



# Arc Flash Hazard ... Reducing Exposure in LV Distribution Systems

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The Canadian Electricity Code 2012<sup>1</sup> recommends that electrical equipment such as switchboards, panelboards, industrial control panels, meter socket enclosures and motor control centres that are likely to require attention while energised shall be field marked to warn personnel of potential arc flash hazards. Appendix B of the same code refers to CSA Z462<sup>2</sup>, ANSI Z535.4<sup>3</sup> and IEEE 1584<sup>4</sup> as the documents to be used to determine severity, selection of Personnel Protective Equipment (PPE), labeling and calculating the arc flash protection boundary (AFB) and incident energy (IE) at a working distance.

A bolted fault is considered the most severe fault when designing distributions systems. Bolted fault, as the name implies, occurs when energized conductors are held together, “bolted”, during a fault. Fault current flows through the conductors and the effect is heat and force on the conductors and supports. This type of fault occurs very rarely in practice. An arcing fault may be started by a loose conductor across energized conductors but almost instantly this loose conductor melts or is thrown off and the current flows through air. This type of fault is common. The effect of an arcing fault is an arc flash and the hazards that accompany an arc flash such as intense light, rapid expansion of hot air, shrapnel, sound and pressure waves, molten metal and vapour at a temperature of 20,000 C. The energy of an arc flash is dependent on system voltage, and magnitude and duration of the arcing fault current. Short-circuit and protective device coordination studies consider bolted fault currents and not arcing fault currents. Arc flash hazard analysis uses the information from the previous two studies but considers arcing fault currents and tripping times based on the arcing fault currents.

CSA Z462 requires the employer establish a safe working condition. If he is unable to do so, he must do an Electrical Hazard Analysis. This analysis is comprised of two parts; Shock hazard and arc flash hazard analysis. An arc-flash hazard analysis will determine the arc flash boundary<sup>5</sup>, incident energy at the working distance and the PPE that personnel within the arc flash protection boundary shall use. One method to determine PPE requirements is to do

detailed calculations using Annex D of CSA Z462. Workers are required (clause 4.3.7.3.1) to wear appropriate PPE wherever they are within the arc flash boundary. The other method is to use table 4A or 4B in CSA Z462 to determine the Hazard Risk Category (HRC) based on the task performed, type and voltage rating of the equipment, maximum fault level and maximum fault clearing time. For instance, ‘Insertion or removal (racking) of CBs with the door open or closed’ in 600V Switchgear has a HRC 4<sup>6</sup>. This level is valid if the maximum short circuit current is 35kA and the maximum fault clearing time is 0.5 seconds (30 cycles). If these parameters are exceeded, then detailed calculations will have to be done.

IEEE 1584 provides formulas (and an Excel Worksheet) to calculate the incident energy at a working distance and the arc flash boundary for different types of equipment. It is evident from the formulas that the time taken to clear an arcing fault has a major impact on arc flash incident energy and arc flash boundary. For example, consider a 1500kVA, 13.8kV/600V transformer feeding a load through a secondary circuit breaker. The bolted fault is 30kA but the arcing fault is 20kA. A circuit breaker that clears the arcing fault in 0.13 seconds will let an incident energy of 6 cal/cm<sup>2</sup> impact the face and chest at a working distance of 609mm from the source of the arc. This requires a PPE rated 6 cal/cm<sup>2</sup> to adequately protect the worker. If the circuit breaker settings were based on bolted fault, the clearing time at the arcing fault current would be 1.25 seconds. This would result in incident energy of 57 cal/cm<sup>2</sup> at a distance of 609mm from the source of the arc flash. This is above the maximum 40 cal/cm<sup>2</sup> PPE and may not be survivable. It is very important to note that arcing fault currents are always lower than the bolted fault current. For example, CSA Z462 considers at 480V, the minimum level for sustaining arcing fault is 38% of bolted fault current. Data from other sources<sup>7</sup> shows for 600V, the minimum is 28% and for 480V, it is 21%.

Proponents of fuses indicate that fuses reduce the incident energy level in a system and that conversion from circuit breaker to fuses should be one of the important considerations to reduce the incident energy in a distribution system. Calculations show that when fuses are in the current limiting mode, they do reduce the incident energy in a distribution system better than circuit breakers, but most arcing faults

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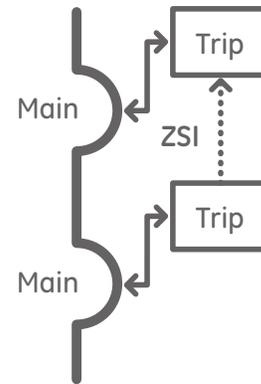
occur when fuses are in the non-current limiting mode where their operations are slower than circuit breakers. For example<sup>6</sup>, a 400A CB at 8.2kA bolted fault will have incident energy of 0.4 cal/cm<sup>2</sup>; whereas a 400A fuses will have an incident energy of 8.4 cal/cm<sup>2</sup>. Modern circuit breakers have better current limiting characteristics than their predecessors, a fact not accounted for in IEEE 1584.

Some distribution systems are required to have complete selectivity. This is invariably done by delaying the clearing/tripping time of upstream devices, which results in higher incident energy levels for faults on the load side of these same devices. Solutions are proposed later in this article to achieve selectivity and low arc flash incident energy at the same time.

Arc flash hazard analysis involves performing calculations based on formulas provided in IEEE 1584. The worksheet that accompanies the standard is good for small distribution systems. The worksheet requires the manual entry of protective device clearing times at the arcing fault current. Larger systems would require professional power system analysis software that integrates short circuit study; protective device coordination and arc flash hazard calculations to enable analysis to be done at various levels of arcing fault currents and protective device clearing times to arrive at an optimum solution for the complete distribution system. These software packages will print out reports and even print labels giving all relevant information pertaining to that specific equipment.

After completing an arc flash hazard analysis there may be a number of locations with very high incident energy levels and some even higher than 40 cal/cm<sup>2</sup>, the highest level identified by CSA Z462? Besides putting appropriate labels, providing proper PPE and training personnel, you need to review your distribution system to be able to reduce the arc flash hazards to safer levels. Here are a few solutions to consider.

- Dynamic Zone Selective Interlock – permits circuit breakers to trip in the shortest possible time (less than 92 msec) for faults in their zone but delay the tripping for faults outside their zone. This enables the down-stream device to clear the fault with no loss of selectivity. The system is said to be dynamic when the zones are automatically re-defined based on the status (on/off) of the various circuit breakers (main-tie-main) in the switchgear.



- Bus Differential protection – permits the circuit breakers that feed into a bus fault (bus zone) to trip in the shortest possible time (less than 92 msec) but not for a through fault. In combination with zone selective interlocking, this protection is reliable from 20% of the highest rating of circuit breaker (800A for a main circuit breaker rated 4000A) to the full short circuit level of the switchgear. Bus zones must be automatically re-defined based on the status (on/off) of the various circuit breakers in the switchgear.
- Remote HMI – permits the operator to be located outside the arc flash boundary of the equipment and still operate, examine, adjust, service and maintain the switchgear.





- Remote Racking Operator – permits the circuit breaker to be racked in and out from a distance of at least 10 meters (potentially well outside the arc flash boundary). CSA Z462 lists the highest HRC when racking the CB or the MCC bucket in or out with the door open.



- Insulated/Isolated bus – greatly reduces the possibility of an arcing fault within the switchgear.



- Reduced Energy Let-Through Mode – temporarily changes the short time settings to minimum and/or enables the instantaneous trip. This allows the circuit breaker to clear the fault much faster than its normal settings. It can be used when a person needs to approach the switchgear to attach the Remote Racking Operator or when a person is working downstream of this circuit breaker.
- High Resistance Grounding – limits the ground fault to 5A in LV distribution systems and permits the first phase to ground fault to exist while attempts are made to locate and isolate the faulted circuit. Priority tripping may be used to clear the less important circuit if a fault develops in another phase to ground. Pulsing ground systems can identify the feeder, the phase and even the location of the fault.

Selectivity versus reduced arc flash hazard was a compromise with available technology. Innovative technology<sup>9</sup> has made it possible to have selectivity and low arc flash hazards from low arcing fault currents to high bolted fault currents. GE's Entellisys<sup>®</sup> LV Switchgear employs this innovative technology to achieve selectivity and reduce arc flash hazards to the full short circuit rating of the switchgear and also achieve flexibility in design, control and maintenance.



GE's Entellisys® LV Switchgear is able to effectively use Dynamic Zone Selective Interlock and Bus Differential protection to reduce the incident energy of an arc flash. In addition, it uses insulated/isolated bus to reduce the possibility of an arc flash. Control and diagnostics can be done from a Remote HMI. This reduces the potential for injury to the operator. Reduced Energy Let-Through mode and Remote Racking reduce the impact of an arc flash on maintenance personnel. Other solutions listed above are also available in the Entellisys LV Switchgear.

In conclusion, in the past, distribution systems were designed based on the maximum possible fault current – three phase bolted fault. Equipment was selected to withstand and interrupt safely this high fault current. Protection settings were set to the maximum possible to provide selectivity and to be within the thermal and mechanical stress limits of the equipment. However, arc flash hazard analysis now tells us that the setting of protective devices on this basis could be detrimental to operational and maintenance personnel if an arcing fault occurs when the electrical equipment is worked on in the energized state. We must take into account the thermal limits of the human body (onset of second degree burns at 1.2 cal/cm<sup>2</sup>) when selecting protective devices and their settings. Arc flash hazards are an extremely important consideration when designing electrical distribution systems.

- <sup>1</sup> Rule 2-306 Shock and flash protection.
- <sup>2</sup> CSA Z462, Workplace Electrical Safety.
- <sup>3</sup> ANSI/NEMA Z535.4, Product Safety Signs and Labels.
- <sup>4</sup> IEEE 1584, Guide for Performing Arc-Flash Hazard Calculations.
- <sup>5</sup> Arc Flash Boundary (AFB) is the distance from a prospective arc source within which a person could receive second-degree burns. Onset of second-degree burns is caused when the energy level reaches 1.2cal/cm<sup>2</sup>.
- <sup>6</sup> For HRC 4, the minimum arc rating of the PPE should be 40 cal/cm<sup>2</sup>. This requires an arc-rated shirt and pants or coverall, and arc flash suit selected so that the system arc rating meets a minimum of 40 cal/cm<sup>2</sup>.
- <sup>7</sup> Practical Solution Guide to Arc Flash Hazards by Chet Davis et al.
- <sup>8</sup> Optimum Safety, Reliability and Electrical System Performance through Balanced Selective Coordination and Protection by Kevin Lippert & Charles Nochumson.
- <sup>9</sup> The Single-Processor Concept for Protection and Control of Circuit Breakers in Low Voltage Switchgear by Marcelo Valdes, Indrajit Purkayastha and Tom Papalo.



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