Facility: All

Best Practice Title: Calculation Spreadsheet for DC Arc Flash Hazard

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Brief Description of Best Practice: Provide a spreadsheet calculator with equations and method verified by DOE SMEs allowing for determining arc flash hazard Incident Energy and Arc Flash Boundary for the multiple methods directly and indirectly referenced in NFPA 70E.

Why the best practice was used: Approaches for calculating Arc Flash Hazard for DC systems are still in development and methods across the DOE complex vary. EFCOG Electrical Safety Task Group tasked a DC Systems Working Group to review some examples of approaches to determine best practices. A review of the example methods provided allowed the working group to develop and consolidate to a single referenced spreadsheet to submit to the complex as a reviewed set of methods for DC Arc Hazard analysis.

What are the benefits of the best practice: The provided spreadsheet has been reviewed by DC Electrical Safety Subject Matter Experts (SME) to determine that the approaches are valid for use across the DOE complex. The spreadsheet allows for the use of 3 approaches for calculating arc flash with user provided inputs. This allows greatest flexibility for the knowledgeable user to work with the method that best fits the circumstances of the situation. Additionally, new methods are introduced for industry specific applications that include new methods of estimating arc flash energy. These include high voltage capacitors and inductors, solenoid superconductors, and photovoltaic arrays.

What problems/issues were associated with the best practice: DC Arc Flash calculations methods were introduced to NFPA 70E in the 2012 edition. Only one method was introduced in the guide but references were made to other more complicated methods. Use of the spreadsheet requires some specialized knowledge of the field of DC arc flash calculation to best choose the option that best describes the situation. Instructions are provided for each sheet and a reference sheet is added to allow the user to determine the method that applies to the situation.

Because of the variety of approaches to estimate Incident Energy and Arc Flash Boundary, a choice of methods is given. 3 types of Incident Energy and 3 type of Arc Flash Boundary calculation are given as radio button choices for the user.

How the success of the Best Practice was measured: The 2014, 2015 and 2016 EFCOG Electrical Safety Working Group has reviewed a number of approaches to determine the format and use of the attached spreadsheet. A number of SMEs have used this spreadsheet against their own previous calculation and determined that it gives a reliable calculation. The 2017 EFCOG Electrical Safety Working Group included calculation methods for capacitor discharge and were based on typical equations for energy discharge. The results were compared to some work done by the attendees of the workshop. The 2019 EFCOG Electrical Safety Task Group included methods for inductors and superconductors. The 2020 EFCOG Electrical Safety Task Group added methods for photovoltaic arrays.

Description of process experience using the Best Practice: The spreadsheet contains 8 individual worksheets for the user.

The first 3 sheets are used for 3 calculation methods from user inputs. Each of the 3 methods allows for a selection of either Open Air, Closed Box (x3) or Closed Box (Wilkens method).

The first sheet allows the user to input System Voltage, System Short Circuit Current, Clearing Time and Working Distance to determine Incident Energy and Arc Flash Boundary using maximum available power as listed in NFPA 70E Informative Annex D.5 and Doan method. This method requires an estimate of maximum clearing time and is extremely conservative. It is also only applicable to linear systems such as constant resistance battery bank models. Gap effects are not considered.

The second sheet is an improvement on the first sheet Doan method by allowing the entry of a Gap into the method. This refines the worst case Maximum Power method to a more realistic estimate of arcing current. The method is referenced but not described in NFPA 70E Informational Annex D.5. The reference is the Ammerman, et.al, application of the Stokes and Oppenlander equations for DC arc current commonly referred to as the Ammerman equations.

The third and fourth sheets are approaches to estimate arc flash from a capacitor discharge. The energy used is based on the total energy of the capacitor and includes an estimate of standoff distances for ear drum rupture and lung damage as well as the arc flash boundary based on the concussive force of a capacitor discharge. The fourth sheet is for data entry and output and the fifth sheet is a graphic representation of the capacitor PPE requirements.

The fifth sheet is an approach to estimate arc flash from an inductor discharge. The energy used is based on the total energy of the inductor and includes an estimate of standoff distances for ear drum rupture and lung damage as well as the arc flash boundary based on the concussive force of a capacitor discharge.

The sixth sheet is also an approach to estimate arc flash from inductive discharge. This sheet uses long solenoid equations from electromagnetism to eliminate number of turns and amps from the calculation. This allows for estimation of inductive discharge for many superconductor applications such as coils for MRI and NMR applications which typically only provide magnetic field strength in their specifications. Also needed are an approximation of the solenoid winding dimensions to solve the energy available equation.

Caution is advised that the cavity diameter is normally significantly smaller than the coil diameter and is not a conservative estimate of the energy in the superconducting field.

The seventh sheet Allows for the input of a custom value for arcing voltage and arcing current as well as an input for Photovoltaic Cell Temperature compensation on available energy. Additionally a method of estimating arc length and the use of the Ammerman method modified for photovoltaic arrays is applied. This allows the computation for non-linear systems such as PV arrays which would otherwise be underestimated for available energy without the larger estimates that were inherent with the previous Enrique method. The output voltage is limited to the maximum power voltage of the arrays since this would be a limiting factor for arcing energy.

The last sheet is a list of references for methods.

The user determines the correct sheet as follows:

If the gap for the possible fault is uncertain or varied, or the gap effects are not important to the answer, and the system is modeled as a resistive system, such as for the Battery Compartment of a UPS, the first sheet is applicable.

If the system is linear and the gap is well established and important to the solution, such as the bus work in a UPS Cabinet, then the second sheet is applicable.

If the system is a specialty system such as a capacitor bank, high energy inductor, a solenoid superconductor or a photovoltaic array, then the appropriate third through seventh sheets are applicable.