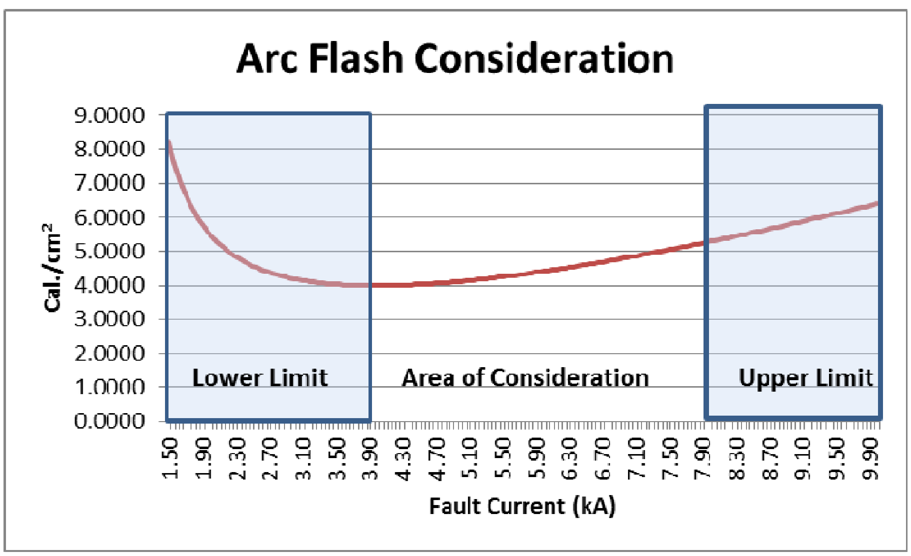

Figure 2:Arc flash values for a U3 curve with boundries

Within the zone of consideration, the maximum arc flash incidental energy for a feeder's zone of protection occurs at one of the three locations: the close-in bus, the reach point, or at the overcurrent ground relay instantaneous knee-point. As illustrated in Figure 3, the close-in bus is closest to power source and has the highest level of fault current. The reach point, despite its distance to the source, can sometimes obtain the highest arc flash energy due to the slower clearing times associated with lower currents. The overcurrent ground relay instantaneous

(INST.) point, as shown in Figure 3C, is associated with the highest time-delayed current and thus a candidate for extreme values.

A thorough study shown in Figure 3 demonstrates the relationship among fault current, clearing time, and arc flash energy. As the fault location moves towards the reach point, the fault current decreases. Once the fault current reduces to INST., the fault clearing goes on time delay, which significantly increases arc flash energy. As the fault current decreases further, it takes longer for the relay to clear. The change of arc flash becomes less straightforward and has to be calculated.

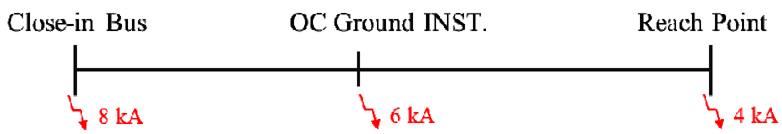

Figure 3A

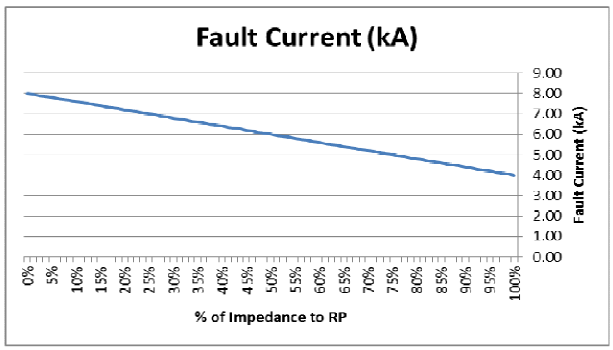

Figure 3B

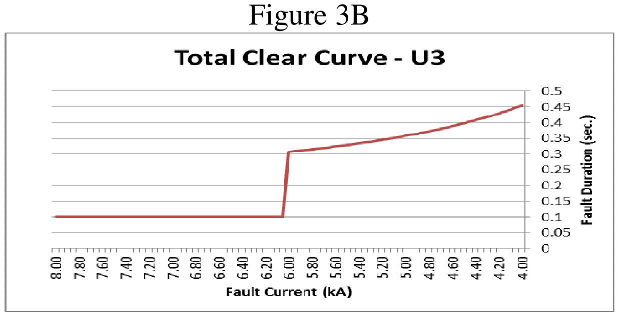

Figure 3C

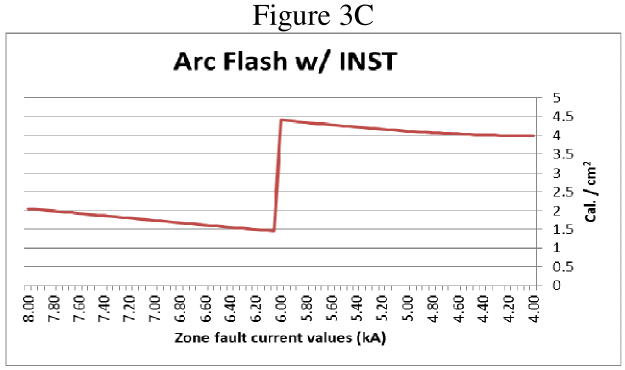

Figure 3D

Figure 3 Arc Flash Calculation from the Close-in Bus to the Reach Point

DER calculation method:

Distributed energy resources (DER) can contribute fault current, reduce the fault current measured by feeder relays, and thus slow down clearing. The increase in fault current and decrease in clearing time exacerbate the intensity of arc flash and result in more safety risks to field personnel. To illustrate the idea, a system is simulated shown in Figure 4 from an actual distributed solar plant rated at 6 MVA.

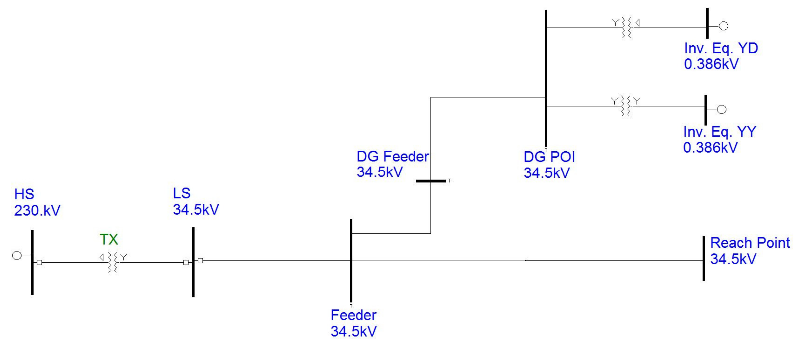

Figure 4 The Arc Flash Testing System with Solar Plants

The inverter/transformer is an equivalent. Two transformer connections, i.e. Yg-Delta and Yg-Y, are modelled for comparison purpose. Single phase ground fault is created continuously over the reach point line at 0.5% interval in order to identify the maximum arc flash energy. It is observed that the Yg-Y connected inverter does not contribute to ground fault due to the fact that the transformer does not provide zero sequence source and does not allow circulating ground current. Yg-Y connection needs to be considered for phase-phase and 3-phase arc flash calculations, if desired.

As for the Yg-Delta connected generator, by comparing Figures 5 and 6, it is observed that: 1) The DER increases total fault current; 2) The ground relay sees less fault current and has slower clearing time. Without DER, the ground relay clears immediately for close-in bus fault. In contrast, the ground relays clears with time delay with the presence of the DER; 3) The DER increase arc flash energy level. The maximum arc flash energy is increased from 7.53 cal/cm^2 to 8.45 cal/cm^2. Based on the preliminary study, it is concluded that DERs with Yg-Delta connected transformers contribute to ground fault current. The presence of DERs can reduce the fault contribution from the normal source and slows down protective relay clearing. The combined effect of higher total fault current at the fault location and slowed relay actions can lead to increased arc flash incidental energy. Therefore, extra precaution is necessary for arc flash field protection if DERs are present.

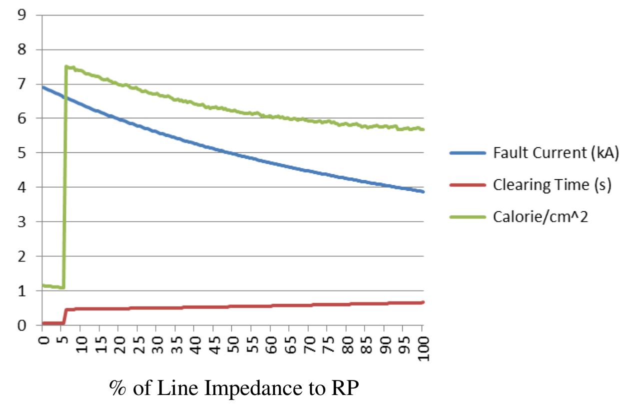

Figure 5 Arc Flash without DER

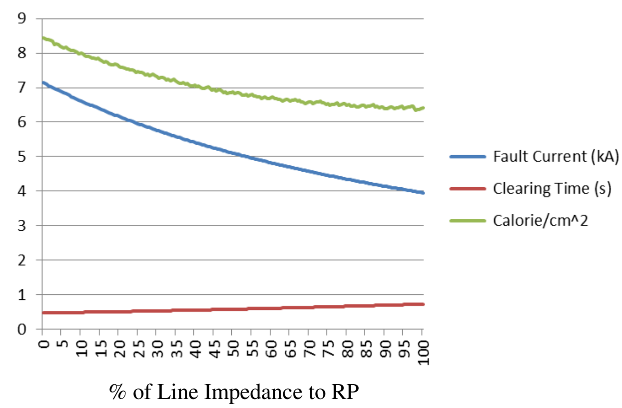

Figure 6 Arc Flash with DER

Conclusion:

Preliminary study indicates that Distributed Energy Resources can potentially increase arc flash incidental energy on distribution networks and field personnel may require additional fire resistant clothing to protect them from arc flash caused injuries. The System Protection Engineering group is actively looking for new arc flash calculation approaches to handle situations where distributed generators contribute to fault current and result in higher arc flash energy. The new approach requires more extensive simulation to ensure that the maximum arc flash energy is identified.

BIBLIOGRAPHY

[1] National Electric Safety Code. Section 410. 2012.
[2] IEEE C37.112–1996 *IEEE Standard Inverse-Time Characteristic Equations for Overcurrent Relays*