POWER PROJECTS

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# ARC-FLASH STUDY

**Steps to be followed (perform) for Arc-Flash Analysis**

By,

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# INTRODUCTION TO THIS ARTICLE:

- ✓ This article covers the Arc-Flash Study/Analysis process (configuration, calculation - Arc Flash Boundary, Incident Energy, and working distance) in accordance with **IEEE-1584**. This article does not include the introduction of Arc-Flash nor the recommendation of **PPE** (Personnel Protective Equipment) to prevent from an Arc-Flash event.

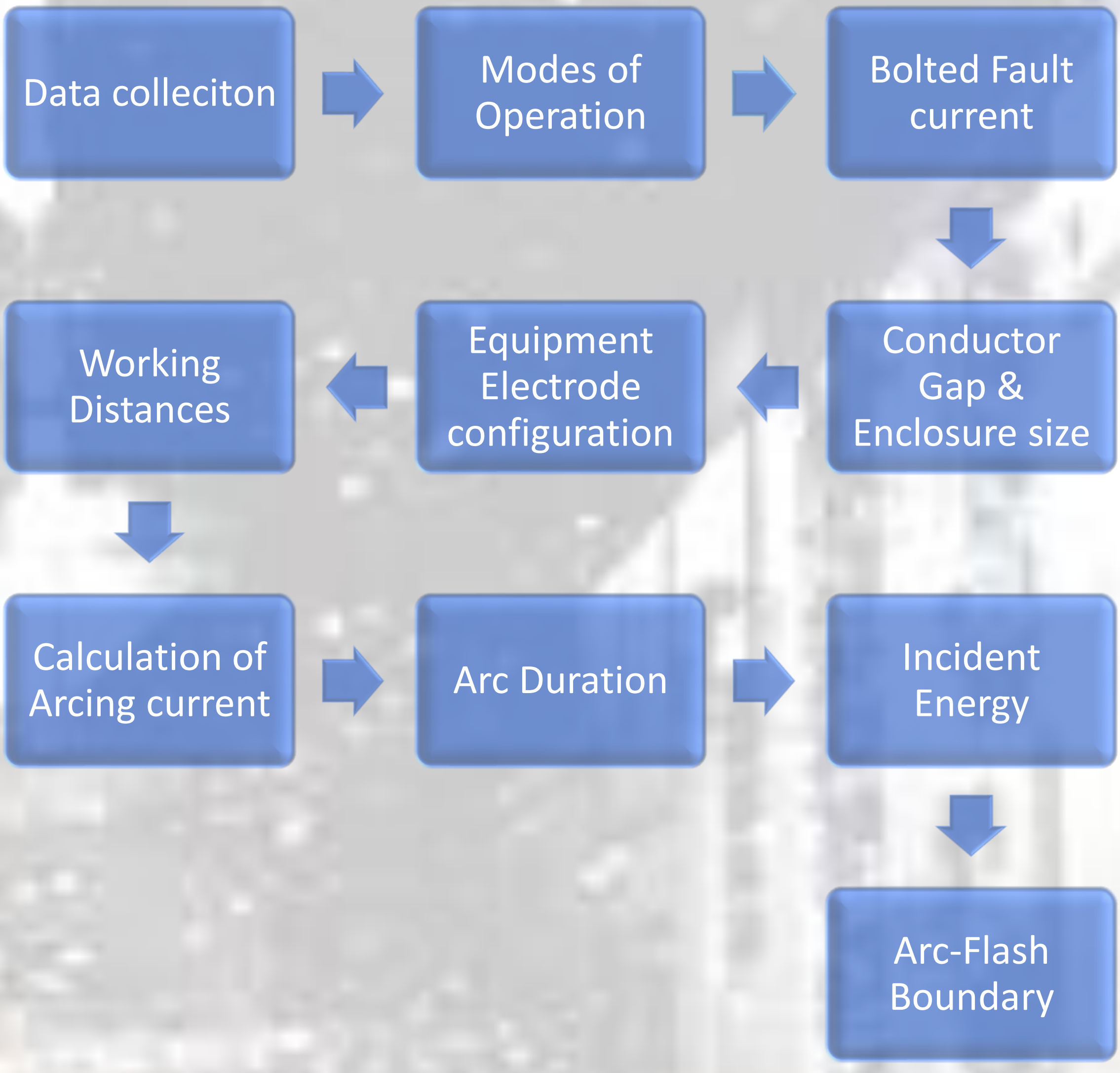
- ✓ The primary objective of the Arc-Flash study is to find Incident Energy for that we need **"i"** and **"t"**, where
  - **"i"** is the fault current determined from Short-Circuit study
  - **"t"** is fault clearing time determined from the Relay coordination study

So Short Circuit and Relay Coordination study is mandatory before doing an Arc-Flash study.

- ✓ Arc Flash study outcomes are
  - Arc Flash Boundary
  - Incident Energy
  - Working Distance

From this outcome, we can recommend what type and which level of **PPE** is required based on **NFPA-70E 2021** standard which will be covered in my next article.

## ANALYSIS PROCESS:



# 1 COLLECTING SYSTEM DATA:

A significant effort is required in performing an Arc-Flash study for the collection of electrical system data. Data collection is to perform Incident Energy calculations on electrical equipment that is likely to require examination, adjustment, servicing or maintenance while energized. This could include equipment such as LV/MV switchgear, Motor starters, MCC, switchboards, panel racks, circuit breakers, power distribution units (PDU), Uninterrupted power supplies (UPS), industrial control panels, meter socket enclosures etc. The following are the required inputs

- ✓ Up-to-date **SLD**
- ✓ For the power source collect available Fault current & X/R ratio. For **Generator, Transformer, switchgear and load** collect relevant nameplate data such as VA, voltage ranges, tap settings, ampacity, and Transient/Sub-transient reactance data, first cycle (momentary or close and latch) or interrupting current rating.
- ✓ For more detailed calculations **enclosure size and electrode configuration** are needed.
- ✓ Collect **conductor and cable data** for all electrical circuits between the power source and the distribution & control equipment for the calculation of impedances.
- ✓ Some of the generalized input required data are tabled below.

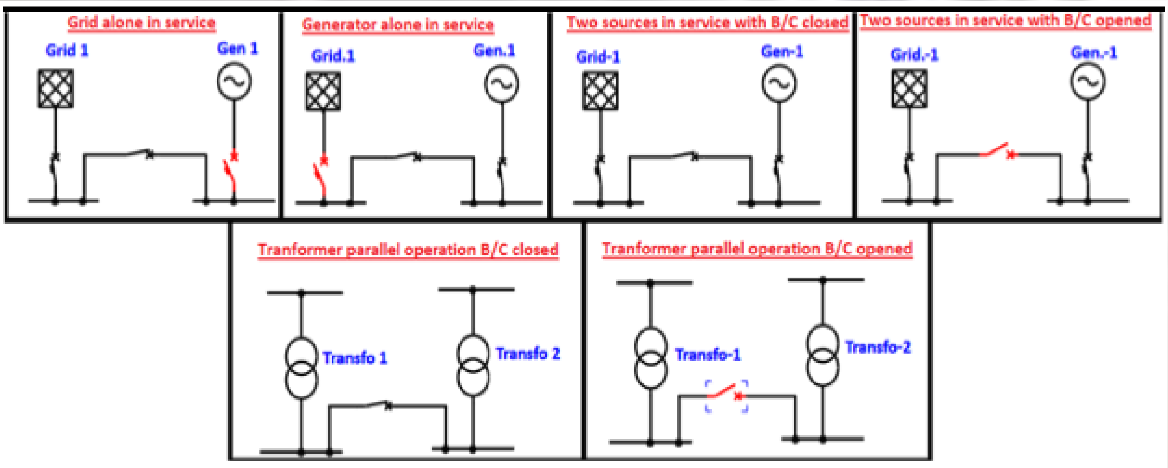
| SI.No. | Equipment | Input Requirements |
|---|---|---|
| 1. | Grid | Voltage, 3phase – $Imax_{SC}/Imin_{SC}$ & X/R |
| 2. | Bus | Fault current (kA), Type of Bus (MCC, Switch Gear etc,), Enclosure size and Electrode configuration |
| 3. | Cable/Conductor | Type of conductor, No. of Runs, Core, Sq.mm & Length |
| 4. | Generator/Motor | V, Rated VA, PF, Transient & Sub-Transient reactance, decrement curve and Grounding |
| 5. | Transformer | Voltages, Rated VA, X/R, Impedance, Vector group & Grounding |
| 6. | Load | V, P, Q or PF |
| 7. | Circuit Breaker | Rated Amps, Make & Model |
| 8. | Current-Transformer | CT ratio |
| 9. | Protective device | Relay/Release setting |

- ✓ Load all the input data in a simulation tool like ETAP or Digsilent power Factory and configure the possible modes of operation based on the number of power sources available which is continued in the next step.

## 2 DECIDING MODES OF OPERATION:

- ✓ After collecting all the input data from the customer then it is important to determine both the maximum and minimum available short circuit currents considering the modes of operation.

  The different modes of operation are,
  - One or more incomer (Utility) in service
  - Utility interface substation bus coupler circuit breaker open or closed
  - Unit substation with one or two primary feeders
  - Unit substation with two transformers with bus coupler opened or closed
  - MCC with one or two feeders, one or both energized
  - Generators running in parallel with the utility supply or on standby
  - Utility system normal switching configured for minimum and maximum possible fault MVA.
  - Shutdown or start-up situation with all motors in an off condition – reduced fault contribution.
- ✓ Some of the cases are shown below




- ✓ After determining all the modes of operation next move to the calculation step.

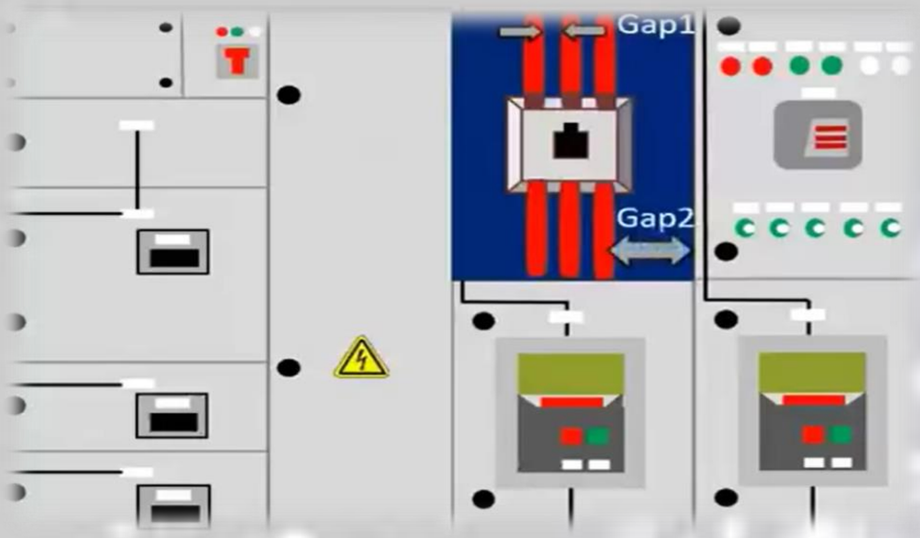
# 3 CALCULATING BOLTED FAULT CURRENTS:

- ✓ Bolted Fault current is a dead short circuit current where the fault has zero impedance.
- ✓ As Per **IEEE-1584**, the process and methodology of calculating short circuit currents and performing protective-device coordination are covered in standards such as **IEEE-551 (Violet Book), IEC-60909-0** and **IEEE-242(Buff Book)**. For example, during short circuit calculation, we can't predict voltage at the moment of the fault so **IEC-60909** introduces C-Factor (Voltage factor) and **IEEE-551** introduces Pre-Fault voltage both available in a tool like **ETAP**.
- ✓ A system containing multiple sources of short circuit current such as Generators, motors or more than one utility supply, can be more accurately modelled with a dynamic simulation method.
- ✓ Different types of Modes of operation have different fault current levels and should not conclude the worst case which is having the highest fault current level, because both larger and smaller available short circuit currents can result in higher available arc-flash energies and should be considered.
  - Higher fault currents may result in shorter trip times for overcurrent protective devices resulting in lower incident energy. If a higher fault current does not decrease in the opening time, then resulting in higher incident energy.
  - Lower fault currents may result in longer trip times for overcurrent protective devices resulting in higher incident energy.

# 4 DETERMINING THE GAP BETWEEN CONDUCTORS AND ENCLOSURE SIZE:

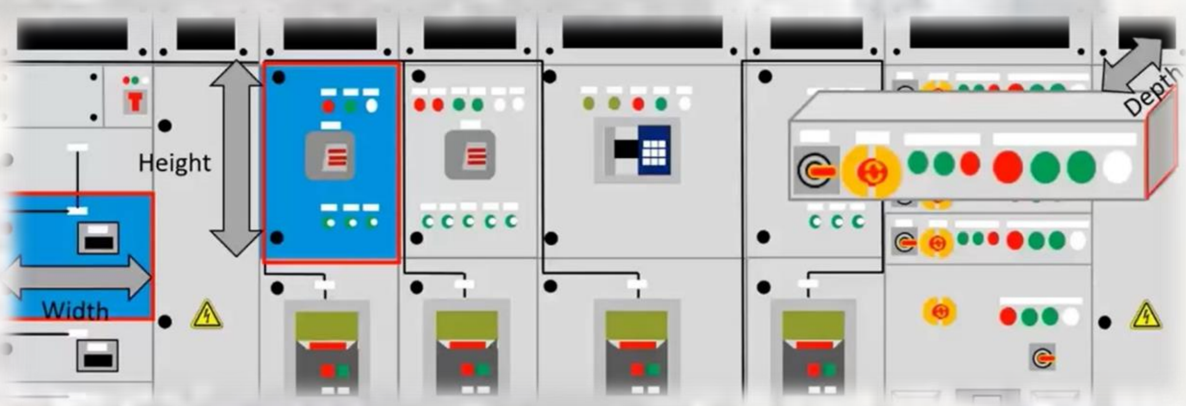
- ✓ The system voltage and the class of equipment can be used to establish typical gaps between conductors as per **IEEE 1584-2018**.

| Voltage | Bolted Fault Current (RMS symmetrical) | Gaps between conductors |
|---|---|---|
| 208 V to 600 V | 500 A to 106 kA | 6.35 to 76.2 mm |
| 601 V to 15 kV | 200 A to 65 kA | 19.05 to 254 mm |




✓ The enclosure sizes were used to derive the enclosure size incident energy correction factor.

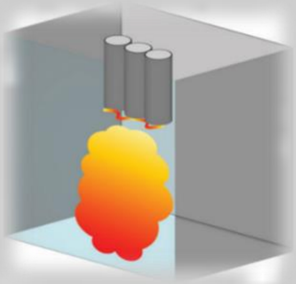
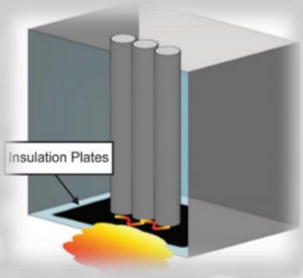
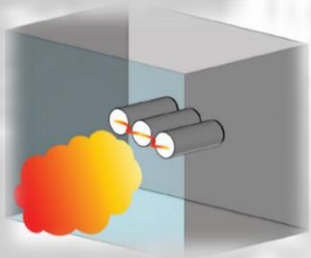
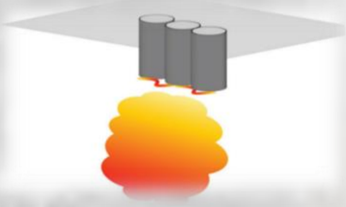
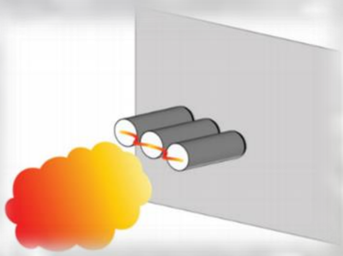
| Open-circuit voltage (V) | Enclosure dimensions (H × W × D) |
|---|---|
| 600 | 508 mm × 508 mm × 508 mm |
| 2700 | 660.4 mm × 660.4 mm × 660.4 mm |
| 14300 | 914.4 mm × 914.4 mm × 914.4 mm |



- ✓ Enclosure Dimension limits
  - Maximum height – 1244.6 mm
  - Maximum opening area – 1.54 $m^2$
  - Minimum width – Should be greater than 4 times the gap between conductors
- ✓ The depth is not considered unless the width and height are less than 508mm and the system voltage less than 600V. The depth is used to classify the enclosure type as "Typical or Shallow". The enclosure is shallow if the below points are true
  - Less than 600V
  - Both height and width are less than 508mm
  - Depth less than or equal to 203.2mm
- ✓ Enclosures with opening areas larger than 1244.6 mm X 1244.6 mm may be encountered in actual equipment.

## 5 DETERMINING EQUIPMENT ELECTRODE CONFIGURATION:

- ✓ The equipment conductor and enclosure arrangement that most closely resembles the actual electrode configurations need to be identified.
- ✓ Each type of equipment such as switchgear, panel boards and motor control centres may contain conductors arranged similarly.
- ✓ Locations within a piece of equipment may contain conductor arrangements similar to more than one electrode configuration such as a panel board may contain both VCB and VCBB electrode configurations. Other types of equipment such as switchgear, disconnect switches and switchboards may have other electrode configurations such as HCB depending on the bus and conductor arrangement.
- ✓ The types of electrode configurations are
  - VCB – Vertical conductors/electrodes inside a metal box/enclosure
  - VCCB – Vertical conductors/electrodes inside a metal box/enclosure with a Barrier
  - HCB – Horizontal conductors/electrodes inside a metal box/enclosure
  - VOA – Vertical conductors/electrodes in Open Air
  - HOA – Horizontal conductors/electrodes in Open Air

| | | |
|---|---|---|
| **VCB** |  |  |
| **VCBB** |  |  |
| **HCB** |  |  |
| **VOA** |  |  |
| **HOA** |  |  |

## 6 DETERMINING WORKING DISTANCES:

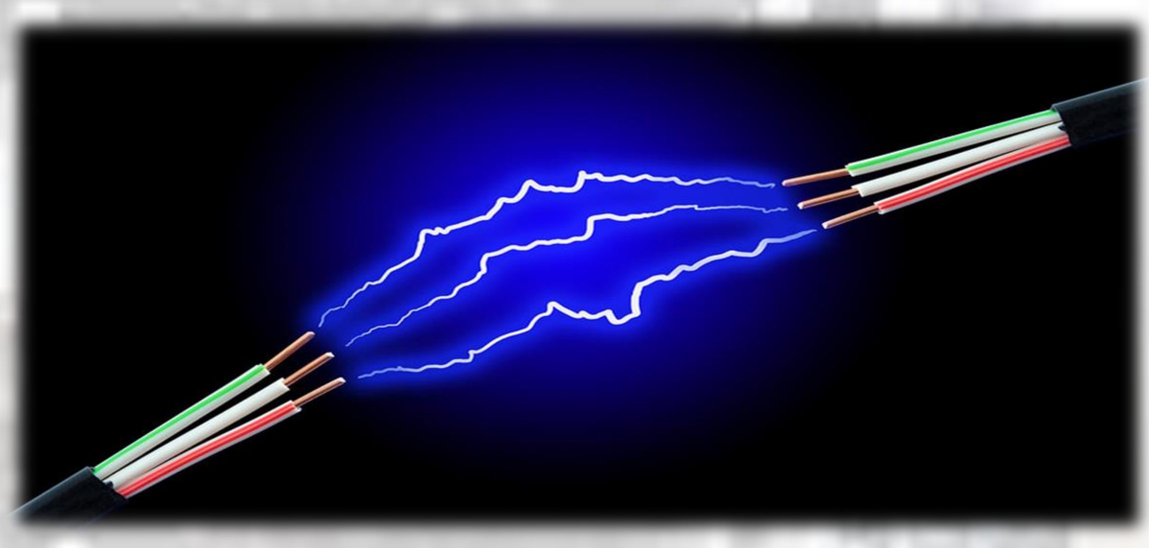
- ✓ Arc-Flash protection is based on the incident energy level on the Person's head and Torso at the working distance and not on the hands or arms.

- ✓ The minimum working distance should be greater than are equal to 305mm.

| Equipment class | Working distance | |
|---|---|---|
| | mm | mm |
| 15 kV switchgear | 914.4 | 36 |
| 15 kV MCC | 914.4 | 36 |
| 5 kV switchgear | 914.4 | 36 |
| 5 kV MCC | 914.4 | 36 |
| Low-voltage switchgear | 609.6 | 24 |
| Shallow low-voltage MCCs and panel boards | 457.2 | 18 |
| Deep low-voltage MCCs and panel boards | 457.2 | 18 |
| Cable junction box | 457.2 | 18 |

# 7 CALCULATING ARCING CURRENT:

- ✓ The arcing current depends on the Bolted fault current, as well as other factors such as the gap between conductors, electrode or conductor configuration and system voltage.
- ✓ SC current contributions through each circuit connected to the fault location need to be classified as coming from energizing or non-energizing sources or from temporary sources of current such as Motors.
- ✓ The calculated arcing current is lower than the bolted fault current due to Arc impedance.



# 8 CALCULATING ARC DURATION:

- ✓ The Arc duration is defined as the time taken by the energizing sources to stop providing arcing current or energy to the Arc fault.
- ✓ When multiple sources are present, the arc duration depends on the time taken by the last protective device to clear the arc current.
- ✓ Under special circumstances, the arc duration is not dependent on protective device opening/trip time, rather it depends on the time taken from the stored energy to be discharged through the arc.
- ✓ Potential delays of the protective devices should be considered. Examples: Protective relay operating time, total clearing time of circuit breakers or operating time of contractors, the delay introduced by intermediate devices such as a lockout or auxiliary relay, delays related to processing times or communication networks and other factors as appropriate.
- ✓ Locations where more than one type of protective device (time over current relay or differential relay) are placed to clear fault current, then the operating times must be compared to determine which will operate first.
- ✓ If the total protective device clearing time is longer than two seconds, consider how long a person is likely to remain in the location of the arc flash. A person exposed to an arc flash will likely move away quickly if it is physically possible, and **2 sec usually is a reasonable assumption for the arc duration to determine the incident energy**. A worker in a bucket truck, or inside an equipment enclosure, could need more time to move away.

**FUSES:**

- ✓ Information from the manufacturer's time-current curves should be used. These curves may include both melting and total clearing time. If both are available, the total clearing time that represents the worst-case duration should be used.
- ✓ If the curve only consists of the average melt time, 10% of the time plus an **additional 0.004s should be added** to determine the total clearing time.
- ✓ **If the fault clearing time at the arcing fault current is less than 0.01s, then 0.01s may be used for the time.**

**LV CIRCUIT BREAKER:**

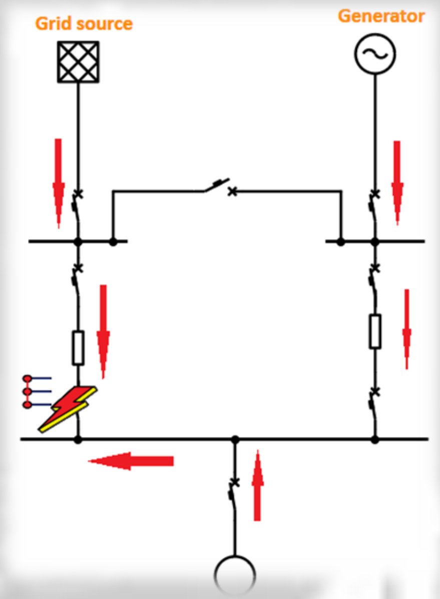
- ✓ For LVCB with integral trip units, the manufacturer's time-current curves include both the device tripping time and clearing time in most cases.
- ✓ If the curves show only the trip unit's operating time, then the CB operating time typically 0.05s or three cycles should be added.
- ✓ When the manufacturer's time-current curves are not available, a conservative method to determine the incident energy based on circuit breakers. This method is based on calculated incident energy levels for the VCB configuration only and may be used only if the arc current is in the instantaneous or magnetic trip range.
- ✓ For current-limiting CB, if the arcing current is greater than the current-limiting threshold then use the manufacturer's recommendation on the total clearing time and effective arc current.

**OVERCURRENT RELAYS AND CIRCUIT BREAKERS:**

- ✓ For protection schemes using overcurrent protective relays and circuit breakers, the relay time-current curves illustrate the relay operating time.
- ✓ The CB interrupting time is added to the relay operating time plus any additional time delays such as for lockout-relays, manufacturer's tolerance and other additional time delay considerations. **Interrupting time is the sum of the CB opening time and Arcing time**.

# 9 CALCULATING INCIDENT ENERGY:

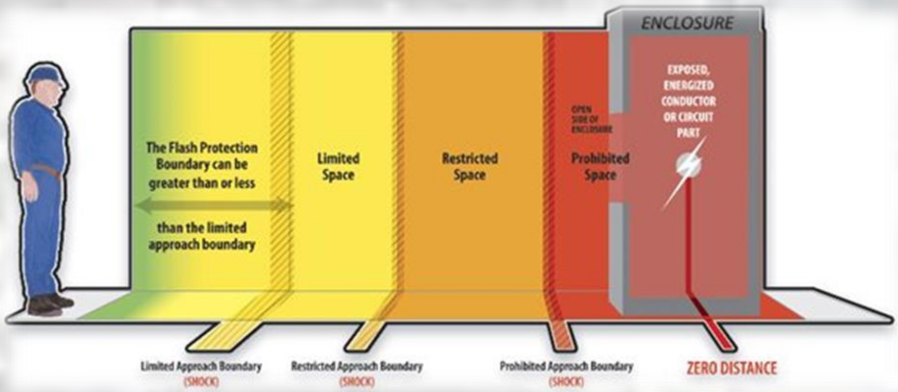
- ✓ It is important to note that **multiple arcing locations** can be found within a single piece of equipment and Incident Energy calculations should be performed at each of the arcing locations to determine the highest magnitude incident energy or worst-case conditions.
- ✓ When a model of the power system is developed, the equipment compartmentalization and fault location need to be considered.
- ✓ The arc fault could occur on the line side, bus side, and load side of protective devices located in different compartments.
- ✓ The incident Energy calculation should consider the change in total arcing current at the fault location caused by the operation of each protective device. The arcing current through each protective device may change based on the removal of other sources of arcing current.




- ✓ Calculate incident energy by using the minimum current data in utility and the appropriate arc duration based on the arcing current variation correction factor. Choose the higher of the two incident energy values.

## 10 ARC-FLASH BOUNDARY FOR ALL EQUIPMENT:

- ✓ To calculate the arc flash boundary for a given piece of equipment, location and equation are used. The arc flash boundary is the distance from a prospective arc flash where the incident energy is $5.0 J/cm^2$ ($1.2 cal/cm^2$).



- ✓ Based on the incident energy level, PPE has to be recommended which ensure the safety of the person, without PPE should stay away from the border, with a lower level of PPE can approach up to some distance and a person who wore a higher level of PPE can approach close to the switchgear. In detail about PPE recommendation will be continued in the next article.

# THANK YOU.