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Understanding Arc Flash Hazards

White Paper

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ABSTRACT

The purpose of this paper is to clarify the use of the recently published IEEE 1584, "Guide for Performing Arc-Flash Hazard Calculations." [1] The paper also discusses the reduction of arc flash hazards by the current limitation of molded case circuit breakers. Understanding arc flash hazards is a critical element in order to reduce the risk of electrical accidents and personal injuries. The Guide contains formulas to numerically quantify the arc flash energy and includes an Excel Spreadsheet "Arc-Flash Hazard Calculator." This Spreadsheet uses the formulas stated in the Guide to automatically perform the calculations to obtain incident energy, and arc flash hazard distances. The present paper provides an expanded explanation of the Guide/Calculator with the objective of simplification. The paper also approaches possible methods for including the impact of molded case circuit breaker current limitation into the calculation methods. The subject of breaker clearing times in the presence of arcing faults will also be addressed. The paper concludes with a discussion of circuit breaker applications for arc flash reduction.

I. INTRODUCTION

There have been several recent codes and standards regulations that relate to the fundamental dangers of arc flash energy. The following provides a brief overview.

The NFPA 70E, Standard for Electrical Safety Requirements for Employee Workplaces[2] presents numerous requirements for a wide range of topics such as electrical equipment, Personal Protective Equipment (PPE), Lockout/Tagout practices and safety training. Where it has been determined that work will be performed within the flash protection boundary, NFPA 70E requires an analysis to determine and document the flash hazard incident energy exposure of a worker. This document also contains some of the initial methods developed in order to quantify the incident energy.

The Occupational Safety and Health Administration (OSHA) is the governmental enforcement agency whose mission is to save lives, prevent injuries and protect the health of America's workers. They refer to their standard Code of Federal Regulations, CFR 1910.333,[3] Selection and Use of Work Practices, which states "Safety-related work practices shall be employed to prevent electric shock or other injuries resulting from either direct or indirect electrical contacts, when work is performed near or on equipment or circuits which are or may be energized." This general statement provides the basis for OSHA's citing and insisting upon compliance with the Arc Flash requirements contained in NFPA 70E. The 2002 edition of the National Electrical Code (NEC), NFPA 70,[4] contained the first arc flash hazard references by adding the following new requirement as Article 110.16.

Flash Protection. Switchboards, panelboards, industrial control panels, and motor control centers that are in other than dwelling occupancies and are likely to require examination, adjustment, servicing, or maintenance while energized, shall be field marked to warn qualified persons of potential electric arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

FPN No. 1: NFPA 70E-2000, Electrical Safety Requirements for Employee Workplaces, provides assistance in determining severity of potential exposure, planning safe work practices, and selecting personal protective equipment.

FPN No. 2: ANSI Z535.4-1998, Product Safety Signs and Labels,[5] provides guidelines for the design of safety signs and labels for application to products.

There were numerous proposals for the 2005 NEC that would expand this requirement to "indicate the incident energy in calories per square centimeter for a worker at a distance of 18 in." Adoption of this requirement would indicate the need for a standardized method for determining incident energy. The IEEE 1584-2002, "Guide for Performing Arc Flash Calculations," provides a method for the calculation of incident energy and arc flash protection boundaries. It presents formulas for numerically quantifying these values. The IEEE 1584 Guide also includes an Excel Spreadsheet "Arc-Flash Hazard Calculator" which performs the actual calculations using the formulas stated in the Guide.

II. IEEE 1584 STANDARD

A. Arc Flash Calculations

Normal system analysis determines the bolted fault current available at various points throughout the electrical system. For incident energy, it is first necessary to input the circuit parameters in order to calculate free-air short-circuit arcing currents. Here it is noted that these arcing currents are significantly less than the available bolted-fault short circuit currents because the arc provides significant circuit impedance. The IEEE 1584 equations for determining arcing currents (for system voltages less than 1000V) are:

$$\log I_a = K + 0.662 \log I_{bf} + 0.0966 V + 0.000526 G + 0.5588 V (\log I_{bf}) - 0.00304 G (\log I_{bf})$$

Where:

log	is the log ₁₀
I _a	is arcing current (kA)
K	is - 0.153 for open configurations and - 0.097 for box configurations
I _{bf}	is bolted fault current for three-phase faults (symmetrical RMS)(kA)
V	is system voltage (kV)
G	is the gap between conductors, (mm)

and convert from $\log I_a = 10^{\log I_a}$

The arcing current is then used for determining the incident energy. The IEEE 1584 equations for determining incident energy are to first determine the log 10 of the incident energy normalized:

$$\log E_n = K_1 + K_2 + 1.081 \log I_a + 0.0011 G$$

K ₁	is -0.792 for open configurations, -0.555 for enclosed
K ₂	is 0 for ungrounded & high resist.; -0.113 for grounded
I _a	is arcing current (kA)
G	is distance between arcing buses (mm), 25 mm for MCC

Then

$$E_n = 10^{\log E_n}$$

Finally, convert from normalized:

$$E = C_f \cdot E_n (t/0.2)^{(610^x/D^x)}$$

E	E is incident energy in cal/cm ²
C _f	is calculation factor, 1.0 > 1kV; 1.5 <= 1kV
E _n	is incident energy <u>normalized for time & distance</u>
t	is arcing time (seconds)
D	is distance from arc to person (mm); typical to use 455 mm (18") for MCC
x	is distance exponent from IEEE table (based upon equipment type-conductor gap); 1.641 for MCC

The apparent complexity of these equations makes solving them by hand cumbersome, but the IEEE 1584 Guide supplies an Excel Spreadsheet that will automatically solve them, using input of basic information. While the IEEE 1584 Guide provides another step forward in the understanding of arc flash hazards, there are several points that are frequently misunderstood. The following explanations are intended to help clarify this information. (References to specific "cells" apply to the Excel Spreadsheet calculator.)

B. Issues to Consider When Performing IEEE 1584 Arc Flash Calculations

- 1) At what "point(s)" in the system should arc flash hazard calculations be performed?

There could be multiple calculations performed depending on the particular task being undertaken. At a minimum, (either a or b) plus c below should be performed.

- a) A value shall be calculated either at the incoming point to the enclosure,
or,
- b) if the cables terminate immediately into the main device, and are not readily accessible, at the load terminals of an incoming overcurrent protective device, OCPD (if one exists).
And,
- c) At the load side of OCPDs that are sensibly partitioned/separated from their line side. (For example; when working inside the bucket of an MCC.)

2) Is the Overcurrent Protective Device a fuse?

For certain specific low-voltage fuses, and within a specific tested range of bolted fault currents, it is possible to input the fuse-type, and the calculation then automatically takes into account both the current-limiting effect of the fuse and the actual time of interruption. Thus both of the important parameters for arc flash, the arc current magnitude and the arc current duration, are taken into account. This is the most accurate method for these certain types of low-voltage fuses. Cells G-24, H-24, J-24 & K-24 should be empty because input of the fuse's time/current curve information (total clearing times) is NOT required for this method. Cell O-24 requests input of a number 1 through 8, that IEEE 1584 identifies as the "Protective Device Type" as follows:

- | | |
|---|------------------------|
| 1 | Class RK 1 fuse – 100A |
| 2 | Class RK 1 fuse – 200A |
| 3 | Class RK 1 fuse – 400A |
| 4 | Class RK 1 fuse – 600A |
| 5 | Class L fuse – 800A |
| 6 | Class L fuse – 1200A |
| 7 | Class L fuse – 1600A |
| 8 | Class L fuse – 2000A |

If, upon entry of the above information, Cell O-24 turns orange in color, the bolted fault current is outside the model's tested range for that fuse. For these cases the secondary fuse calculation method (for fuses other than specified above) must be used.

3) What if the fuse is not one of the specific ones stated?

If the fuse is not one of those specifically stated, or when outside the model's tested bolted fault current range, input of the fuse's time/current curve information (total clearing times = melting time + arcing time) is required. If the manufacturer shows only the average melt time, add to that time 15%, up to 0.03 seconds and 10% above 0.03 seconds to determine total clearing time. This secondary method is utilized by entering 0 (zero) in Cell O-24. In Cell G-24 enter the fuse's time/current curve information based upon the level of arcing fault current shown in Cell F-24. Cells H-24 and K-24 should be empty. Another input is also required for low-voltage fuses that use this method. In Cell J-24 enter the fuse's time/current curve information (total clearing time) based upon the level of "reduced" arcing fault current shown in Cell I-24.

4) Is the OCPD a circuit breaker?

For circuit breakers, the most accurate calculation method included in the IEEE 1584 Guide, is to use specific manufacturer's time/current information (total clearing times). This method is utilized by entering 0 (zero) in Cell O-24. In Cell G-24 enter the circuit breaker's time/current curve information (total clearing time) based upon the level of arcing fault current shown in Cell F-24. Cells H-24 and K-24 should be empty. Another input is also required for low-voltage circuit breakers that use this method. In Cell J-24 enter the circuit breaker's time/current curve information (total clearing time) based upon the level of "reduced" arcing fault current shown in Cell I-24.

Note: This approach causes concern because commonly published time/current curves in the instantaneous region have not been a focus of circuit breaker manufacturers, and are very conservative.

5) When entering specific OCPD times (for both low-voltage fuses and low-voltage circuit breakers) why do you enter 2 different values; one based upon the arcing current and a second based upon a "reduced" arcing current?

Due to variations in low-voltage arc currents (under 1 kV), a second calculation is performed based upon a "reduced" arcing fault current that is 85% of the originally calculated arcing current. For cases where the arc current falls on the steep part of the time-current curve or falls near a step change, a small variation in arc current could cause a significant change in OCPD tripping or operating time. The highest resulting energy (either based upon arcing current and arcing operating time, or reduced arcing current and reduced current operating time) is then automatically used for the final.

6) What if the circuit breaker time/current information (opening times) is not available?

A secondary method is available for certain low-voltage circuit breakers within specific continuous current ranges and within specific ranges of bolted fault currents. Cells G-24, H-24, J-24 & K-24 should be empty because input of the circuit breaker's time/current curve information (total clearing time) is NOT required for this method. The appropriate Protective Device Type (number 9-14) is then entered in Cell O-24 as follows:

- 9 Molded Case Circuit Breaker, 100-400A
- 10 Molded Case Circuit Breaker, 600-1200A, Thermo-magnetic trip
- 11 Molded Case Circuit Breaker, 600-1200A, Electronic trip w/Long Delay
- 12 Molded Case or Insulated Case Circuit Breaker, 1600-600A
- 13 Low-Voltage Power Circuit Breaker, 800-6300A, w/Instantaneous trip
- 14 Low-Voltage Power Circuit Breaker, 800-6300A, w/o Instantaneous (Short Delay only)

Another input is also required for this method. In Cell P-24 enter the current at which the circuit breaker will instantaneously trip. When the instantaneous tripping current is not known, use a default value of 10 times the continuous current rating of the CB, except for CBs rated 100 A and below, use a default value of 1300A. For a low-voltage power circuit breaker without instantaneous tripping, enter the short-time pick-up current in Cell P-24.

If, upon entry of the above information, Cell O-24 turns orange in color, the bolted fault current is outside the range of the model for that particular low-voltage circuit breaker. For these cases this secondary calculation method can not be used.

Note: Although this secondary circuit breaker method only requires knowledge of bolted fault current, the calculation is based upon circuit breaker interruption times for generic breaker-ratings. These are typically worst-case; maximum-duration interruption times based upon the published time-current curves of many manufacturers. This method is conservative and calculates high values of arc energy that may mandate more protection than is necessary. Therefore this is a secondary method, used for instances when specific time/current curve information is not available!

- 7) Do any of these calculations account for the current limiting characteristics of circuit breakers?

No! Regardless of the selected calculation method for circuit breakers, the present IEEE 1584 calculations do not take into account the current-limiting characteristics of circuit breakers.

III. OVERCURRENT PROTECTIVE DEVICE CURRENT LIMITATION

It is difficult to create models to accurately predict incident energy created by an arc flash in a system using OCPDs. This is due to the fact that there are 2 active systems occurring simultaneously. When an arc occurs on downstream busbars, there is a current magnitude reduction due to the added impedance of the arc at the busbars. The upstream OCPD then begins to open. This breaking of the current flow creates another arc inside the OCPD, and is in series with the busbar arc. Thus, there are 2 arcing systems acting simultaneously to reduce the current magnitude.

A. Current-Limiting Circuit Breakers

There are two major components to consider when attempting to account for the current limiting affects of circuit breakers. One is the arc current duration, which is controlled by the actual time of interruption. As previously stated, commonly published circuit breaker time/current curves in the instantaneous region have not been a focus of circuit breaker manufacturers, and are very conservative. For the purpose of calculating arc flash energy, using those instantaneous region conservative operating times will produce unrealistically high arc flash energy values. Actual operating times will enable more accurate calculations of arc flash energy.

The other major component to consider is the reduction of the arc current magnitude due to the breaker's dynamic impedance.

B. Initial Modeling Approach

An initial attempt has been made to take the reduction in peak current associated with current-limiting circuit breakers into consideration. In this approach, the tested interruption data obtained for current-limiting breakers subjected to given bolted fault currents is used. The data provides actual clearing times and actual peak let-through currents. An rms value associated with the let-through current is entered into the IEEE spreadsheet rather than the available bolted fault current. The actual clearing time associated with the available bolted fault current is also inputted.

1) Results of current limiting model

Table 1 shows calculated values based upon a 480V, MCC, 18" distance from arc, ungrounded system.

CALCULATED VALUES BASED UPON 480V, MCC, 18" DISTANCE FROM ARC, UNGROUNDED SYSTEM				
	Energy, cal/cm ²			
Bolted Fault Test Circuit kA	Using IEEE 1584 Shortcut Equations	IEEE 1584 Equations Using Manufacturer's Interrupting Time From Curves	Using Initial Model	
100	200A MCB			
	4.6	2.8	0.2	
	400A MCB			
	4.6	2.1	0.4	
	1200A MCB			
	9.3	5.1	1.9	

Table 1

2) Verification of initial model

To determine the validity of the initial model, some preliminary testing was conducted according to information extracted from previously published IEEE papers. This testing was based upon the parameters of 480V, MCC, 18" distance from arc, on an ungrounded system. The calorimeters used were constructed to ASTM Standard F-1959, Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing.

ACTUAL TEST VALUES BASED UPON 480V, MCC, 18" DISTANCE FROM ARC, UNGROUNDED SYSTEM				
	Energy, cal/cm ²			
Bolted Fault Test Circuit kA	Using IEEE 1584 Shortcut Equations	IEEE 1584 Equations Using Manufacturer's Interrupting Time From Curves	Using Initial Model	Actual Calorimeter Measurements of Arcing Energy
100	200A MCB			
	4.6	2.8	0.2	0.1
	400A MCB			
	4.6	2.1	0.4	0.15
	1200A MCB			
	9.3	5.1	1.9	1.3

Table 2

3) Initial model conclusions

The initial results indicate that MCCB current limiting significantly reduces the energy levels (when in the instantaneous range). Additionally, they suggest that the IEEE 1584 calculation methods are very conservative when compared with the actual measurements associated with MCCBs. (Need to correct this situation).

However, few test points have been verified. Although the resultant arc energies are significantly lower, this methodology is preliminary and still needs to be refined.

IV. USE OF OTHER EXISTING TECHNOLOGIES FOR REDUCING ARC FLASH

When arc flash considerations are a significant factor in the selection of electrical distribution equipment, the following existing technologies should be considered:

- **Zone Selective Interlocking (ZSI):** ZSI deactivates the preset delay on the circuit breaker closest to the fault, which then trips with no intentional delay. Faster tripping reduces the amount of time that current flows during a fault condition. Thus, zone-selective interlocking reduces the amount of arc flash and stress (I²t energy) that the system encounters during fault conditions, resulting in improved personal protection and prolonged equipment life.
- **Ground Fault Detection:** trips the circuit breaker during the early stages of fault development and prior to “bolted fault” conditions.
- **Use of finger-safe electrical components** as much as possible. This can reduce the chance that an arcing fault will occur.
- **Use of insulated bus** for equipment such as motor control centers, switchboards, switchgear, etc. This will reduce the chance that an arc fault may occur. In addition, it increases the probability that an arc fault will self-extinguish.
- **Sizing the current-limiting branch circuit over-current protective devices** as low as possible. Typically, the lower the ampere rating, the greater the degree of current-limitation.
- **Limiting the ampere rating size of main and feeders** where possible. For example by splitting large feeders into two feeders.

V. CONCLUSIONS

The IEEE 1584 Guide provides another advancement in calculating arc flash energies. It is important for the user to understand the required input information. An attached “Step By Step” explanation should aid the user with properly understanding the Excel Spreadsheet Calculator that is provided with the IEEE 1584 Guide. There are different methods included in the IEEE 1584 Guide for calculating arc flash energies associated with circuit breakers. The most accurate method included is to acquire specific device characteristics from the circuit breaker manufacturer. When this information is not available, the IEEE 1584 Guide also includes a secondary circuit breaker method which is more conservative, and therefore calculates high values of arc energy that may mandate more protection than is necessary. For circuit breakers, neither calculation method takes into account the current-limiting characteristics of circuit breakers which are indicated by initial modeling and testing. Efforts continue in this area. When arc flash considerations are a significant factor in the selection of electrical distribution equipment, there are many existing technologies that should be considered. When properly considered, altogether this is another step forward towards increasing the safety of personnel.

VI. APPENDIX A

The authors have complied the attached step by step instructions for using the IEEE 1584 Arc Flash Hazard Calculator[6]. This should aid the reader in first time navigation through the 1584 Calculator software.

The IEEE 1584 Guide also includes an Excel Spreadsheet "Arc-Flash Hazard Calculator" which performs the actual incident energy and arc flash hazard distance calculations using the formulas stated in the Guide. While the IEEE 1584 Guide provides another step forward in the understanding of arc flash hazard, there are several points that are frequently misunderstood. The following explanations are an attempt to help with those understandings. (References to specific "cells" apply to the Excel Spreadsheet calculator.)

- 1) At what "point(s)" in the system should arc flash hazard calculations be performed?

There could be multiple calculations performed depending on the particular task being undertaken. At a minimum, (either a or b) plus c below should be performed.

- a) A value shall be calculated either at the incoming point to the enclosure, or,
 - b) if the cables terminate immediately into the main device, and are not readily accessible, at the load terminals of an incoming overcurrent protective device, OCPD (if one exists). And,
 - c) At the load side of OCPDs that are sensibly partitioned/separated from their line side. (For example; when working inside the bucket of an MCC.)
- 2) The "Arc-Flash Hazard Calculator" Excel spreadsheet consists of several different worksheets. What are they all for?

Sheet titled "Basic Information" - this is an introduction page that contains brief Instructions, Range of Models, Cautions and Disclaimers, and other general information. The date and user defined title is the only requested input data for this sheet (although this input is optional).

Sheet titled "Data-Normal" - this is the sheet that requires the specific user input. Along with the sheet titled "Summary", these will be the most frequently used areas.

Sheet titled "Calcs-Normal" - this sheet contains an all-inclusive listing of the input data and all of the results from the calculations performed.

Sheet titled "Summary" - this sheet contains a simplified summary listing of the most important outputs calculated. For most situations, this is the preferred area to access the outputs calculated.

Sheets titled "Reference Tables" and "CB Reference" - these sheets contain further explanatory information. There is no input or output on these sheets.

- 3) How do you begin to use the "Arc-Flash Hazard Calculator"?

Begin on the sheet titled "Data-Normal", which is where the user input is required. User input should only be placed in cells colored yellow or blue.

Cell B-2 requests input of the description of the operating mode. With a simple radial system the mode is always normal, but with a more complex system there can be many modes (Tie open, tie closed, two or more utility feeders in service, generators in parallel, etc., etc.) Although input into this cell is optional and has no affect on the calculation, it is important to determine the available short circuit current for all modes.

Cell D-19 requests input for the Arc Flash Boundary Value. The default value is 1.2 cal/cm^2 (calories per centimeter squared) and should be used unless a particular situation specifies differently. Cell B-19 is also for specifying the Boundary Value, but it is used only when the units are specified in J/cm^2 (Joules per centimeter squared). The default value for this secondary system of units is 5.0 J/cm^2 . Presently, the majority of domestic US situations are based upon cal/cm^2 , in which case cell B-19 is left blank.

Cell B-21 requests input for the estimate of the Motor Contribution Factor expressed in percent of total fault current. The default is 0.03 (i.e. 3%), but leaving this empty (or entering zero) is also acceptable. This is the motor current which does NOT flow through the OCPD that is being analyzed. (Also see explanatory information for Cell D-24.)

- 4) How do you begin to input specific user information into the “Arc-Flash Hazard Calculator”?

The following comments reference various cells on Row 24. The explanation for all cells on this row are also applicable to rows numbered 25 through 107. Different rows are applicable for other “points” and/or OCPDs in the system that is being evaluated.

Cell A-24 requests input of the name of the bus. While this is optional, it is suggested to enter some type of alpha or numeric identifier. This will make it easier to coordinate the calculated output back to its corresponding system location.

Cell B-24 requests input of the bus voltage (required). This should be in kilo-volts, expressed in decimal form. (i.e. 480V=0.48, 600V=0.6, 5000V=5, 13,000V=13, etc., etc.)

Cell C-24 (required). This should be the total bolted fault current in kilo-amps (including any motor contributions) that is available at that point in the system that is being analyzed. This value can be determined directly from the separately conducted fault study.

Cell D-24. If the amount of bolted fault current that could flow through the OCPD being analyzed is known, enter that number in kilo-amps. (Although input here is not mandatory, the following is an explanation about the relevance of this information:

- When a value is NOT entered into Cell D-24, and the motor contribution factor from Cell B-21 is empty (or zero), the arcing fault current (F-24) is calculated from the value previously entered in Cell C-24.
- When a value is NOT entered into Cell D-24, but the motor contribution factor from Cell B-21 contains a value, the arcing fault current (F-24) is calculated from the value previously entered in Cell C-24 minus the motor contribution current.
- When a value IS entered into Cell D-24, regardless of whether a motor contribution factor was entered in Cell B-21, the arcing fault current (F-24) is calculated from the value entered here in Cell D-24.)

Unless colored yellow or blue, cells do not require input. Cells relating specifically to the OCPD (G-24, H-24, J-24, K-24, O-24 & P-24) are discussed later.

Cell L-24 requests input of the working distance in millimeters (required). This is the dimension between the possible arc point and the head and body of the worker positioned in place to perform the assigned task. (Numerical sum of the distance between the worker standing in front of the equipment, and from the front of the equipment to the potential arc source inside the equipment.) Unless other specific information has been determined, it is recommended to input one of the following IEEE 1584 stated typical working distances*:

5kV Switchgear (& motor starters**)	910 mm
15kV Switchgear	910 mm
Low-Voltage Switchgear	610 mm
Low-Voltage MCCs and Panelboards (& Switchboards**)	455 mm
Cables	455 mm

* = From IEEE discussions, IEEE 1584 assumes that the typical depth of equipment decreases between Switchgear and LV MCCs, making a worker closer to the potential arc source.

Cell M-24 requests input of a number 1 through 4, that IEEE 1584 identifies as the “Equipment Class” as follows:

- | | |
|---|---|
| 1 | Open air; |
| 2 | Cables; |
| 3 | Switchgear; or |
| 4 | MCCs and Panelboards (& Switchboards**) |

(Entering number 1 results in the least amount of calculated incident energy, increasing up to the highest amount calculated when entering number 4.)

** = Recommended, but not specifically stated in IEEE 1584.

Cell N-24 requests input of a number 1 or 2, that IEEE 1584 identifies as the system's "Grounding Type" as follows:

- 1 Solidly grounded; or
- 2 Ungrounded, high-resistance grounded and low-resistance grounded.

(Entering number 1 results in the lesser amount of calculated incident energy, compared to entering number 2 which results in a higher amount. This factor was included because IEEE analysis of their test results revealed a statistically significant difference between solidly grounded and other systems. IEEE provides no other technical explanation for this difference, but it may involve arcing to the metal enclosure.)

5) What is the specific OCPD?

Determine whether the specific OCPD is a circuit breaker or a fuse. Proceed to the appropriate explanation for each that follows.

Is the OCPD a fuse?

For certain specific low-voltage fuses, and within a specific tested range of bolted fault currents, it is possible to input the fuse-type, and the calculation then automatically takes into account both the current-limiting effect of the fuse and the actual time of interruption. Thus both of the important parameters for arc flash, the arc current magnitude and the arc current duration, are taken into account. This is the most accurate method for these certain types of low-voltage fuses. Cells G-24, H-24, J-24 & K-24 should be empty because input of the fuse's time/current curve information (total clearing times) is NOT required for this method. Cell O-24 requests input of a number 1 through 8, that IEEE 1584 identifies as the "Protective Device Type" as follows:

- 1 Class RK 1 fuse – 100A
- 2 Class RK 1 fuse – 200A
- 3 Class RK 1 fuse – 400A
- 4 Class RK 1 fuse – 600A
- 5 Class L fuse – 800A
- 6 Class L fuse – 1200A
- 7 Class L fuse – 1600A
- 8 Class L fuse – 2000A

If, upon entry of the above information, Cell O-24 turns orange in color, the bolted fault current is outside the model's tested range for that fuse. For these cases the secondary fuse calculation method (for fuses other than specified above) must be used.

What if the fuse is not one of the specific ones stated?

If the fuse is not one of those specifically stated, or when outside the model's tested bolted fault current range, input of the fuse's time/current curve information (total clearing times = melting time + arcing time) is required. If the manufacturer shows only the average melt time, add to that time 15%, up to 0.03 seconds and 10% above 0.03 seconds to determine total clearing time. This secondary method is utilized by entering 0 (zero) in Cell O-24. In Cell G-24 enter the fuse's time/current curve information based upon the level of arcing fault current shown in Cell F-24. Cells H-24 and K-24 should be empty. Another input is also required for low-voltage fuses that use this method. In Cell J-24 enter the fuse's time/current curve information (total clearing time) based upon the level of "reduced" arcing fault current shown in Cell I-24.

Is the OCPD a circuit breaker?

For circuit breakers, the most accurate calculation method included in the IEEE 1584 Guide, is to use specific manufacturer's time/current information (total clearing times). This method is utilized by entering 0 (zero) in Cell O-24. In Cell G-24 enter the circuit breaker's time/current curve information (total clearing time) based upon the level of arcing fault current shown in Cell F-24. Cells H-24 and K-24 should be empty. Another input is also required for low-voltage circuit breakers that use this method. In Cell J-24 enter the circuit breaker's time/current curve information (total clearing time) based upon the level of "reduced" arcing fault current shown in Cell I-24.

What if the circuit breaker time/current information (opening times) is not available?

A secondary method is available for certain low-voltage circuit breakers within specific continuous current ranges and within specific ranges of bolted fault currents. Cells G-24, H-24, J-24 & K-24 should be empty because input of the circuit breaker's time/current curve information (total clearing time) is NOT required for this method. The appropriate Protective Device Type (number 9-14) is then entered in Cell O-24 as follows:

- 9 Molded Case Circuit Breaker, 100-400A
- 10 Molded Case Circuit Breaker, 600-1200A, Thermo-magnetic trip
- 11 Molded Case Circuit Breaker, 600-1200A, Electronic trip w/Long Delay
- 12 Molded Case or Insulated Case Circuit Breaker, 1600-600A
- 13 Low-Voltage Power Circuit Breaker, 800-6300A, w/Instantaneous trip
- 14 Low-Voltage Power Circuit Breaker, 800-6300A, w/o Instantaneous (Short Delay only)

Another input is also required for this method. In Cell P-24 enter the current at which the circuit breaker will instantaneously trip. When the instantaneous tripping current is not known, use a default value of 10 times the continuous current rating of the CB, except for CBs rated 100 A and below, use a default value of 1300A. For a low-voltage power circuit breaker without instantaneous tripping, enter the short-time pick-up current in Cell P-24.

If, upon entry of the above information, Cell O-24 turns orange in color, the bolted fault current is outside the range of the model for that particular low-voltage circuit breaker. For these cases this secondary calculation method can not be used.

Note: Although this secondary circuit breaker method only requires knowledge of bolted fault current, the calculation is based upon circuit breaker interruption times for generic breaker-ratings. These are typically worst-case; maximum-duration interruption times based upon the published time-current curves of many manufacturers. This method is conservative and calculates high values of arc energy that may mandate more protection than is necessary. Therefore this is a secondary method, used for instances when specific time/current curve information is not available!

Do any of these calculations account for the current limiting characteristics of circuit breakers?

No! Regardless of the selected calculation method for circuit breakers, the present IEEE 1584 calculations do not take into account the current-limiting characteristics of circuit breakers.

When entering specific OCPD times (for both low-voltage fuses and low-voltage circuit breakers) why do you enter 2 different values; one based upon the arcing current and a second based upon a "reduced" arcing current?

Due to variations in low-voltage arc currents (under 1 kV), a second calculation is performed based upon a "reduced" arcing fault current that is 85% of the originally calculated arcing current. For cases where the arc current falls on the steep part of the time-current curve or falls near a step change, a small variation in arc current could cause a significant change in OCPD tripping or operating time. The highest resulting energy (either based upon arcing current and arcing operating time, or reduced arcing current and reduced current operating time) is then automatically used for the final energy calculations. Medium-voltage arc currents do not exhibit those same variations and therefore a second input is not required.

What if you have a "relay operated" (MV) circuit breaker?

For "relay operated" (MV) circuit breakers, the specific relay time setting, in seconds, is entered into Cell H-24. This is then automatically added to the circuit breaker's opening time (previously input into Cell G-24) and the sum is then used for the final energy calculations.

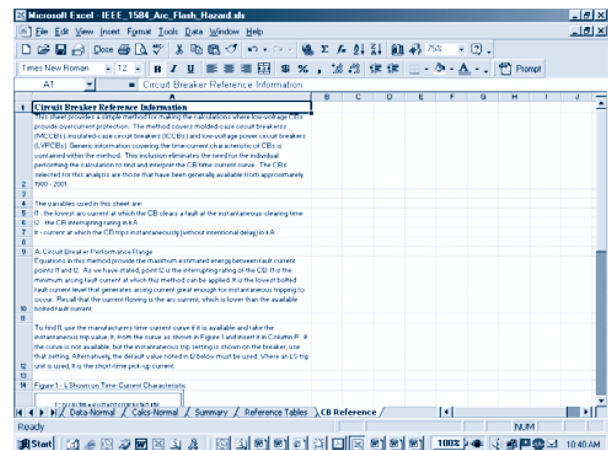
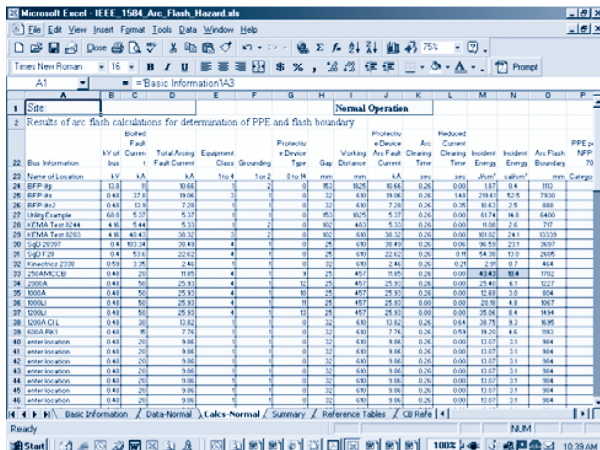
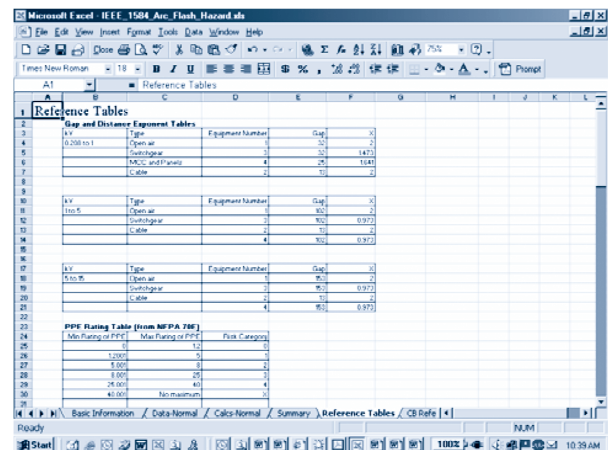
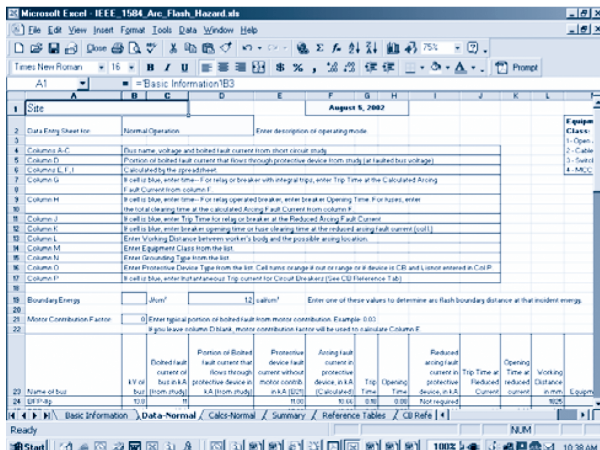
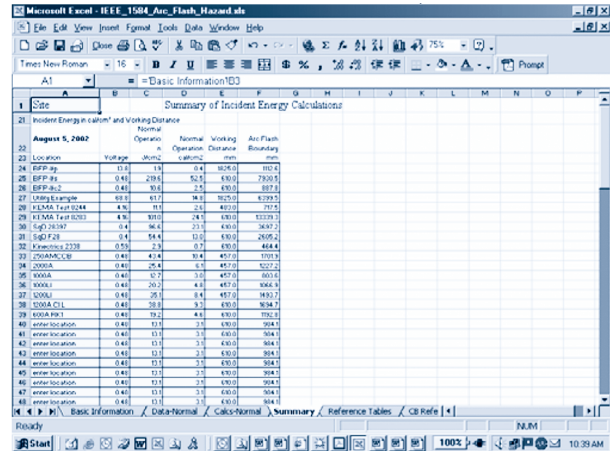
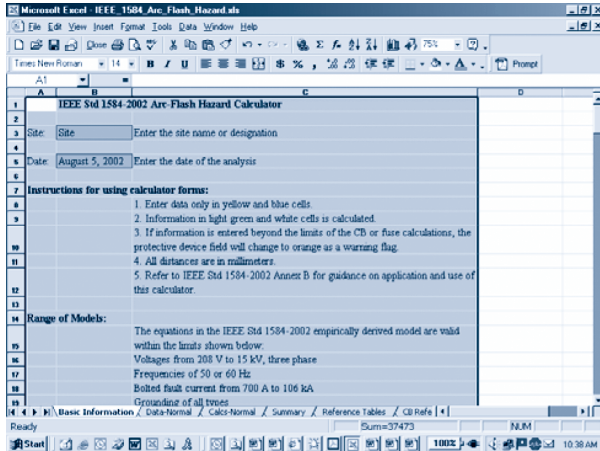
After you have entered all the data, then what?

After all previously described data is entered, a summary of the automatically calculated output is shown in the applicable rows of the sheet titled "Summary."

Understanding Arc Flash Hazards

VII. APPENDIX B

The Following are screenshots that depict the “sheets” from the IEEE 1584 Arc Flash Hazard Calculator[6] Excel Spreadsheet and are referenced in VI. Appendix A.



REFERENCES

- [1] IEEE 1584-2002, "*Guide for Performing Arc-Flash Hazard Calculations.*"
- [2] NFPA 70E-2000, "*Standard for Electrical Safety Requirements for Employee Workplaces.*"
- [3] The Occupational Safety and Health Administration (OSHA), "*Code of Federal Regulations,*" CFR 1910.333, Selection and Use of Work Practices.
- [4] NFPA 70-2002 the "*National Electrical Code*" (NEC).
- [5] ANSI Z535.4-1998, "*Product Safety Signs and Labels.*"
- [6] IEEE 1584 "*Arc-Flash Hazard Calculator*" Excel Spreadsheet provided with IEEE 1584-2002 Guide.



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