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The Electrical Power Engineers

EXAMPLE COMPARISON OF 1584-2002 AND 1584-2018 INCIDENT ENERGY CALCULATIONS

1.0 INTRODUCTION

The IEEE Guide for Performing Arc-Flash Hazard Calculations was first published in 2002. It was a ground-breaking document that provided guidance to the industry for making arc flash calculations. The publication of that document also set in motion a significant testing project to expand the knowledge base in this area. Based on this work, the standard was updated in 2018. One of the significant variables, which was investigated since 2002, included the placement of the three electrodes (or phases). In Figures 1 and 2, the variation of the phases is illustrated.

In Figure 1, a vertical arrangement of the three phases is illustrated with an arc flash at the bottom of the electrodes. There can be a significant difference in the heat that is expelled out the open front of the enclosure, depending upon how open the area is where the arc occurs. The configuration on the left is labeled as VCB with the electrodes in a vertical position and an open space at the bottom of the electrodes. The configuration at the right is labeled as VCBB with the electrodes also in a vertical position but with very little open space at the bottom. The VCBB configuration generally results in more heat being expelled out the front opening toward the person. It should be noted that the testing which produced the 2002 document was predominantly done with configurations that were similar to VCB.

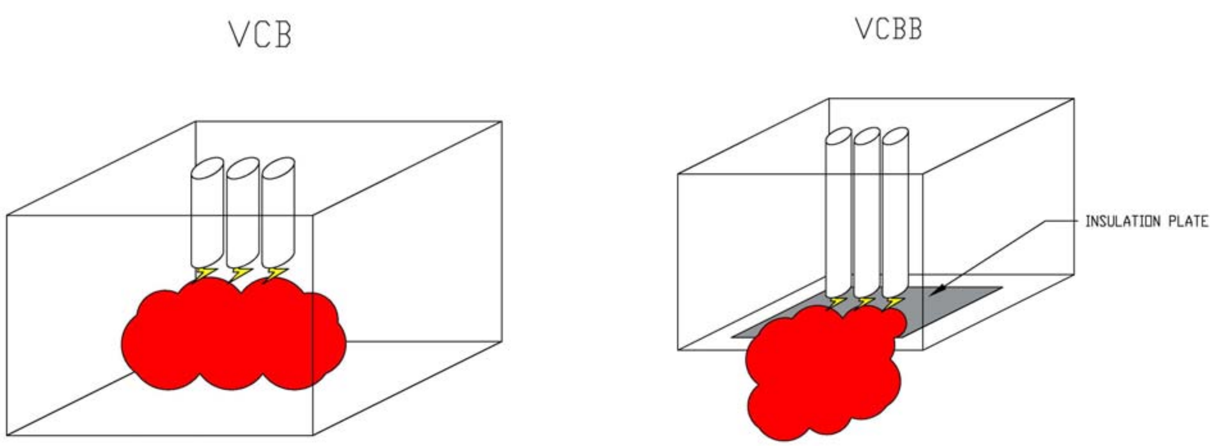

Figure 1 – Vertical Electrodes

In Figure 2, a horizontal arrangement of the three phases is illustrated with an arc flash at the end of the electrodes. This configuration is labeled as HCB. With the electrodes in a horizontal position, even more heat, i.e. incident energy, can be expelled out the front opening toward the person.

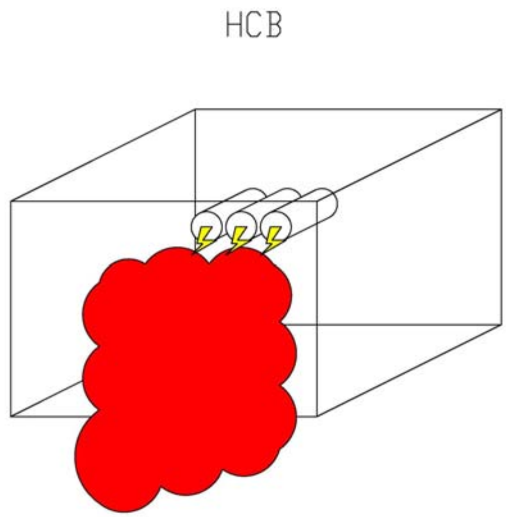

Figure 2 – Horizontal Electrodes

IEEE Standard 1584-2018 provides the equations for making the incident energy calculations for these three configurations. The dimensions of the enclosure are also variables in the calculations. The result is that the new equations are more complex and require more information about the physical configuration of the equipment.

2.0 EXAMPLE – COMPARING 1584-2002 WITH 1584-2018

An example system is used to compare the equations in 1584-2002 with those in 1584-2018. It is setup with very specific parameters, but it does give a big-picture view of how the incident energy calculations can change. The calculations for the example system are given in Figures 3 thru 6 as follows:

- Figure 3 IEEE 1584-2002
- Figure 4 IEEE 1584-2018 VCB Configuration
- Figure 5 IEEE 1584-2018 VCBB Configuration
- Figure 6 IEEE 1584-2018 HCB Configuration

The results of the calculations are given in Tables 1 thru 3. The following observations are noted:

- In Table 1, the calculations are compared in calories/cm^2 at 13.8 kV and 480V.
- In Table 2, the calculations are given in % of the 1584-2002 methodology.
    - o The VCB configuration gives results that are closest to the 1584-2002 methodology.
    - o The VCBB configuration tends to give incident energies that are approximately 1.5 times the VCB calculations, except for the 480V panelboard and MCC equipment where the values are closer.
    - o The HCB configuration tends to give incident energies that are approximately 2.0 times the VCB calculations.
- In Table 3, the calculations are summarized by PPE level where PPE = 2 is for incident energy values $\leq$ 8 cal/cm^2 and PPE = 4 is for values $\leq$ 40 cal/cm^2. The areas where a PPE level would change are noted in the table.

IEEE 1584-2002

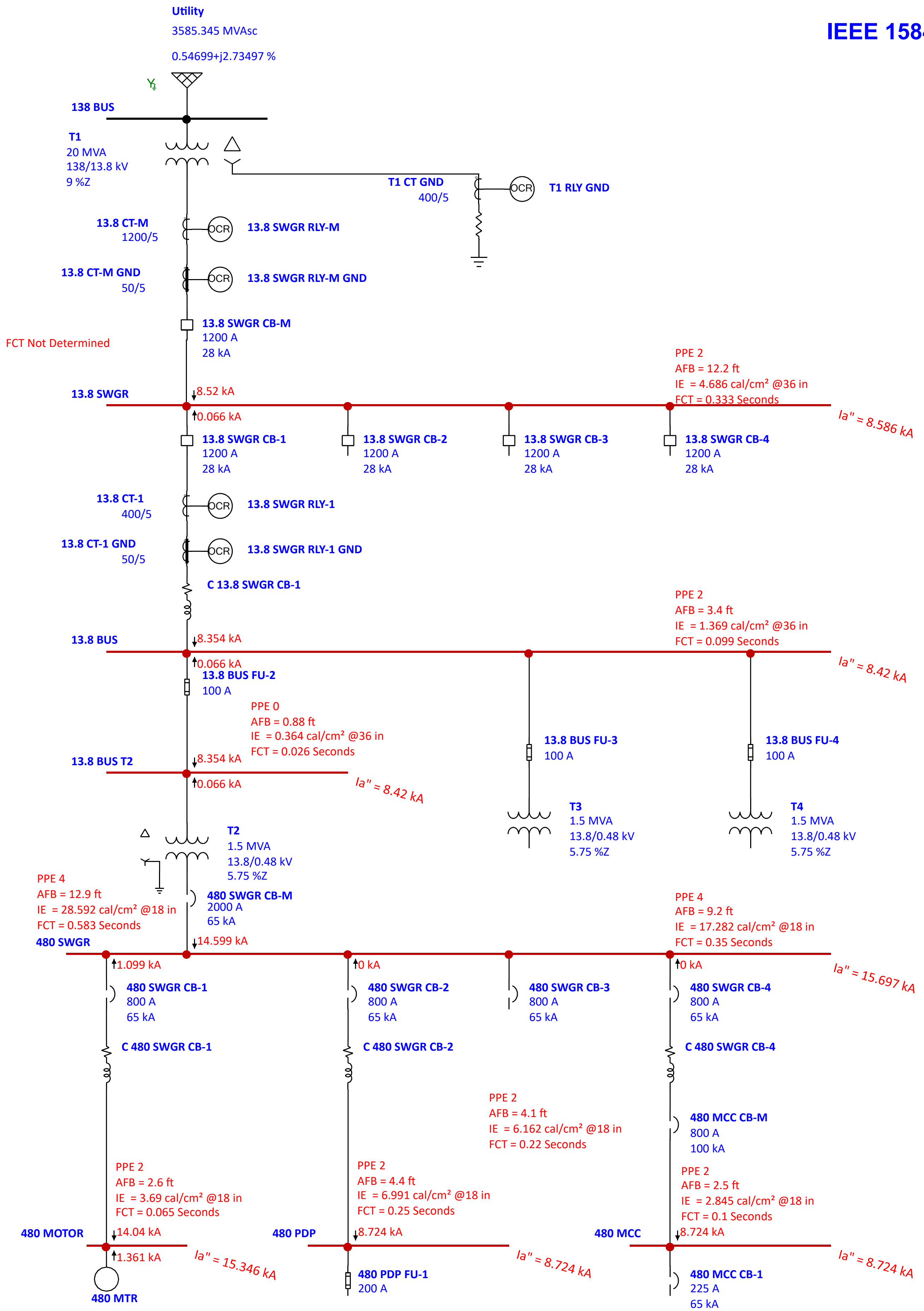

Figure 3

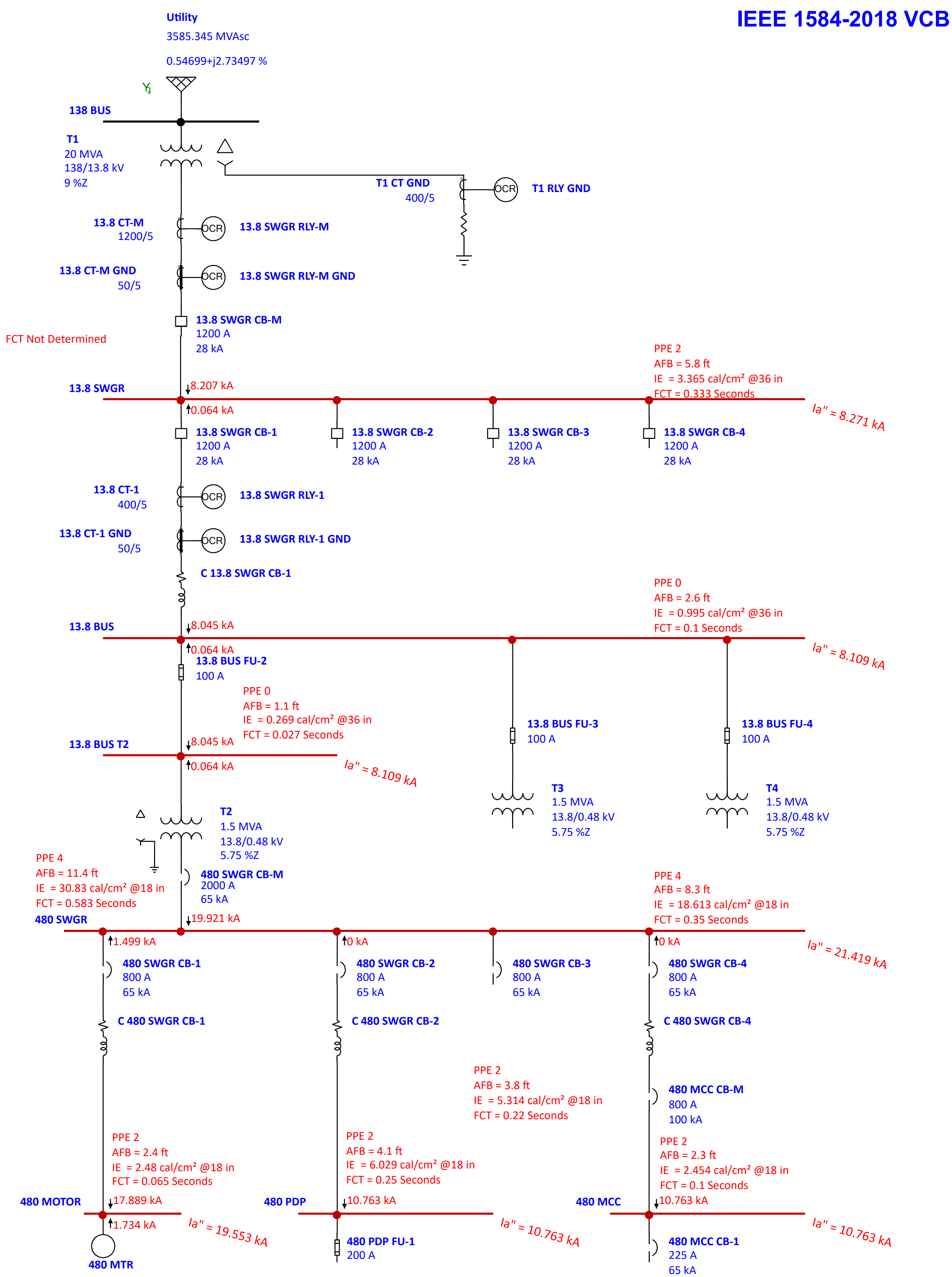
IEEE 1584-2018 VCB
Utility
3585.345 MVAsc
0.54699+j2.73497 %
138 BUS
T1
20 MVA
138/13.8 kV
9 %Z
T1 CT GND
400/5
T1 RLY GND
13.8 CT-M
1200/5
13.8 SWGR RLY-M
13.8 CT-M GND
50/5
13.8 SWGR RLY-M GND
13.8 SWGR CB-M
1200 A
28 kA
FCT Not Determined
PPE 2
AFB = 5.8 ft
IE = 3.365 cal/cm² @36 in
FCT = 0.333 Seconds
13.8 SWGR
8.207 kA
0.064 kA
Ia" = 8.271 kA
13.8 SWGR CB-1
1200 A
28 kA
13.8 SWGR CB-2
1200 A
28 kA
13.8 SWGR CB-3
1200 A
28 kA
13.8 SWGR CB-4
1200 A
28 kA
13.8 CT-1
400/5
13.8 SWGR RLY-1
13.8 CT-1 GND
50/5
13.8 SWGR RLY-1 GND
C 13.8 SWGR CB-1
PPE 0
AFB = 2.6 ft
IE = 0.995 cal/cm² @36 in
FCT = 0.1 Seconds
13.8 BUS
8.045 kA
0.064 kA
Ia" = 8.109 kA
13.8 BUS FU-2
100 A
PPE 0
AFB = 1.1 ft
IE = 0.269 cal/cm² @36 in
FCT = 0.027 Seconds
13.8 BUS FU-3
100 A
13.8 BUS FU-4
100 A
13.8 BUS T2
8.045 kA
0.064 kA
Ia" = 8.109 kA
T3
1.5 MVA
13.8/0.48 kV
5.75 %Z
T4
1.5 MVA
13.8/0.48 kV
5.75 %Z
T2
1.5 MVA
13.8/0.48 kV
5.75 %Z
PPE 4
AFB = 11.4 ft
IE = 30.83 cal/cm² @18 in
FCT = 0.583 Seconds
480 SWGR CB-M
2000 A
65 kA
PPE 4
AFB = 8.3 ft
IE = 18.613 cal/cm² @18 in
FCT = 0.35 Seconds
480 SWGR
19.921 kA
1.499 kA
0 kA
0 kA
Ia" = 21.419 kA
480 SWGR CB-1
800 A
65 kA
480 SWGR CB-2
800 A
65 kA
480 SWGR CB-3
800 A
65 kA
480 SWGR CB-4
800 A
65 kA
C 480 SWGR CB-1
C 480 SWGR CB-2
C 480 SWGR CB-4
PPE 2
AFB = 3.8 ft
IE = 5.314 cal/cm² @18 in
FCT = 0.22 Seconds
480 MCC CB-M
800 A
100 kA
PPE 2
AFB = 2.4 ft
IE = 2.48 cal/cm² @18 in
FCT = 0.065 Seconds
PPE 2
AFB = 4.1 ft
IE = 6.029 cal/cm² @18 in
FCT = 0.25 Seconds
PPE 2
AFB = 2.3 ft
IE = 2.454 cal/cm² @18 in
FCT = 0.1 Seconds
480 MOTOR
17.889 kA
1.734 kA
Ia" = 19.553 kA
480 PDP
10.763 kA
Ia" = 10.763 kA
480 MCC
10.763 kA
Ia" = 10.763 kA
480 PDP FU-1
200 A
480 MCC CB-1
225 A
65 kA
480 MTR

Figure 4

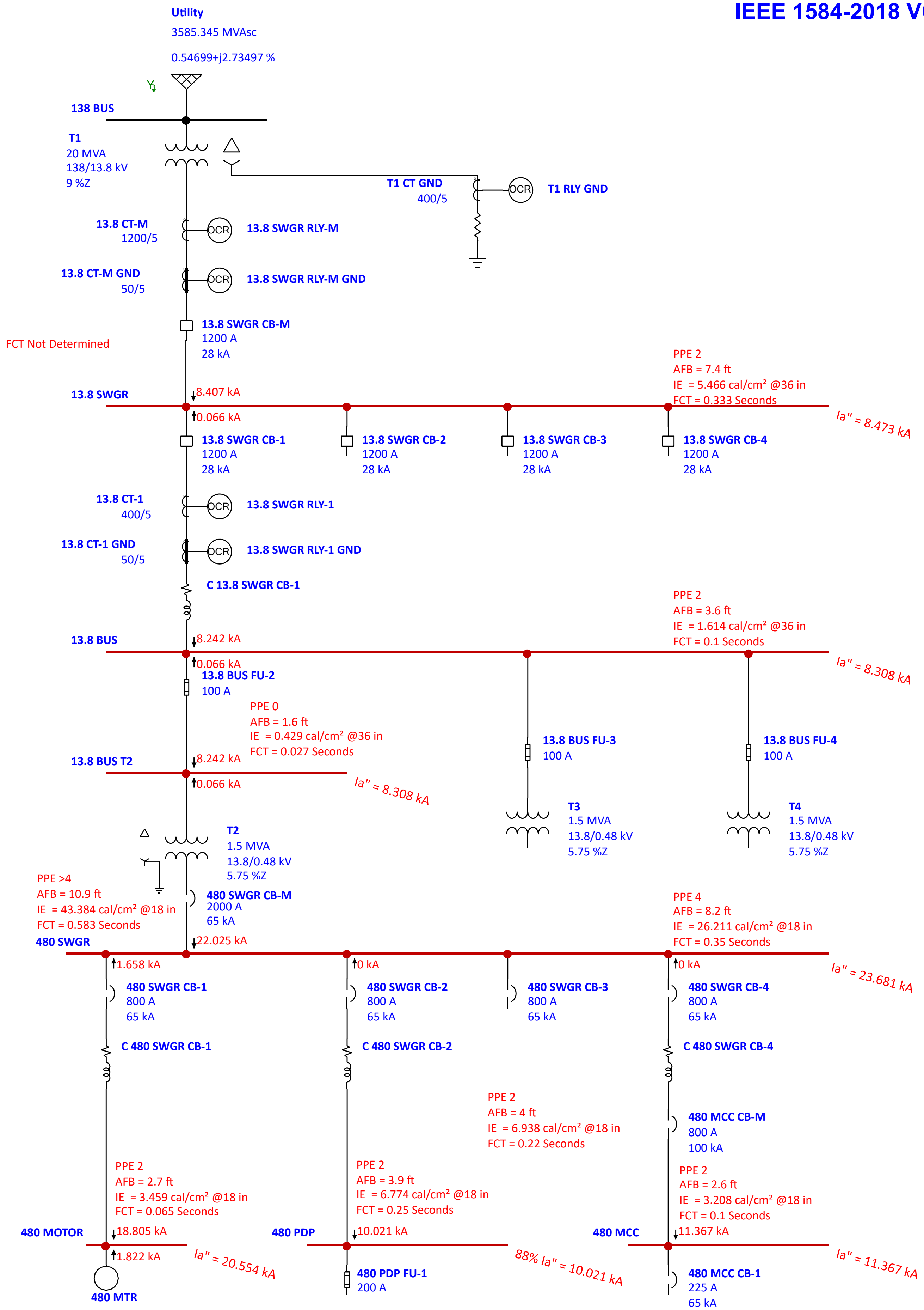
Utility
3585.345 MVAsc
0.54699+j2.73497 %
138 BUS
T1
20 MVA
138/13.8 kV
9 %Z
T1 CT GND
400/5
OCR
T1 RLY GND
13.8 CT-M
1200/5
13.8 SWGR RLY-M
13.8 CT-M GND
50/5
13.8 SWGR RLY-M GND
13.8 SWGR CB-M
1200 A
28 kA
FCT Not Determined
PPE 2
AFB = 7.4 ft
IE = 5.466 cal/cm² @36 in
FCT = 0.333 Seconds
13.8 SWGR
8.407 kA
0.066 kA
Ia" = 8.473 kA
13.8 SWGR CB-1
1200 A
28 kA
13.8 SWGR CB-2
1200 A
28 kA
13.8 SWGR CB-3
1200 A
28 kA
13.8 SWGR CB-4
1200 A
28 kA
13.8 CT-1
400/5
13.8 SWGR RLY-1
13.8 CT-1 GND
50/5
13.8 SWGR RLY-1 GND
C 13.8 SWGR CB-1
PPE 2
AFB = 3.6 ft
IE = 1.614 cal/cm² @36 in
FCT = 0.1 Seconds
13.8 BUS
8.242 kA
0.066 kA
Ia" = 8.308 kA
13.8 BUS FU-2
100 A
PPE 0
AFB = 1.6 ft
IE = 0.429 cal/cm² @36 in
FCT = 0.027 Seconds
13.8 BUS FU-3
100 A
13.8 BUS FU-4
100 A
13.8 BUS T2
8.242 kA
0.066 kA
Ia" = 8.308 kA
T3
1.5 MVA
13.8/0.48 kV
5.75 %Z
T4
1.5 MVA
13.8/0.48 kV
5.75 %Z
T2
1.5 MVA
13.8/0.48 kV
5.75 %Z
PPE >4
AFB = 10.9 ft
IE = 43.384 cal/cm² @18 in
FCT = 0.583 Seconds
480 SWGR CB-M
2000 A
65 kA
PPE 4
AFB = 8.2 ft
IE = 26.211 cal/cm² @18 in
FCT = 0.35 Seconds
480 SWGR
22.025 kA
1.658 kA
0 kA
0 kA
Ia" = 23.681 kA
480 SWGR CB-1
800 A
65 kA
480 SWGR CB-2
800 A
65 kA
480 SWGR CB-3
800 A
65 kA
480 SWGR CB-4
800 A
65 kA
C 480 SWGR CB-1
C 480 SWGR CB-2
C 480 SWGR CB-4
PPE 2
AFB = 4 ft
IE = 6.938 cal/cm² @18 in
FCT = 0.22 Seconds
480 MCC CB-M
800 A
100 kA
PPE 2
AFB = 2.7 ft
IE = 3.459 cal/cm² @18 in
FCT = 0.065 Seconds
PPE 2
AFB = 3.9 ft
IE = 6.774 cal/cm² @18 in
FCT = 0.25 Seconds
PPE 2
AFB = 2.6 ft
IE = 3.208 cal/cm² @18 in
FCT = 0.1 Seconds
480 MOTOR
18.805 kA
1.822 kA
Ia" = 20.554 kA
480 MTR
480 PDP
10.021 kA
88% Ia" = 10.021 kA
480 PDP FU-1
200 A
480 MCC
11.367 kA
Ia" = 11.367 kA
480 MCC CB-1
225 A
65 kA

Figure 5

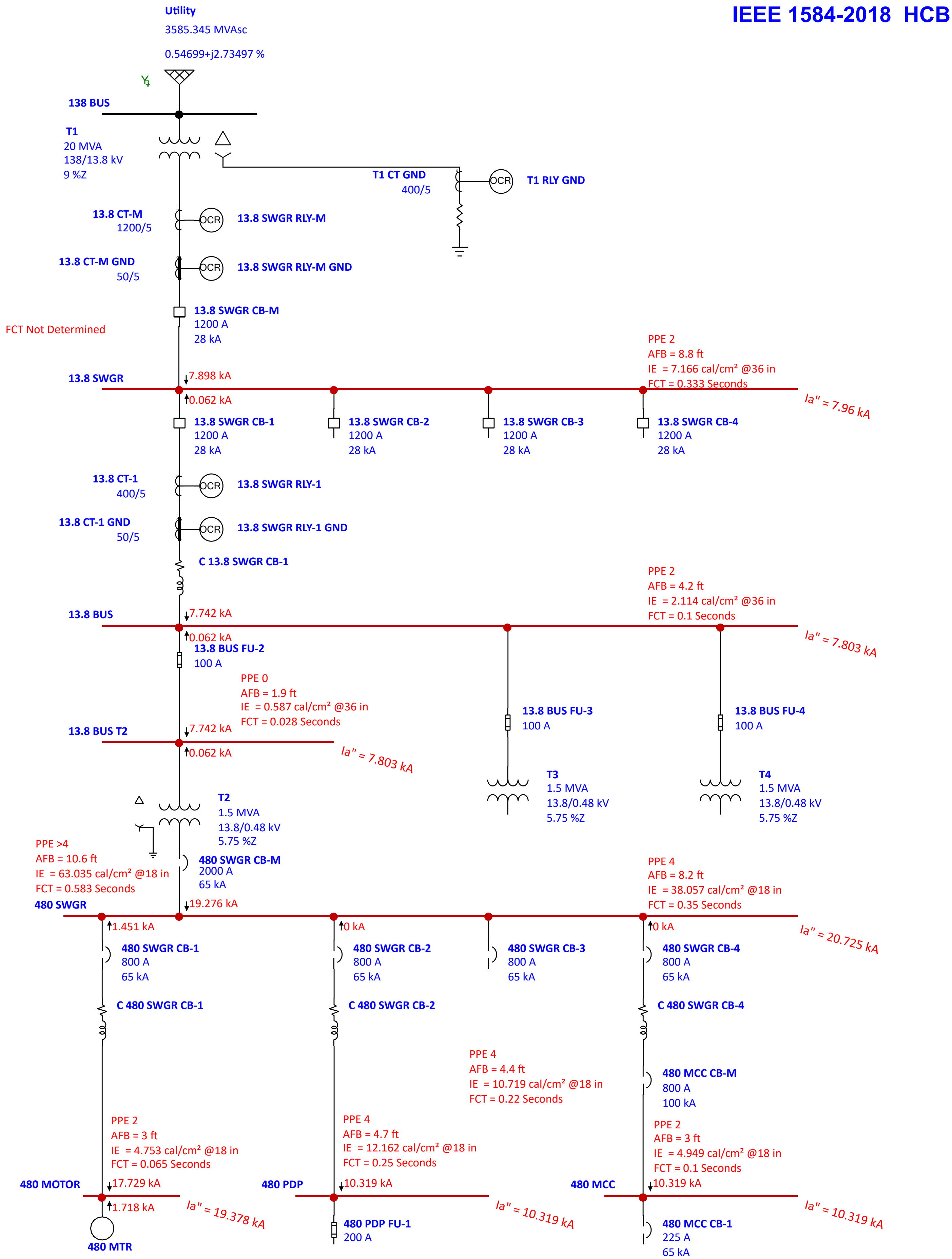
IEEE 1584-2018 HCB
Utility
3585.345 MVAsc
0.54699+j2.73497 %
138 BUS
T1
20 MVA
138/13.8 kV
9 %Z
T1 CT GND
400/5
OCR
T1 RLY GND
13.8 CT-M
1200/5
13.8 SWGR RLY-M
13.8 CT-M GND
50/5
13.8 SWGR RLY-M GND
13.8 SWGR CB-M
1200 A
28 kA
FCT Not Determined
PPE 2
AFB = 8.8 ft
IE = 7.166 cal/cm² @36 in
FCT = 0.333 Seconds
13.8 SWGR
7.898 kA
0.062 kA
Ia" = 7.96 kA
13.8 SWGR CB-1
1200 A
28 kA
13.8 SWGR CB-2
1200 A
28 kA
13.8 SWGR CB-3
1200 A
28 kA
13.8 SWGR CB-4
1200 A
28 kA
13.8 CT-1
400/5
13.8 SWGR RLY-1
13.8 CT-1 GND
50/5
13.8 SWGR RLY-1 GND
C 13.8 SWGR CB-1
PPE 2
AFB = 4.2 ft
IE = 2.114 cal/cm² @36 in
FCT = 0.1 Seconds
13.8 BUS
7.742 kA
0.062 kA
Ia" = 7.803 kA
13.8 BUS FU-2
100 A
PPE 0
AFB = 1.9 ft
IE = 0.587 cal/cm² @36 in
FCT = 0.028 Seconds
13.8 BUS T2
7.742 kA
0.062 kA
Ia" = 7.803 kA
13.8 BUS FU-3
100 A
13.8 BUS FU-4
100 A
T3
1.5 MVA
13.8/0.48 kV
5.75 %Z
T4
1.5 MVA
13.8/0.48 kV
5.75 %Z
T2
1.5 MVA
13.8/0.48 kV
5.75 %Z
PPE >4
AFB = 10.6 ft
IE = 63.035 cal/cm² @18 in
FCT = 0.583 Seconds
480 SWGR CB-M
2000 A
65 kA
PPE 4
AFB = 8.2 ft
IE = 38.057 cal/cm² @18 in
FCT = 0.35 Seconds
480 SWGR
19.276 kA
1.451 kA
0 kA
0 kA
Ia" = 20.725 kA
480 SWGR CB-1
800 A
65 kA
480 SWGR CB-2
800 A
65 kA
480 SWGR CB-3
800 A
65 kA
480 SWGR CB-4
800 A
65 kA
C 480 SWGR CB-1
C 480 SWGR CB-2
C 480 SWGR CB-4
PPE 4
AFB = 4.4 ft
IE = 10.719 cal/cm² @18 in
FCT = 0.22 Seconds
480 MCC CB-M
800 A
100 kA
PPE 2
AFB = 3 ft
IE = 4.753 cal/cm² @18 in
FCT = 0.065 Seconds
PPE 4
AFB = 4.7 ft
IE = 12.162 cal/cm² @18 in
FCT = 0.25 Seconds
PPE 2
AFB = 3 ft
IE = 4.949 cal/cm² @18 in
FCT = 0.1 Seconds
480 MOTOR
17.729 kA
1.718 kA
Ia" = 19.378 kA
480 MTR
480 PDP
10.319 kA
Ia" = 10.319 kA
480 PDP FU-1
200 A
480 MCC
10.319 kA
Ia" = 10.319 kA
480 MCC CB-1
225 A
65 kA

Figure 6

Table 1 - Comparison of Incident Energy Calculations

Bus	Voltage (kV)	Equipment Type	Working Distance (Inches)	Enclosure Dimensions (Inches) H	x	W	x	D	Clearing Time (seconds)	Incident Energy (cal/cm^2) 2002	2018 VCB	2018 VCBB	2018 HCB
13.8 SWGR	13.8	Switchgear	36	45		30		30	0.33	4.7	3.4	5.5	7.2
13.8 BUS	13.8	Switchgear	36	45		30		30	0.10	1.4	1.0	1.6	2.1
13.8 BUS T2	13.8	Switchgear	36	45		30		30	0.03	0.4	0.3	0.4	0.6
480 SWGR CB-M	0.48	LVCB	18	20		20		20	0.58	28.6	30.8	43.4	63.0
480 SWGR	0.48	Switchgear	18	20		20		20	0.35	17.3	18.6	26.2	38.1
480 MOTOR	0.48	Other	18	14		12		8	0.07	3.7	2.5	3.5	4.8
480 PDP	0.48	Panelboard	18	14		12		8	0.25	7.0	6.0	6.8	12.2
480 MCC	0.48	MCC	18	14		12		8	0.10	2.9	2.5	3.2	4.9

Table 2 - Comparison of % of 2002 Calculation Method

Bus	Voltage (kV)	Equipment Type	Working Distance (Inches)	Enclosure Dimensions (Inches) H	x	W	x	D	Clearing Time (seconds)	Incident Energy as % of 2002 2002	2018 VCB	2018 VCBB	2018 HCB
13.8 SWGR	13.8	Switchgear	36	45		30		30	0.33	100%	72%	117%	153%
13.8 BUS	13.8	Switchgear	36	45		30		30	0.10	100%	73%	118%	154%
13.8 BUS T2	13.8	Switchgear	36	45		30		30	0.03	100%	74%	118%	161%
480 SWGR CB-M	0.48	LVCB	18	20		20		20	0.58	100%	108%	152%	220%
480 SWGR	0.48	Switchgear	18	20		20		20	0.35	100%	108%	152%	220%
480 MOTOR	0.48	Other	18	14		12		8	0.07	100%	67%	94%	129%
480 PDP	0.48	Panelboard	18	14		12		8	0.25	100%	86%	97%	174%
480 MCC	0.48	MCC	18	14		12		8	0.10	100%	86%	113%	174%

Table 3 - Comparison of PPE Levels

Bus	Voltage (kV)	Equipment Type	Working Distance (Inches)	Enclosure Dimensions (Inches) H	x	W	x	D	Clearing Time (seconds)	PPE Level (2 or 4) 2002	2018 VCB	2018 VCBB	2018 HCB
13.8 SWGR	13.8	Switchgear	36	45		30		30	0.33	2	2	2	2
13.8 BUS	13.8	Switchgear	36	45		30		30	0.10	2	2	2	2
13.8 BUS T2	13.8	Switchgear	36	45		30		30	0.03	2	2	2	2
480 SWGR CB-M	0.48	LVCB	18	20		20		20	0.58	4	4	>4	>4
480 SWGR	0.48	Switchgear	18	20		20		20	0.35	4	4	4	4
480 MOTOR	0.48	Other	18	14		12		8	0.07	2	2	2	2
480 PDP	0.48	Panelboard	18	14		12		8	0.25	2	2	2	4
480 MCC	0.48	MCC	18	14		12		8	0.10	2	2	2	2

(highlighted) This is a change in PPE from the 2002 calculation method.

3.0 EXAMPLE – REEVALUATION BASED ON 1584-2018

Based on the information determined in Section 2.0, the example system is reevaluated with the following considerations:

1. Step 1 – Choose an appropriate electrode configuration for the equipment in this example:
   a. For the 13.8 kV switchgear, HCB is chosen. Based on the ability to draw out the medium voltage switchgear, this is often an appropriate choice.
   b. For the 480V main switchgear, HCB is also chosen. Based on the use of low voltage switchgear that can be drawn out, this is often an appropriate choice.
   c. For the down-line 480V equipment, VCBB is chosen. This is often composed of molded case circuit breakers and other equipment where the cables are brought in from above to make bolted connections.

   These electrode configurations and resultant incident energies are listed in Table 4. (The incident energies are taken from Table 1.)

2. Step 2 – Consider working distance changes:
   a. In reviewing Table 4, the area where there is a significant difference in incident energy is at the 480V main switchgear.
   b. This was evaluated using 18” previously to maintain a consistent working distance for all 480V equipment. Standard 1584 suggests that 24” is often used for low-voltage, draw-out switchgear.

   Consequently, for the low-voltage switchgear, 24” is chosen for this reevaluation. Based on the revised information, the detailed calculations are given in Figure 7 and summarized in Table 5, the incident energy at the main switchgear is significantly reduced by a factor of approximately 1.8 to less than 40 cal/cm^2 when working at 24”.

3. Step 3 – Determine PPE levels:
   a. Based on steps 1 and 2 with an increase in working distance at the main 480V switchgear, the PPE levels at the locations evaluated are summarized in Table 6. They are the same as previously determined.
   b. In other applications, it may be necessary to change the settings of overcurrent devices or add faster methods of determining the fault condition to achieve an acceptable incident energy level, which could result in some miscoordination of overcurrent devices.
   c. In this particular case, the key area became the 480V switchgear. Without changing the working distance, the incident energy in this area could have been reduced by reducing the clearing times for faults above and below the main 480V circuit breaker.

REEVALUATION BASED ON 1584-2018

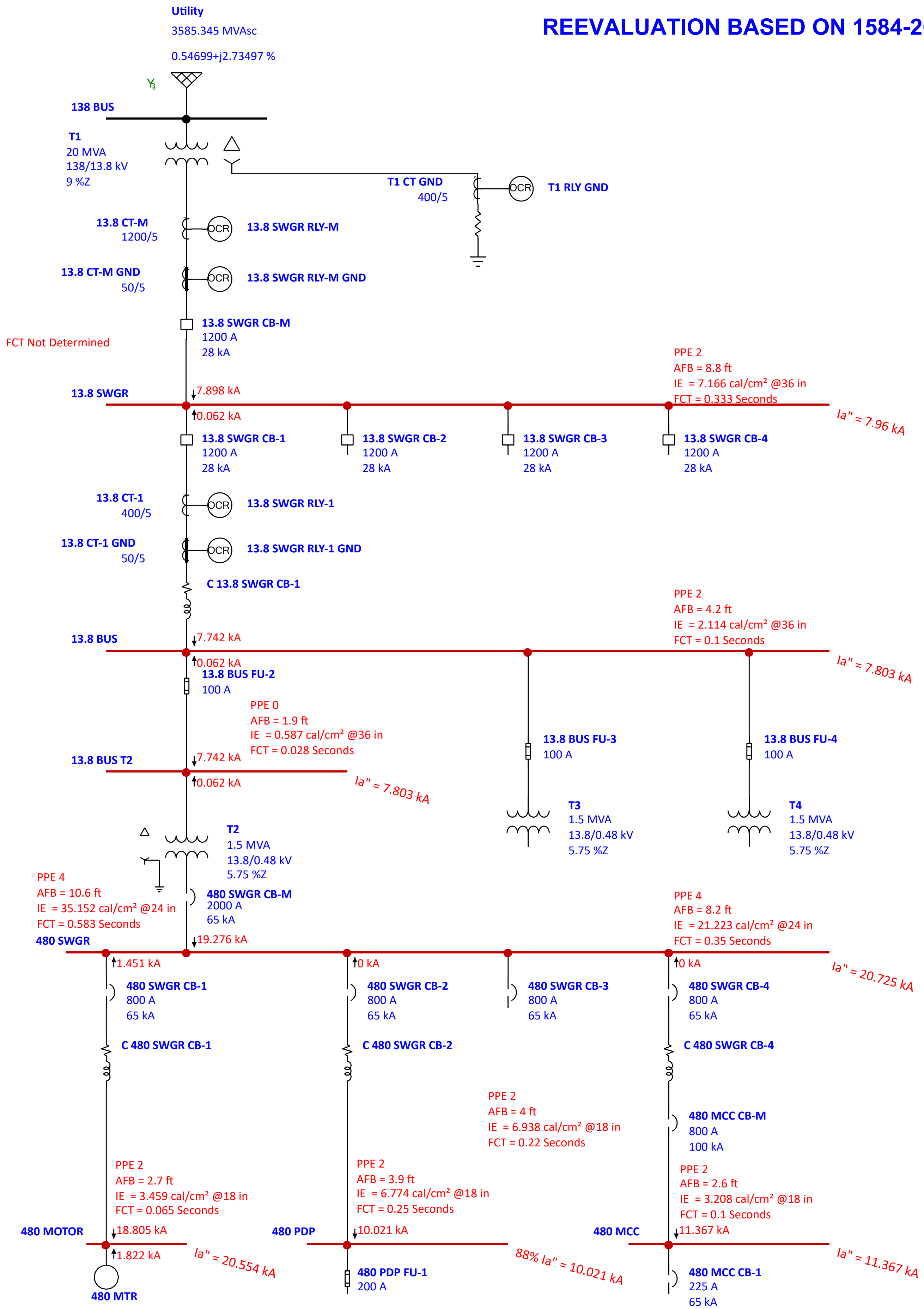

Figure 7

Table 4 - Step 1 --> Choose Appropriate Electrode Configurations

Bus	Voltage (kV)	Equipment Type	2002 Working Distance (Inches)	Enclosure Dimensions (Inches) H	x W	x D	Clearing Time (seconds)	Incident Energy (cal/cm²) 2002	2018 Electrode Configuraton	2018
13.8 SWGR	13.8	Switchgear	36	45	30	30	0.33	4.7	HCB	7.2
13.8 BUS	13.8	Switchgear	36	45	30	30	0.10	1.4	HCB	2.1
13.8 BUS T2	13.8	Switchgear	36	45	30	30	0.03	0.4	HCB	0.6
480 SWGR CB-M	0.48	LVCB	18	20	20	20	0.58	28.6	HCB	63.0
480 SWGR	0.48	Switchgear	18	20	20	20	0.35	17.3	HCB	38.1
480 MOTOR	0.48	Other	18	14	12	8	0.07	3.7	VCBB	3.5
480 PDP	0.48	Panelboard	18	14	12	8	0.25	7.0	VCBB	6.8
480 MCC	0.48	MCC	18	14	12	8	0.10	2.9	VCBB	3.2

Table 5 - Step 2 --> Consider Working Distance Changes

Bus	Voltage (kV)	Equipment Type	2018 Working Distance (Inches)	Enclosure Dimensions (Inches) H	x W	x D	Clearing Time (seconds)	Incident Energy (cal/cm²) 2002	2018 Electrode Configuraton	2018
13.8 SWGR	13.8	Switchgear	36	45	30	30	0.33	4.7	HCB	7.2
13.8 BUS	13.8	Switchgear	36	45	30	30	0.10	1.4	HCB	2.1
13.8 BUS T2	13.8	Switchgear	36	45	30	30	0.03	0.4	HCB	0.6
480 SWGR CB-M	0.48	LVCB	24	20	20	20	0.58	28.6	HCB	35.2
480 SWGR	0.48	Switchgear	24	20	20	20	0.35	17.3	HCB	21.2
480 MOTOR	0.48	Other	18	14	12	8	0.07	3.7	VCBB	3.5
480 PDP	0.48	Panelboard	18	14	12	8	0.25	7.0	VCBB	6.8
480 MCC	0.48	MCC	18	14	12	8	0.10	2.9	VCBB	3.2

Table 6 - Step 3 --> Determine PPE Levels

Bus	Voltage (kV)	Equipment Type	2018 Working Distance (Inches)	Enclosure Dimensions (Inches) H	x W	x D	Clearing Time (seconds)	PPE Level (2 or 4) 2002	2018 Electrode Configuraton	2018
13.8 SWGR	13.8	Switchgear	36	45	30	30	0.33	2	HCB	2
13.8 BUS	13.8	Switchgear	36	45	30	30	0.10	2	HCB	2
13.8 BUS T2	13.8	Switchgear	36	45	30	30	0.03	2	HCB	2
480 SWGR CB-M	0.48	LVCB	24	20	20	20	0.58	4	HCB	4
480 SWGR	0.48	Switchgear	24	20	20	20	0.35	4	HCB	4
480 MOTOR	0.48	Other	18	14	12	8	0.07	2	VCBB	2
480 PDP	0.48	Panelboard	18	14	12	8	0.25	2	VCBB	2
480 MCC	0.48	MCC	18	14	12	8	0.10	2	VCBB	2

Electrode Configurations Chosen (yellow)

Working Distance Change (peach)

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