# CREATING A COMPARATIVE MAP OF RELATIVE POWER FOR DC ARC FLASH METHODOLOGIES

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# ABSTRACT

Creating a Comparative Map of Relative Power for DC Arc Flash Methodologies

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Although arc flash has been a concern amongst the electrical industry for many years, it is only relatively recently that standards by the IEEE have been established on calculating the amount of energy behind an arc flash event. However, these standards only apply to AC systems, where extensive testing and research have been performed. Although the NFPA has provided recommendations on how to calculate the incident energy for DC arc flash events, these have not become the defining standard like those seen for AC. One equation outlined in the NFPA70E, the Maximum Power Method, does provide engineers with a formula to calculate DC arc flash incident energy but as the NFPA states this can be quite conservative. However, the NFPA70E also mentions a Detailed Arcing Current and Energy Calculations Method which contains formulas proposed by various researchers who conducted their own DC arc flash testing but there is scarce info on how these methods compare to the Maximum Power Method.

This paper will investigate the relative power of two of the formulas proposed in the alternate method, the results from Stokes/Oppenlander and the results from Paukert, over a variety of parameters that affect DC arcing power. These will then be compared to relative power of the Maximum Power Method, as well as the relative power of the AC equations formed from measurements. Although the results in this paper are not aiming to be a defining standard, the aim is to provide engineers with information on when one methodology is more suitable to use for a given set of certain parameters.

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# 1. Introduction

Arc flash is a topic that has increased in popularity and awareness over the past few decades. Although the hazard itself has been around for much longer, it is only relatively recently that awareness on the topic has become a mainstream concern. Because of the risks and hazards present from an arc flash, safety agencies such as the National Fire Protection Association (NFPA) and the Occupational Safety and Health Administration (OSHA) have been involved, with the latter being able to fine companies and pursue legal action if an employer does not provide guidelines for assessing an arc flash hazard or provides its employees with the proper protection against an arc flash event. OSHA standards for assessing an arc-flash hazard and determining an estimate for the amount of incident energy during an arc flash often reference the standards created in the NFPA70E, as well as the methods created by the Institute of Electrical and Electronics Engineers (IEEE) in their standard that deals with arc flash calculations, IEEE1584.

Although the standards set by IEEE were published in 2002 and have been the defining method for calculating incident energy, these standards are limited in that they only apply to alternating current (AC) systems under certain parameters. While these standards will suffice for the majority of the systems encountered, the push for “green” and renewable energy also introduces more and more systems using direct current (DC) power such as photovoltaic (PV) solar installations and wind energy or batteries used for energy storage. Not only this, but the exponential increase of computers and the Internet

over the past few decades has in turn significantly multiplied the need for servers to deal with data storage. Because many companies rely on storing and accessing data at any time, the increase of uninterruptible power supply (UPS) modules has also increased, which also use DC power in the form of batteries. However, unlike the AC systems which compose the majority of the power systems we use, DC systems do not have defining standards for arc flash calculations.

The NFPA70E does offer a few calculation methodologies to conduct a DC arc flash system assessment, the most prominent being the Maximum Power Method, however these had not the extensive testing that the equations for AC testing have had. In fact, the NFPA70E states that this calculation method is “conservatively high”. The NFPA70E does provide an alternate calculation methodology, the Detailed Arcing Current and Energy Calculations Method, based on an IEEE paper but it merely references the paper and does not go into detail so it is hard to know how the two methods compare.

The goal of this thesis is to compare the arcing power delivered to DC systems based on the methodologies proposed by NFPA70E: the Maximum Power Method, and the equations proposed by Paukert and Stokes/Oppenlander as seen in the Detailed Arcing Current and Energy Calculations Method. Chapter 2 gives an overview of the developments in arc flash calculations, starting with a history of the research done for AC calculations and then proceeding to recount the work done for DC calculations. Chapter 3 will detail the methodology used for the comparison. Chapter 4 displays the results and findings. Chapter 5 reports the conclusions made and gives a brief look into further steps.

# 2. Background

## 2.1. History of AC Arc Flash

AC arc flash was first brought to people's attention by Ralph Lee in his paper *The Other Electrical Hazard: Electrical Arc Blast Burns* which was the first official publication to identify arc flash as a hazard and provide a calculation method to assess an arc flash hazard [1]. In order to formulate the equations, Lee essentially considered the arcs as spheres, and then used heat transfer theory to determine the arc energy as shown in Figure 1 below.

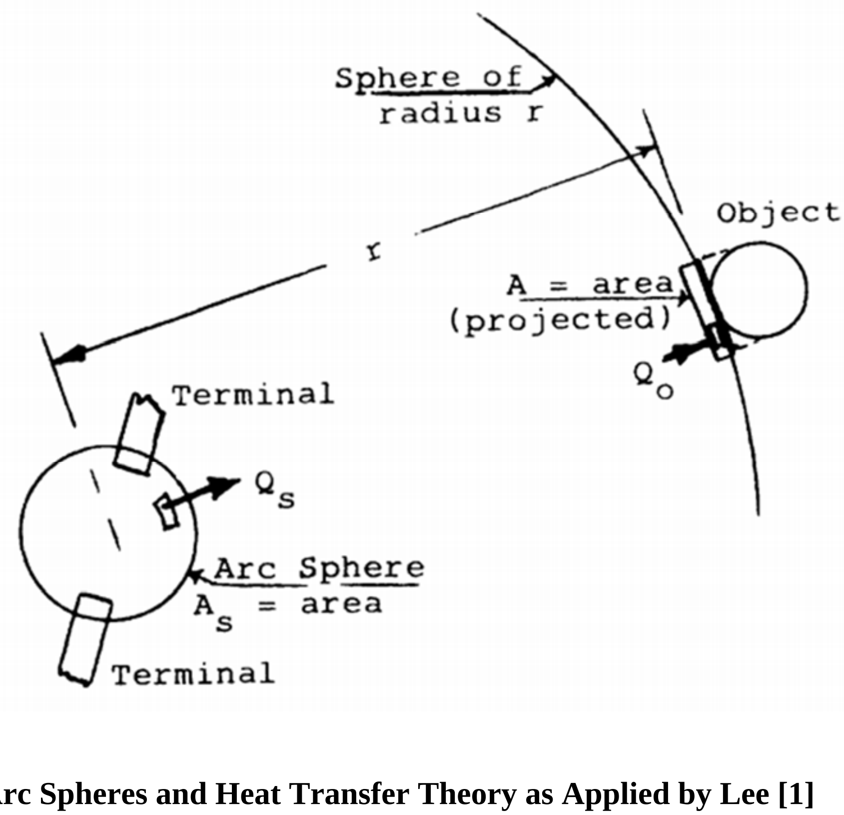



**Figure 1: Arc Spheres and Heat Transfer Theory as Applied by Lee [1]**

Lee realized that the size of the sphere was determined by the arcing current and the voltage drop across the arc, which equals the power delivered to the arc. By treating the arc as an impedance as part of a Thevenin equivalent circuit as seen in Figure 2, Lee was able to formulate his equations.

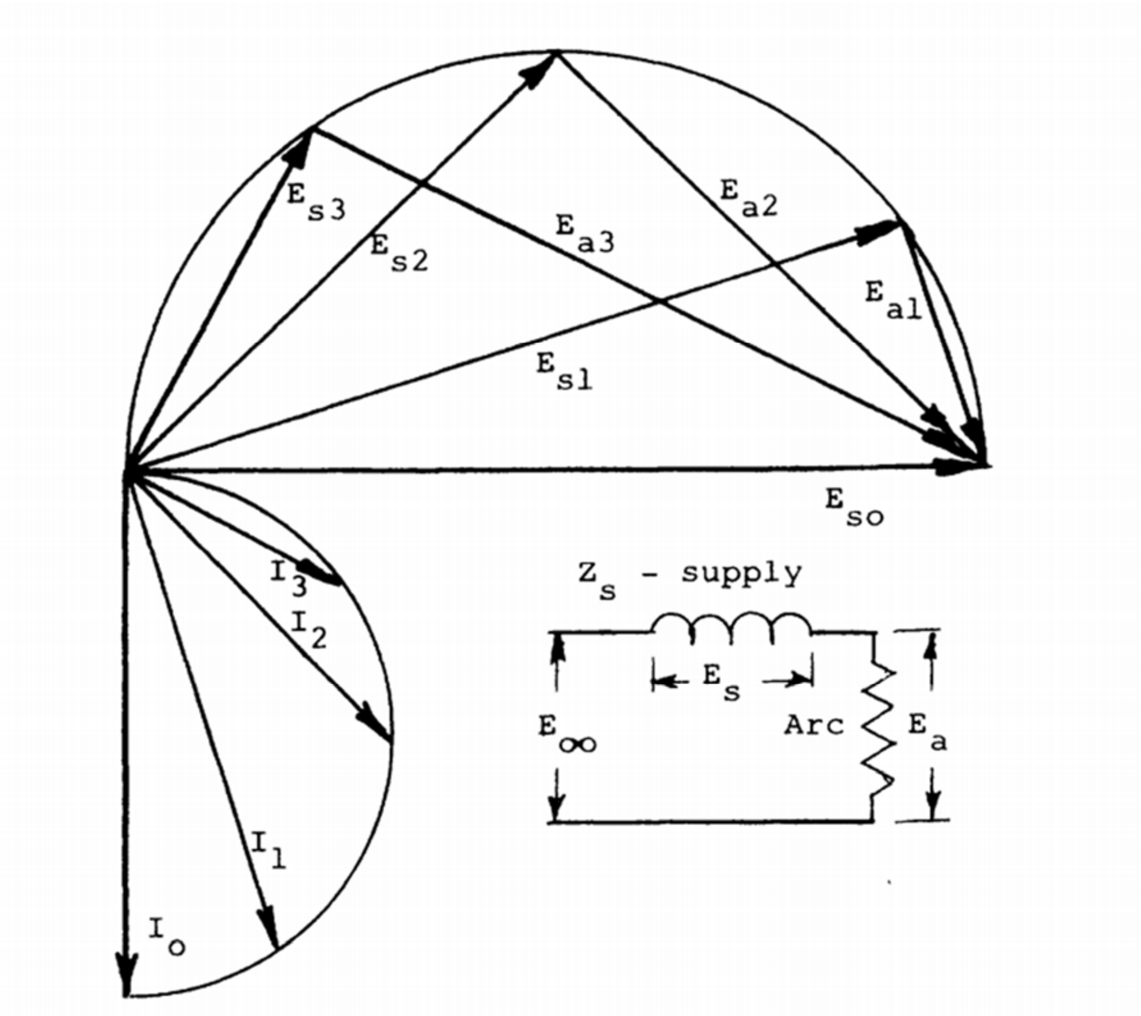



**Figure 2: Thevenin Equivalent Circuit and Vectors Showing Arc Size [1]**

However, determining the arc voltage and current or arcing impedance in the system is a difficult task as "free-burning arcing faults are extremely chaotic in nature" [2] and there are various factors such as electromagnetic forces and electrode material

that constantly change the arc's length and geometry. In order to estimate the arc impedance, Lee went back to circuit theory basics and used the Maximum Power Transfer theory which states that the maximum power delivered to a load is through impedance matching, or when the load impedance matches the equivalent input source impedance. For example, in Figure 3 if the arc impedance Za were to match the system impedance Zs, this would result in the maximum power delivered to the arc.

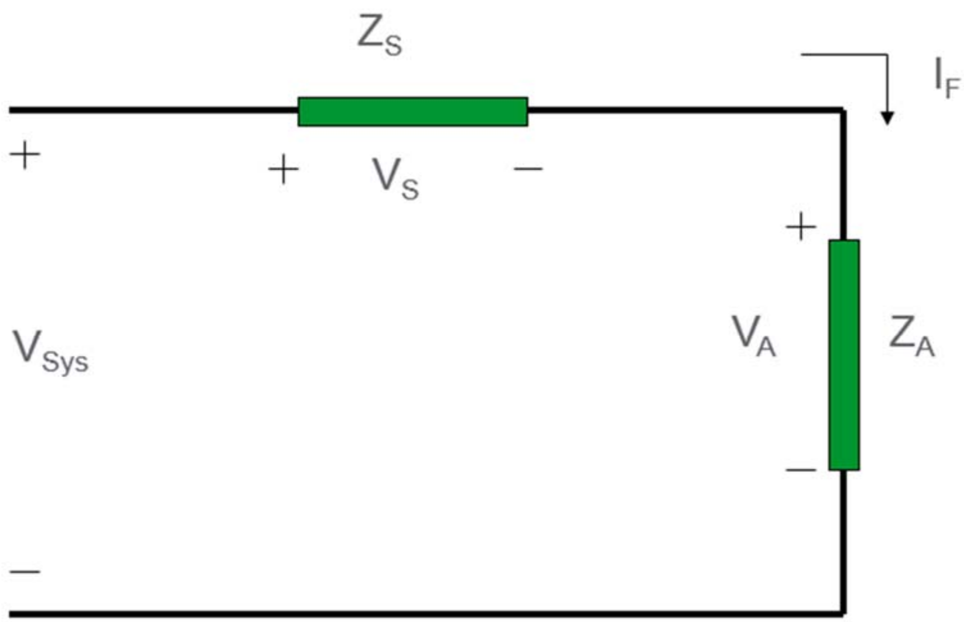



**Figure 3: Thevenin Circuit and Arc Impedance Load Za**

Lee then used these system conditions to formulate equations that calculated the distances for "just curable burns" and "just fatal burns" (or incurable). Despite some of the factors that Lee considered which later proved to be irrelevant to calculations, such as color of personal protective equipment (PPE), color and cleanliness of skin, his work was very influential since it was the first official paper to offer any sort of calculation method

for assessing an arc flash hazard and he provided the first recommendations for arc flash PPE.

Lee's use of the Maximum Power transfer theory also led to the development of equations to estimate the energy as seen in IEEE 1584 and the NFPA70E and shown below. It should be noted that from this point on, unless otherwise noted, any mention of energy refers to incident energy, which is actually energy density or energy per unit area.

$$\mathbf{E = 2.142 \times 10^6 V I_{bf} \left(\frac{t}{D^2}\right)} \qquad (2\text{-}1)$$

where E is the incident energy in terms of J/cm$^2$, V is the system voltage in kV, $I_{bf}$ is the bolted fault current in kA, t is the arcing time in seconds, and D is the distance from the arc to the person or working distance in mm. Lee's equation is still used for situations where the IEEE 1584 equations are not applicable such as certain bus gaps, fault currents, and voltages.

With Lee's paper on arc flash published, awareness of the hazard began to grow in the industry, however there was no concentrated effort to mitigate the hazard until some incidents and fatalities sparked the interest to gain a better understanding of arc flashes. This led to a joint research effort between IEEE and NFPA to fund and support testing on the subject [3]. Although there are several methods for assessing an arc flash hazard including the use of tables and other calculation methods, the research done by the joint project provides the calculation methods and equations as published in IEEE 1584 which has become a popular industry standard since the equations are based off extensive testing.

The research and testing provided a set of equations for calculating the arcing current and incident energy of an arc under certain conditions. The resulting equation for calculating the arcing current for a system voltage less than 1000V (but at least 208V) is as follows:

$$\mathbf{\log I_a = K + 0.662\log I_{bf} + 0.0966V + 0.000526G + 0.5588V * \log I_{bf} - 0.00304G * \log I_{bf}} \quad (2\text{-}2)$$

where $I_a$ is the arcing current (kA), K is -0.153 for open configurations and -0.097 for box configurations, $I_{bf}$ is the bolted three-phase fault current (kA symmetrical RMS), V is the system voltage (kV) and G is the gap between conductors (mm). For system voltages in the range of 1000V and 15kV, the equation for calculating the arcing current is as follows:

$$\mathbf{\log I_a = 0.00402 + 0.983 * \log I_{bf}} \qquad (2\text{-}3)$$

using the same applicable variables as the previous equation. Since the equations are in terms of log $I_a$, the actual arcing current can be found using the following identity:

$$\boldsymbol{I_a = 10^{\log I_a}} \quad (2\text{-}4)$$

To find the incident energy for voltages from 208V to 15kV, the normalized incident energy must first be calculated using the following equations:

$$\mathbf{\log E_n = K_1 + K_2 + 1.081 * \log I_a + 0.0011G} \quad (2\text{-}5)$$

Then En is calculated from its log as:

$$\mathbf{E_n = 10^{\log E_n}} \quad (2\text{-}6)$$

where $E_n$ is the normalized incident energy (J/cm$^2$), $K_1$ is -0.792 for open configurations and -0.555 for box configurations, $K_2$ is 0 for ungrounded and high-resistance grounded systems and -0.113 for grounded systems, and G is the gap between conductors (mm). In order to find the actual incident energy, it must be converted from the normalized value using the following equation:

$$\mathbf{E = 4.184 C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{D^x}\right)} \quad (2\text{-}7)$$

where E is the incident energy (J/cm$^2$), Cf is 1.0 for voltages above 1kV and 1.5 for voltages 1kV and less, $E_n$ is the normalized incident energy, t is the arcing time (sec), D is the distance from the possible arc point to the person (mm), and x is a distance exponent as shown in Table 1. Note that although the energy is in terms of J/cm$^2$, it is more common in the United States to define the energy in terms of cal/cm$^2$.

**Table 1: IEEE 1584 Table 6 Showing Typical Bus Gap Values**

| System voltage (kV) | Equipment type | Typical gap between conductors (mm) | Distance *x* factor |
|---|---|---|---|
| 0.208–1 | Open air | 10–40 | 2.000 |
| | Switchgear | 32 | 1.473 |
| | MCC and panels | 25 | 1.641 |
| | Cable | 13 | 2.000 |
| > 1– 5 | Open air | 13–102 | 2.000 |
| | Switchgear | 13–102 | 0.973 |
| | Cable | 13 | 2.000 |
| > 5–15 | Open air | 13–153 | 2.000 |
| | Switchgear | 153 | 0.973 |
| | Cable | 13 | 2.000 |

Through these tests, various observations were made about the factors that affected arc flash characteristics and the resulting incident energy. For instance, it was seen that the system X/R ratio, frequency, electrode material, and some other variables had a negligible effect on the arc current and incident energy. It was also observed that the system grounding had a minor effect on the accuracy of the developed equations. The arcing current depended mainly on the amount of available fault current with bus gap (distance between conductors), system voltage as smaller factors. The incident energy in turn was affected by the arcing current and arcing time. The incident energy had an inverse exponential effect with the distance from the arc [4]. It was also seen that the exponent varied if the arc was in an open configuration or in a box, with the box leading to higher incident energy. This was significant since arc flash situations are more likely to occur for in-a-box configurations.

Despite the more accurate equations based off testing and published in IEEE 1584, as seen in the NFPA 70E, these equations are limited to certain system conditions such as certain bus gap, current, and voltage ranges. Lee's equations are still used for scenarios outside the limitations of the IEEE 1584 methodologies although they are conservative. Although Lee's equations were considered to be on the conservative side, they were not too far off from the results for low voltage cases, as confirmed by the joint research. Lee's equations and in particular his use of the Maximum Power Transfer theory were later applied to DC arc flash analysis.

## 2.2. History of DC Arc Flash

Although there was a development of standards for assessing AC arc flash hazards, there was a lack of information for calculating DC arc flash energy. However, engineers and safety personnel may sometimes ask what amount of PPE would be required when working with DC systems [5]. Daniel Doan used Lee's approach with the Maximum Power Transfer theorem and applied it to DC circuits.

Referring back to Figure 3, since the maximum power conditions would result in the resistances of the arc and the system being equal, this would thus result in the arcing voltage being half of the system voltage as seen in the equation below for a voltage divider:

$$\mathbf{V_{arc} = V_{sys}\frac{R_A}{R_s+R_A} = V_{sys}\frac{R_A}{R_A+R_A} = \frac{V_{sys}}{2}} \qquad (2\text{-}8)$$

Using this result and impedance matching, it can be shown that at maximum power, the arcing current is half of the fault current:

$$\mathbf{P_{max} = I_{arc}V_{arc} = \frac{V_{arc}^2}{R_{arc}}} \qquad \text{(2-9)}$$

$$\mathbf{I_{arc} = \frac{V_{arc}}{R_{arc}} = \frac{V_{sys}}{2R_{arc}} = \frac{V_{sys}}{2R_{sys}} = \frac{I_{sys}}{2}} \qquad \text{(2-10)}$$

where $I_{sys}$ is equal to the fault current. Using the fact that at maximum power, the arc voltage is half the system voltage and that the arc impedance is equal to the system impedance yields the following equation for maximum power:

$$\mathbf{P_{max} = \frac{V_{arc}^2}{R_{arc}} = (V_{sys}/2)^2/R_{sys}} \qquad \text{(2-11)}$$

Since power is energy over a certain time period, energy can be considered the product of power and time. Using the above equation, and converting from Joules to calories (1 J = 0.239 cal) yields the following equation for energy:

$$\mathbf{E_{max\,power} = 0.239 * \frac{(V_{sys}/2)^2}{R_{sys}} T_{arc}} \qquad \text{(2-12)}$$

Arc flash incident energy is defined as energy per area so by treating the arc flash as a sphere as Lee did:

$$\mathbf{Area_{sphere} = 4 * 3.14 * D^2} \qquad \text{(2-13)}$$

Dividing the maximum energy by the area of sphere and simplifying yields the following equation for determining the incident energy for DC arc flashes:

$$\mathbf{E_{max\,power} = 0.005 * \left(V_{sys}^2/R_{sys}\right) * \frac{T_{arc}}{D^2}} \qquad \text{(2-14)}$$

However, as mentioned by the NFPA 70E, early testing has shown that this method is conservatively high and limited up to 1000V [6].  Doan also states that many assumptions are made using this simplified approach and that the system must be carefully assessed for different situations such as a lower arcing fault but longer arcing time or using a multiplying factor for arcing fault is in an enclosure.

The NFPA 70E and an update to Doan's paper both present an alternate paper by Ammerman et al. that provides alternate calculation methods based on early DC arc researchers and the tests they performed.  However, these tests were limited in the scope examined and the researchers often failed to specify under what conditions the tests were performed [2].

One of the problems with Doan's approach of using the Maximum Power Method is that this assumes the arc impedance follows a linear model through Ohm's law (V = IR).  However, because of the dynamic and complex nature of arcs, they do not follow a linear model.  For one thing, the arc voltage (and therefore the arc impedance) is dependent on the arc length.  An example profile showing the voltage gradient affected by the arc length is shown in Figure 4 below.

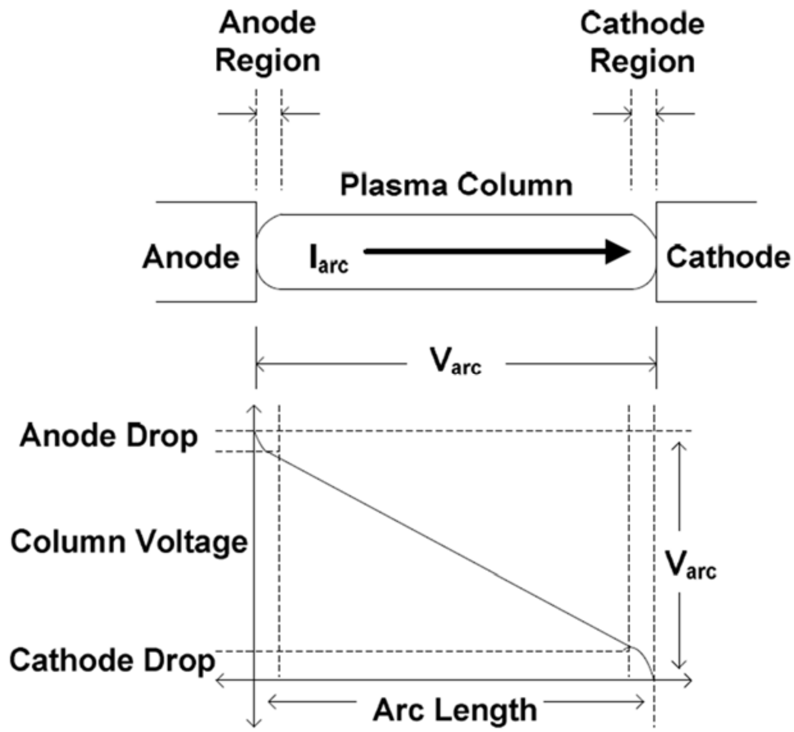



**Figure 4: Electrical Arc Characterization Showing Voltage Gradient [2]**

Unlike resistors which show a linear increase in voltage proportional to the current, V-I characteristics of arcs (for a fixed length) shows a different profile that depends on the region of current examined. For low currents, the arc voltage has an inverse relationship with the arc current and decreases as current increases. Thus, arc power (P=VI) remains relatively constant. Increasing the current past a transition current the characteristics change. For currents higher than this transition, the voltage increases slightly as the current increases but for the most part, remains relatively constant [2]. The V-I characteristics of an arc are shown in Figure 5 below.

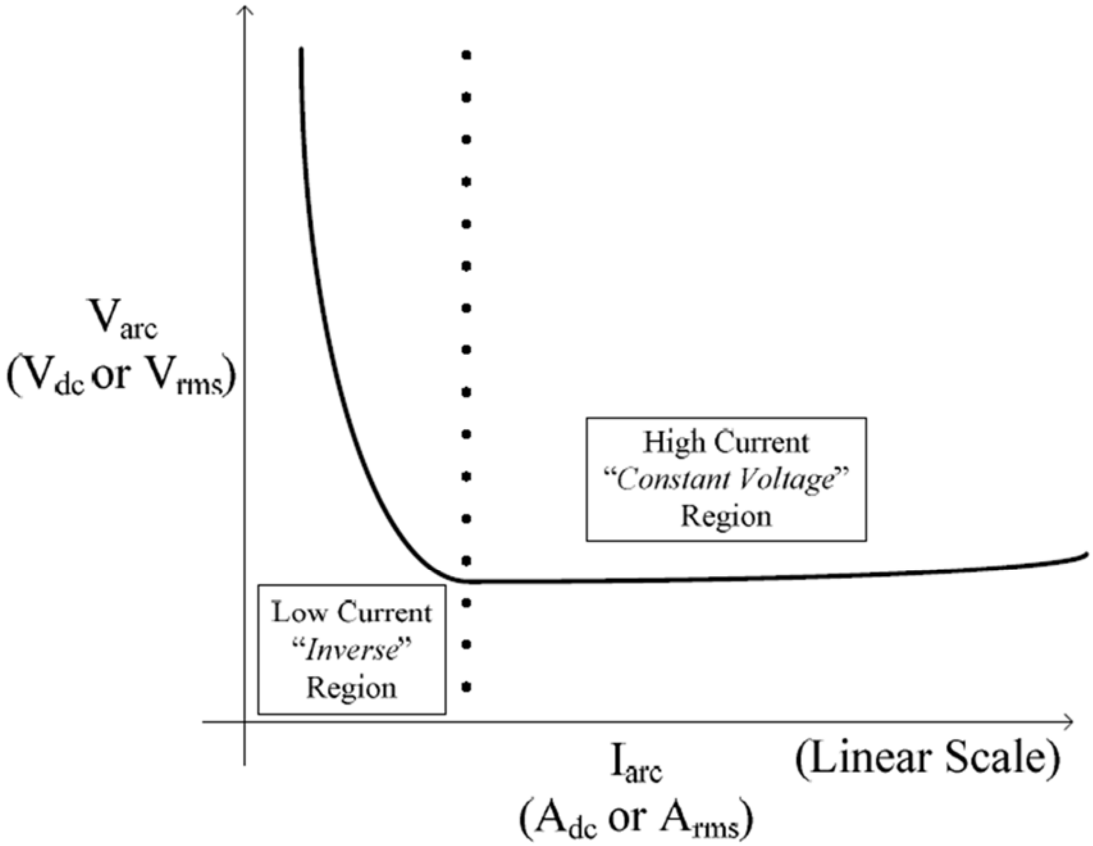



**Figure 5: V-I Characteristics of an Arc [2]**

One issue researchers have had in defining equations that capture V-I characteristics is measuring the arc length. While the arcing voltage and arcing current can be measured easily enough, as seen in Figure 6, the arc length is difficult to measure due to the dynamic nature of arcs and can vary greatly. Although the length of the arc may approximately equal the bus gap length under certain conditions (series electrodes, low currents, and short gap widths), the arc length may be significantly longer than the gap width [2]. However, many researchers use the gap width in the equations since this

parameter can actually be measured but it should be noted that the arcing impedance is dependent on the actual arc length.

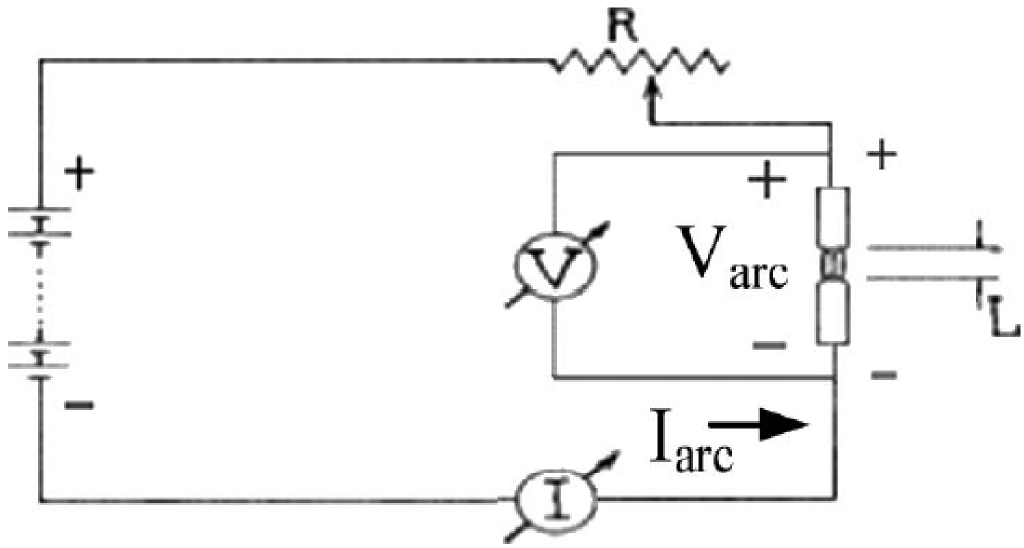



**Figure 6: Test Circuit for Measuring DC Arc Characteristics [2]**

Although Ammerman et al. presented the equations of various researchers and experimenters in their paper, the focus of their paper and this thesis is the results of two researchers, Stokes/Oppenlander and J. Paukert. Stokes/Oppenlander conducted studies on vertical and horizontal arcs in open air looking at currents from 0.1A to 1,000A, for 50Hz arcs with amplitudes from 30A to 20kA [7]. With their results, Stokes/Oppenlander found that a minimum arc voltage for series electrodes was needed to sustain the arc, with the voltage being dependent on the arcing current magnitude, gap width, and electrode orientation as seen in Figure 7 and Figure 8 below. The continuous lines represent measured data while the broken lines represent the formulated equations by Stokes/Oppenlander for calculating the arcing voltage.

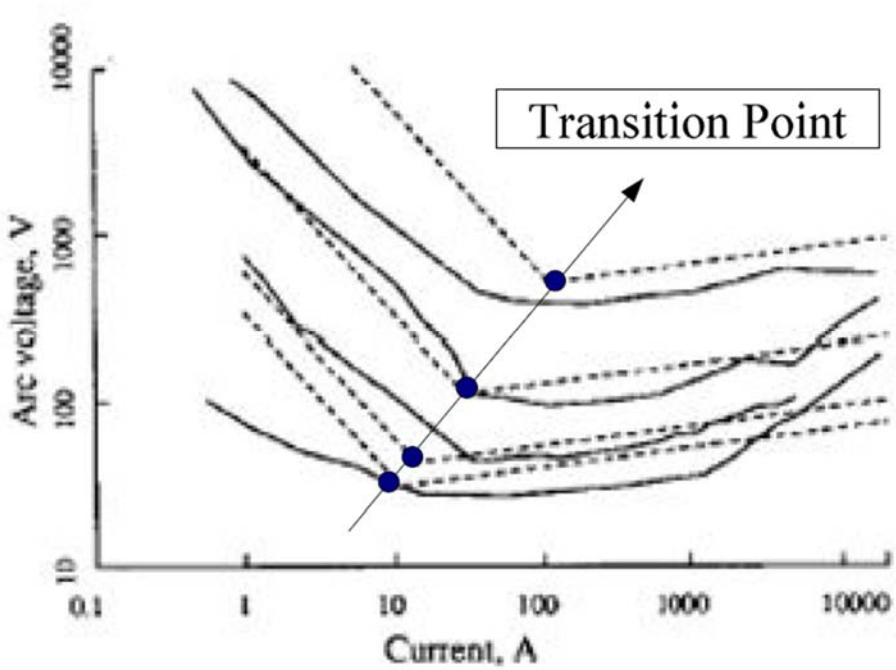



**Figure 7: Minimum Arc Voltage for Horizontal Arcs [2]**

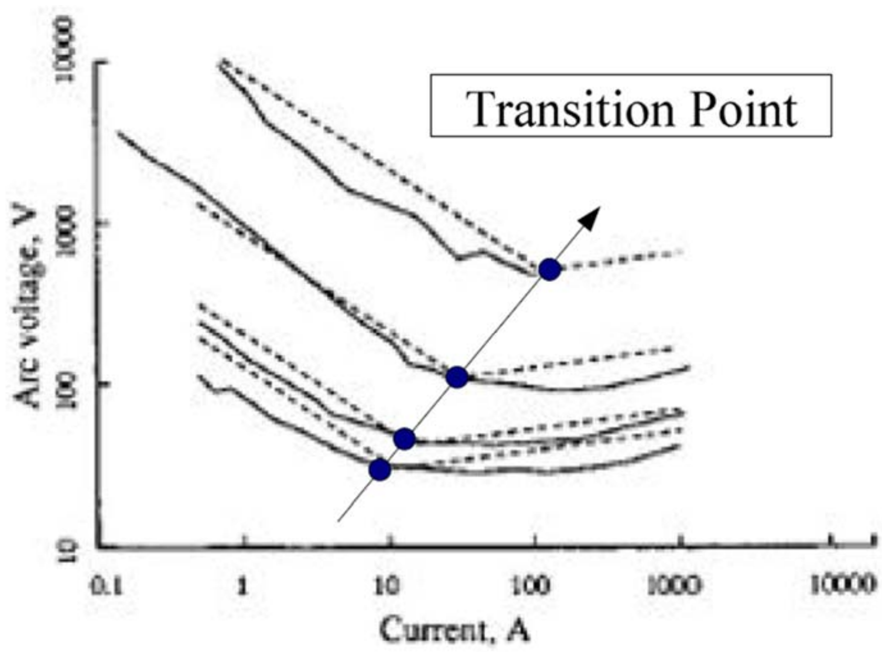



**Figure 8: Minimum Voltage for Vertical Arcs [2]**

Each of the lines represents the results at different gap widths. As seen earlier with the V-I characteristics for an arc, there is a transition point where the arcing voltage starts to slowly increase as current increases rather than decreasing with rising current. The transition current point is defined by the equation below

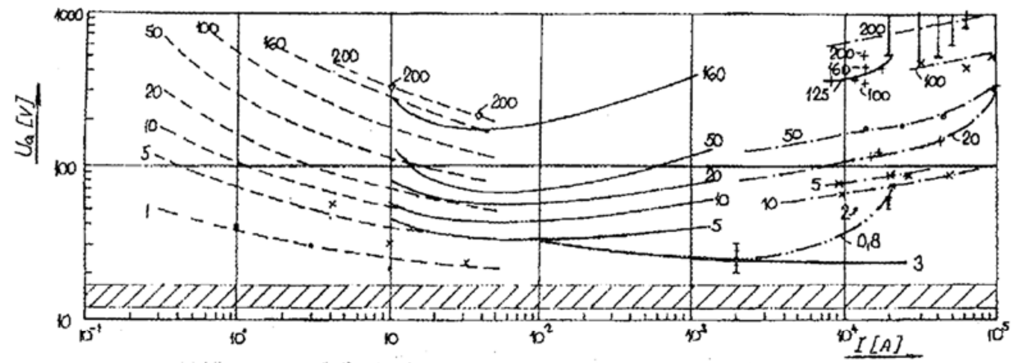
$$\mathbf{I_t = 10 + 0.2z_g} \qquad \text{(2-15)}$$

where $z_g$ is the length of the gap expressed in mm [7]. As mentioned above, a formula for calculating the arc voltage based on the gap width and arc current was developed as shown below. The equation is also rewritten to be in terms of arc resistance and shows the current-voltage characteristics [7].

$$\mathbf{V_{arc} = (20 + 0.534z_g)I_{arc}^{0.12}} \quad \text{(2-16)}$$

$$\mathbf{R_{arc} = \frac{20+0.534z_g}{I_{arc}^{0.88}}} \qquad \text{(2-17)}$$

where $z_g$ is the length of the gap expressed in mm. Paukert also published an article presenting the arc voltage characteristics by compiling data from published work from several researchers, including Stokes/Oppenlander, as well as his own work [2]. Paukert compiled data covered both horizontal and vertical arcs and a range of arcing currents from 0.3A to 100kA and electrode gaps of 1 to 200mm [8]. The results of his work are shown in Figure 9 below.




| Marking | Author | Electrodes | Current | Arc |
|---|---|---|---|---|
| — — — — | Rieder [2] | Cu ⌀ 6 | DC | vertical |
| ——— V | Amft [3] | Mo | DC | vertical |
| — · — · — | Rybář [4] | Cu horns 10x30...500 | 50 Hz | horizontal |
| — · — · — | Paukert [5] | Cu horns 10x30...500 | 50 Hz | horizontal |
| ——— + | Harča [6] | Cu 30x5 | 50 Hz | not stated |
| ━━━ | Burkhard [7] | Fe, Cu plated, 2 mm | 50 Hz | horizontal |
| — · · — · · | Gremmel [8] | ⌀ 8, Ag, Cu, CuCr | impulse | vertical |

**Figure 9: Paukert's Compiled Data [8]**

Based on this data, Paukert was able to formulate equations to calculate the arc voltage and arc resistance, but unlike Stokes/Oppenlander, the equations would change depending on the gap width as seen in the Tables below [2]:

**Table 2: Arc Voltage and Resistance Formulae for Arc Current < 100A [2]**

EMPIRICAL ARC FORMULAE FOR $I_{arc}$ < 100 A [18]

| Electrode Gap (mm) | Arc Voltage (V) | Arc Resistance (Ω) |
|---|---|---|
| 1 | $36.32\ I_{arc}^{-0.124}$ | $36.32\ I_{arc}^{-1.124}$ |
| 5 | $71.39\ I_{arc}^{-0.186}$ | $71.39\ I_{arc}^{-1.186}$ |
| 10 | $105.25\ I_{arc}^{-0.239}$ | $105.25\ I_{arc}^{-1.239}$ |
| 20 | $153.63\ I_{arc}^{-0.278}$ | $153.63\ I_{arc}^{-1.278}$ |
| 50 | $262.02\ I_{arc}^{-0.310}$ | $262.02\ I_{arc}^{-1.310}$ |
| 100 | $481.20\ I_{arc}^{-0.350}$ | $481.20\ I_{arc}^{-1.350}$ |
| 200 | $662.34\ I_{arc}^{-0.283}$ | $662.34\ I_{arc}^{-1.283}$ |

**Table 3: Arc Voltage and Resistance Formulae for Arc Current > 100A up to 100kA [2]**

EMPIRICAL ARC FORMULAE FOR 100 A < $I_{arc}$ < 100 kA [18]

| Electrode Gap (mm) | Arc Voltage (V) | Arc Resistance (Ω) |
|---|---|---|
| 1 | $13.04\ I_{arc}^{0.098}$ | $13.04\ I_{arc}^{-0.902}$ |
| 5 | $14.13\ I_{arc}^{0.211}$ | $14.13\ I_{arc}^{-0.789}$ |
| 10 | $16.68\ I_{arc}^{0.163}$ | $16.68\ I_{arc}^{-0.837}$ |
| 20 | $20.11\ I_{arc}^{0.190}$ | $20.11\ I_{arc}^{-0.810}$ |
| 50 | $28.35\ I_{arc}^{0.194}$ | $28.35\ I_{arc}^{-0.806}$ |
| 100 | $34.18\ I_{arc}^{0.241}$ | $34.18\ I_{arc}^{-0.759}$ |
| 200 | $52.63\ I_{arc}^{0.264}$ | $52.63\ I_{arc}^{-0.736}$ |

Paukert's data was shown to have good agreement with Stokes/Oppenlander as seen in Figure 10 and Figure 11 below. The bolded lines represent Paukert's data while the continuous lines are representative of the data presented by Stokes/Oppenlander.

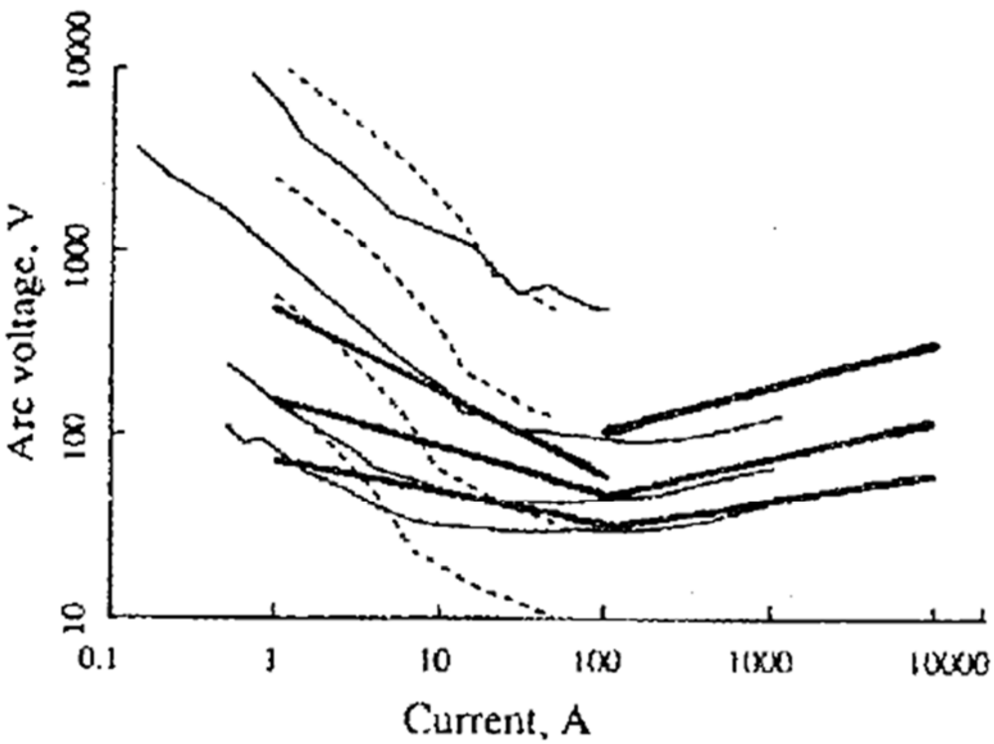



**Figure 10: Comparison of Stokes/Oppenlander Data with Paukert's Data for Horizontal Arcs [8]**

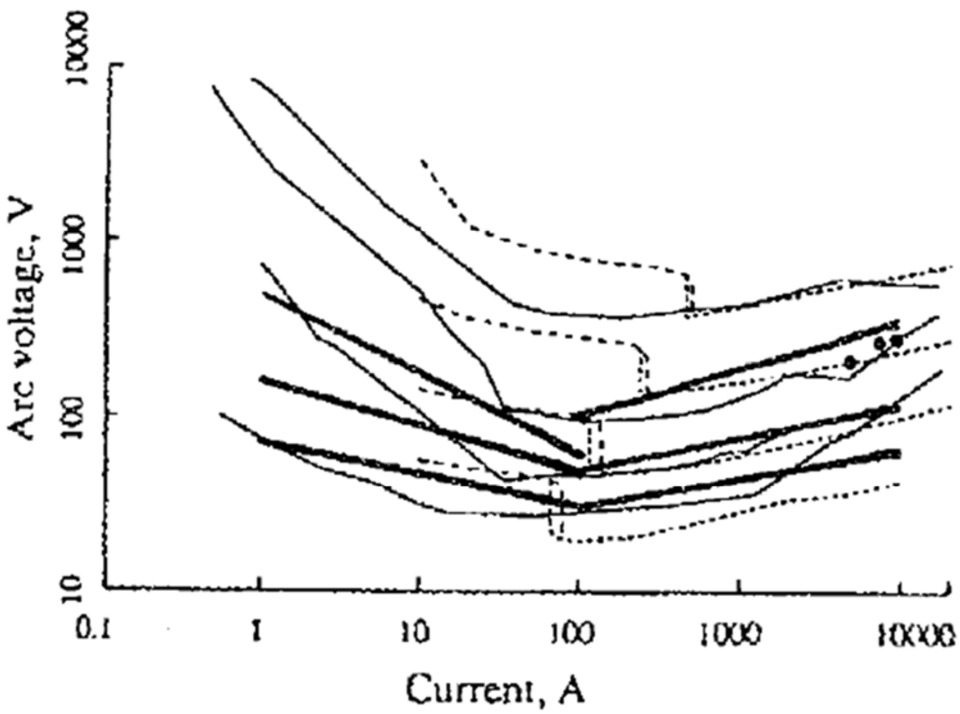



**Figure 11: Comparison of Stokes/Oppenlander Data with Paukert Data for Vertical Arcs [8]**

Despite the agreement, Paukert concluded, "Although the author's approximating formulae for minimal arc voltage and minimal arc resistance have been found to be in good agreement with other authors' results, the uncertainty connected with the determination of actual arc length will hamper their successful application for exact calculation…However, they can be valuable help for considerations about arc stability and for preliminary calculations [8]".

Ammerman et al. did their own comparison between the data of Stokes/Oppenlander and Paukert to analyze the arc resistance as seen in Figure 12 and Figure 13 below. Their data was used since their research included the largest number of

test points for DC arcs and it was found that the results were more or less consistent: arc resistance is nonlinear, decreases rapidly with increasing arc current for low magnitudes but approaches a constant value at high magnitudes, and increases linearly with the electrode gap for a given arc current [2]. In general, Paukert predicted larger arc resistances than Stokes/Oppenlander.

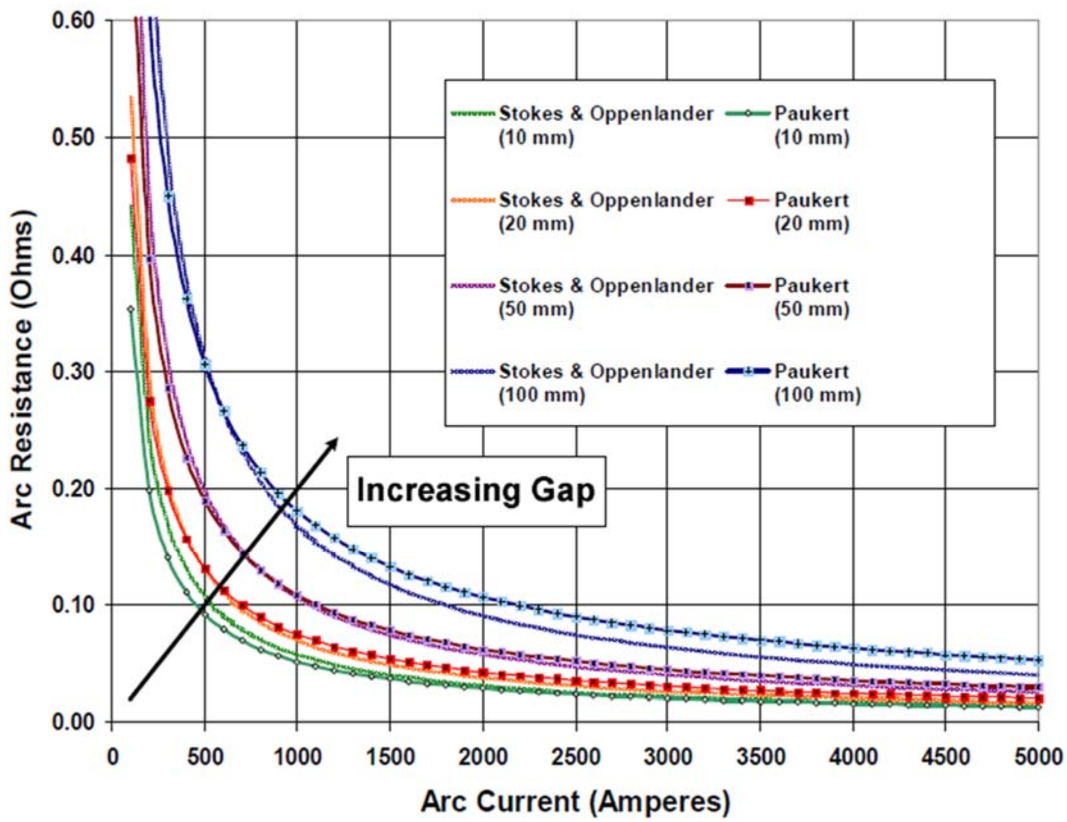



**Figure 12: DC Arc Resistance Comparison with Varying Bus Gap [2]**

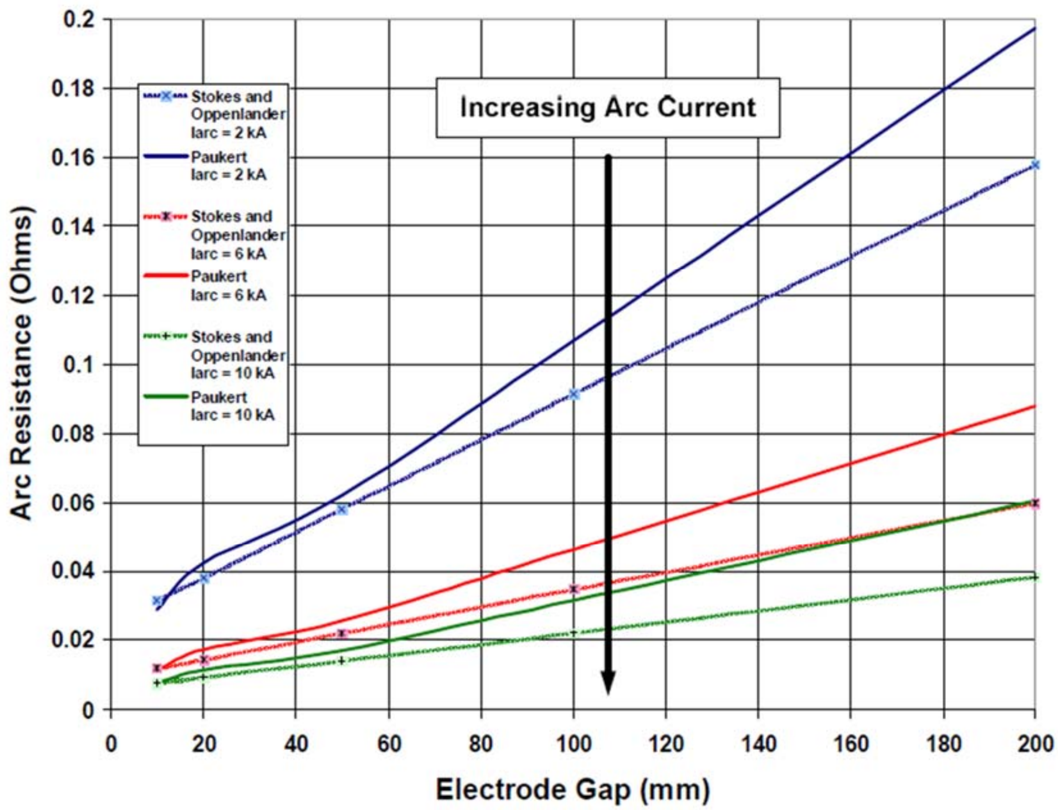



**Figure 13: DC Arc Resistance Comparison with Constant Arc Current [2]**

Although Stokes/Oppenlander and Paukert proposed equations which modelled the arcing resistance, it is really the incident energy that is the main concern. Since arc voltage, arc current, and arc resistance could be found using their equations, the power can easily be calculated. Using this information along with the arcing time to calculate the energy, Ammerman et al. then provided formulae based on the semi-empirical models to calculate the incident energy depending on whether the arc is in open-air or in-a-box as seen in the equations below:

$$\mathbf{E_s = \frac{E_{arc}}{4\pi d^2}\ (open - air)} \qquad (2\text{-}18)$$

$$\mathbf{E_1} = \mathbf{k}\frac{\mathbf{E_{arc}}}{\mathbf{a^2+d^2}} \ (\mathbf{arc - in - a - box}) \ (2\text{-}19)$$

It should be noted here that $E_{arc}$ is an energy term (J or cal) and is not energy density. $E_s$ and $E_1$, are the incident energy (energy density) for arcs in open-air and arc-in-a-box situations, respectively. The coefficients a and k are based on the type of enclosure and are as shown in Table 4 below [9]. The variable d is the distance from the arc or working distance, and $E_{arc}$ is the product of arc power and time.

**Table 4: Optimum Values of a and k as Proposed by Wilkins [2]**

| Enclosure | Width (mm) | Height (mm) | Depth (mm) | *a* (mm) | *k* |
|---|---|---|---|---|---|
| Panelboard | 305 | 356 | 191 | 100 | 0.127 |
| LV Switchgear | 508 | 508 | 508 | 400 | 0.312 |
| MV Switchgear | 1143 | 762 | 762 | 950 | 0.416 |

Although there are semi-empirical models that capture the nonlinear nature of arcs better than the Maximum Power method, there is not a wide knowledge of their presence as the NFPA 70E mentions the paper by Ammerman et al. only as a reference, but does not present the equations in the standard as it does with the Maximum Power method. Although the NFPA 70E states the Maximum Power method is conservatively high as mentioned earlier, there is not much comparison data on how it matches up to the semi-empirical models of Stokes/Oppenlander and Paukert.

Though the majority of arc flash calculations are performed for AC systems, the rising use of power electronics and DC equipment has increased the need to examine DC

arc flash. Customer requirements, and in a certain respect OSHA's, are requiring that a DC arc flash assessment is performed in order to protect electricians and other personnel when maintenance on DC equipment such as solar panel installations and UPS systems is performed. Although a conservative approach is better than underestimating the hazard, it is desirable to provide the accurate amount of incident energy available. Being under-protected is of course an issue but having too much protection can also lead to higher chances of an incident occurring due to the lack of visibility and maneuverability with PPE rated for higher incident energies. Table 5 below shows the PPE guidelines for selecting the appropriate arc-rated clothing based on the NFPA 70E 2015. As seen, as the amount of incident energy increases, the amount of arc-rated PPE required also increases. Although it is always recommended to wear the appropriate PPE for the task at hand, the thick nature of PPE makes the wearer uncomfortable due to heat stress and the lack of dexterity may make it even more difficult to perform the task thus it is desired to use less PPE if possible. However, with the lack of resources available to engineers regarding DC arc flash calculations, many engineers proceed with the conservative Maximum Power Method.

**Table 5: NFPA 70E 2015 PPE Guidelines [6]**

**Table H.3(b) Guidance on Selection of Arc-Rated Clothing and Other PPE for Use When Incident Energy Exposure Is Determined**

| Incident Energy Exposure | Protective Clothing and PPE |
|---|---|
| **≤ 1.2 cal/cm²** | |
| Protective clothing, nonmelting (in accordance with ASTM F 1506) or untreated natural fiber | Shirt (long sleeve) and pants (long) or coverall |
| Other PPE | Face shield for projectile protection (AN)<br>Safety glasses or safety goggles (SR)<br>Hearing protection<br>Heavy-duty leather gloves or rubber insulating gloves with leather protectors (AN) |
| **≥ 1.2 to 12 cal/cm²**<br>Arc-rated clothing and equipment with an arc rating equal to or greater than the determined incident energy *(See Note 3.)* | Arc-rated long-sleeve shirt and arc-rated pants or arc-rated coverall or arc flash suit (SR) *(See Note 3.)*<br>Arc-rated face shield and arc-rated balaclava or arc flash suit hood (SR) *(See Note 1.)*<br>Arc-rated jacket, parka, or rainwear (AN) |
| Other PPE | Hard hat<br>Arc-rated hard hat liner (AN)<br>Safety glasses or safety goggles (SR)<br>Hearing protection<br>Heavy-duty leather gloves or rubber insulating gloves with leather protectors (SR) *(See Note 4.)*<br>Leather footwear |
| **> 12 cal/cm²** | |
| Arc-rated clothing and equipment with an arc rating equal to or greater than the determined incident energy *(See Note 3.)* | Arc-rated long-sleeve shirt and arc-rated pants or arc-rated coverall and/or arc flash suit (SR)<br>Arc-rated arc flash suit hood<br>Arc-rated gloves<br>Arc-rated jacket, parka, or rainwear (AN) |
| Other PPE | Hard hat<br>Arc-rated hard hat liner (AN)<br>Safety glasses or safety goggles (SR)<br>Hearing protection<br>Arc-rated gloves or rubber insulating gloves with leather protectors (SR) *(See Note 4.)*<br>Leather footwear |

Also of note, another approach available for both AC and DC arc flash assessments is a table based approached per the NFPA 70E tables as seen in Table 6 below. To use the tables, the user would select the PPE based on where it lies in the table which would depend on the system conditions. Although this provides a simplistic way of selecting PPE, the table itself is very limited in the conditions it specifies and the process

for selecting PPE is oversimplified. For one, the tables also do not specify situations where the incident energy exceeds any PPE level that is recommended by the NFPA (formerly known as category Dangerous!). The tables also do not take into account efforts to mitigate the hazard such as maintenance settings on protective devices which would lower the amount of available incident energy. With the limitations of the tables it is thus preferred to use calculation methods to assess arc flash hazards.

**Table 6: NFPA 70E Table Method for Assessing a DC Arc Flash Hazard [6]**

**Table 130.7(C)(15)(B) Arc-Flash Hazard PPE Categories for Direct Current (dc) Systems**

| Equipment | Arc Flash PPE Category | Arc-Flash Boundary |
|---|---|---|
| Storage batteries, dc switchboards, and other dc supply sources<br><br>100 V > Voltage < 250 V<br>Parameters:<br>Voltage: 250 V<br>Maximum arc duration and working distance: 2 sec @ 455 mm (18 in.) | | |
| Short-circuit current < 4 kA | 1 | 900 mm<br>(3 ft) |
| 4 kA ≤ short-circuit current < 7 kA | 2 | 1.2 m<br>(4 ft) |
| 7 kA ≤ short-circuit current < 15 kA | 3 | 1.8 m<br>(6 ft) |
| Storage batteries, dc switchboards, and other dc supply sources<br><br>250 V ≤ Voltage ≤ 600 V<br>Parameters:<br>Voltage: 600 V<br>Maximum arc duration and working distance: 2 sec @ 455 mm (18 in.) | | |
| Short-circuit current 1.5 kA | 1 | 900 mm<br>(3 ft) |
| 1.5 kA ≤ short-circuit current < 3 kA | 2 | 1.2 m<br>(4 ft) |
| 3 kA ≤ short-circuit current < 7 kA | 3 | 1.8 m<br>(6 ft.) |
| 7 kA ≤ short-circuit current < 10 kA | 4 | 2.5 m<br>(8 ft) |

Oftentimes, customers would like to have a DC arc flash analysis performed in order to implement some sort of safety policy, however their knowledge on DC arc flash

calculations is even more limited so they leave it up to the engineer to determine the best approach. Because there is scarce test data that shows how the models generated by Stokes/Oppenlander and Paukert compare to the Maximum Power Method, engineers don't really have any information as to which method may be most appropriate to use. Although the NFPA70E has stated that the Maximum Power Method is conservatively high, such that it suggests using higher PPE than may be necessary, it does not say over what range of values or how much more conservative it is compared to other methods such as those of Stokes/Oppenlander or Paukert.

Engineers who perform arc flash studies, such as those at Schneider Electric Engineering Services (SEES), may have to calculate the arc flash energy for both AC and DC equipment depending on customer requirements. Although AC arc flash energy levels can easily be calculated using industry wide software that utilizes the equations standardized by IEEE, engineers can have a little more trouble when it comes to calculating DC arc flash energy since the closest method to a standard is the Maximum Power Method proposed by the NFPA70E but as discussed before, this has been shown to be conservatively high and does not accurately capture the nonlinear nature of DC arcs.

# 3. Methodology

## 3.1. Goals

As there are few resources regarding how the Maximum Power Transfer Method compares to the models proposed by Stokes/Oppenlander and Paukert, the aim of this thesis is to provide a more detailed comparison in regards to the power delivered to an arc. Since the Maximum Power Transfer Method is claimed to be conservatively high, there may be situations where the actual power delivered to an arc is much lower. By creating a comparison “map”, the goal is to provide a rough guide for engineers on when to use which method until further data can be acquired.

Because the methods proposed by Stokes/Oppenlander and Paukert are not as widely known, even to engineers within SEES, the goal of this thesis is to provide information to SEES engineers so that they have a better understanding if the Maximum Power method may be too conservative for the system they are analyzing. Extensive empirical models and physical testing should be implemented to enforce a standard on DC arc flash energy calculation, as was the case with AC arc flash. However, this would take significant time to formulate equations, as well as considerable amounts of resources and funding. In the meantime, this thesis aims to provide a better understanding of the equations and research performed by Stokes/Oppenlander and Paukert so that alternative calculation methods may be used when performing DC arc flash analyses. The idea is to map out the relative power of both formulas over a range of values that affect arcing resistance and compare this map with the relative power map of the Maximum Power Method.

Although knowing the power delivered to an arc is useful information, it is actually the incident energy, or energy density, that is a concern to engineers as this is how PPE is rated. Thus, the incident energy based on the equations by Doan, Stokes/Oppenlander, and Paukert discussed in the previous section will be calculated under different scenarios to compare the results in a manner relatable to engineers. Although not directly comparable due to differences in system characteristics between AC and DC, the AC IEEE 1584 equations comparison to the theoretical Lee equations will be examined to see if there is any correlation to the DC results, since the AC equations are based off measured results.

The end goal is to provide some information to engineers so as to have a rough guide of when to use the Detailed Arcing Current and Energy Calculations Method over the Maximum Power Method based on where a system falls in the map. However, the goal is not to provide a definitive standard as it is believed that this should be done after extensive testing has been conducted and a better understanding of DC arcs is realized, much like the process for AC arcs.

In the end, because there is very little DC arc test information that can establish a solid baseline to compare results, it may be difficult to draw many solid conclusions especially in regards to suggestions as to use one particular method. At the very least, the goal would be to know when performing the Stokes/Oppenlander or Paukert method yields more accurate results than using the Maximum Power method.

### 3.2. Methodology

One difficult thing with comparing the different DC calculation methodologies is deciding which parameters to compare. The Stokes/Oppenlander and Paukert methodologies both use equations that calculate variables that are normally not dealt with in an AC analysis, namely the arc voltage and arc resistance. The AC equations outlined in IEEE 1584 are more concerned with the arcing current and incident energy since the incident energy determines the amount of PPE personnel will need to wear and the arcing current directly affects the incident energy based on how long the arc will be sustained so protective devices may have the opportunity to be adjusted based on the arcing current so that it is cleared quickly.

Since the arcing current is assumed to be half of the fault current for the Maximum Power method, the percentage of arcing fault as a percentage of the bolted fault current will be examined to see how the Stokes/Oppenlander and Paukert methods compare. Since AC arcs are a function of the bolted fault current as in the IEEE 1584 equations, the bolted fault current makes a good independent variable to compare. Additionally, the bolted fault current, rather than the arcing current, is something that is generally given in data sheets or can easily be calculated during a power systems analysis so it is often a known variable. In order to determine the arcing current using the equations proposed by Stokes/Oppenlander and Paukert, iterative calculations must be used to find the arcing current. Since arcing voltage and arc resistance are not something usually dealt with in a power system study, it is more useful to compare the arc current with the amount of available fault current.

It should be noted that since the DC equations for calculating arc voltage and resistance do not distinguish between open-air and arc-in-a-box configurations, it is assumed that the arcing current is the same in either case. In reality, this may not be the case as the IEEE 1584 equations in Section 2.1 show that there is a difference between the two scenarios. However, since no further data is available for DC arcs, the difference is factored when calculating for the incident energy.

The next part is developing the power maps and comparing how much power is delivered to the arc. In order to create these "maps", the power will be calculated using Stoke's/Oppenlander's and Paukert's equations over a variety of gap ranges (6mm, 13mm, 25mm, 50mm, 100mm, 150mm, 200mm, 250mm, 300mm, and 400mm), voltages (125V, 208V, 250V, 480V, 500V, 1000V, and 1500V) and fault currents (1kA, 10kA, 20kA, 50kA, 75kA, and 100kA). The power will also be calculated using the Maximum Power Transfer Method over the same range of voltages and fault currents in order to establish the theoretical maximum. The results will then be compared with each other (as a percentage of the theoretical maximum power) to see where they produce similar values or may differ greatly. Graphs will be produced that will show an engineer, based on voltage, current, and bus gap, what the relative power is for each of the methods. Since the Maximum Power method assumes the max power is being delivered at all times, the other two methods should give a better idea of how the power delivered to a DC arc actually is characterized based on a nonlinear resistance. Many iterations will need to be performed so calculations will be done using equations from the reference papers in Excel in order to efficiently calculate the range of values. Some of these calculations will be compared with software commonly used in industry such as ETAP, which allows

calculations to be performed under all three methods, in order to verify accuracy. However, the results of this paper will be based on the results from the Excel files using the equations mentioned in Section 2 from the references.

Unlike the Stokes/Oppenlander model which does not have any particular bus gap restrictions, the Paukert model uses different equations depending on the gap value. However, the equations are given for discrete gap values rather than for a range. Following the ETAP guide shown in Table 7, gap values to be examined that do not fall at the discrete points will follow the range of values suggested by the ETAP guide to determine the results.

**Table 7: Paukert Equations Used for Bus Gap Ranges in ETAP [10]**

| Gap Range | Equations used for $V_{arc}$ and $R_{arc}$ |
|---|---|
| $0 < Zg \leq 2.5$ mm | 1 mm equations |
| $2.5 < Zg \leq 7.5$ | 5 mm equations |
| $7.5 < Zg \leq 15$ | 10 mm equations |
| $15 < Zg \leq 37.5$ | 20 mm equations |
| $37.5 < Zg \leq 75$ | 50 mm equations |
| $75 < Zg \leq 150$ | 100 mm equations |
| $150 < Zg \leq 200$ | 200 mm equations |
| $Zg > 200$ | 200 mm equations. |

This may bring up the question as to why bus gap values that do not line up with Paukert's equations are being examined in the first place. For 6mm, this was seen to be a typical minimum gap value and was examined in a presentation by Parsons [11]. The reason 13mm and 25mm gap values are chosen to be examined, even though 10mm and

20mm are more appropriate based on the models Paukert proposed, is because 13mm is the lower limit of the applicable gap values for the IEEE 1584 equations and 25mm is the typical gap value for motor control centers (MCCs) and panelboards at low voltage. When equipment type is unknown or miscellaneous, the SEES standard is to treat it as a panelboard thus 25mm is a very commonly used bus gap value. Because of this, if an engineer were to use the Paukert method for analysis it would often be at 25mm rather than 20mm.

It should also be noted that the Max Power method is only supposed to be valid up to 1000V per the NFPA 70E. However, its basic theory will still be used to calculate the theoretical maximum power at 1500V. Although the Stokes/Oppenlander and Paukert equations do not have an explicit limit to the applicable voltage, it is likely that they would have limitations at high voltages as well. However, this voltage level will be examined to take a peek at the results.

As mentioned earlier, since PPE is rated using the incident energy (or energy density) rather than the arcing power, the incident energy will be compared for all three of the DC calculation methods since it is the ultimate concern for engineers and electrically qualified personnel. Since the IEEE 1584 equations allow for calculating the incident energy directly rather than having to calculate the power first, the incident energy of the IEEE 1584 equations will also be compared to the theoretical Lee equations. Although they do not directly compare, since the AC model is empirical, it is the closest the DC models have to any sort of measured baseline based on extensive research and may give insight into any odd results from the DC analysis.

Once the maps have been established, a look at past DC arc flash analyses performed by SEES will be re-examined to see how they fit into the map. If applicable, the analysis will be re-evaluated using either Stokes'/Oppenlander's equation or Paukert's equations.

# 4. Results

## 4.1. Arcing Fault vs Bolted Fault Current

For all situations, the results showed that as the bolted fault current increased, the arcing current as a percentage of the bolted fault current would decrease. Up until approximately 10kA, the arcing fault current showed a steep drop but past this point the arcing fault would decrease at a much slower rate that it was almost constant thus making a curve reminiscent of the arcing resistance seen earlier in Chapter 2. Generally, as the bus gap increased, the less arcing current there would be for the corresponding fault current such that the curve essentially shifted down. Interestingly, arcing current levels at a bus gap of 13mm for Paukert were actually greater than the arcing current levels seen at 6mm under Paukert as shown in Figure 14. For equal bus gap and fault current, the 13mm Paukert curve generally produces higher arcing currents than the Stokes curve. However, this is partly due to the 13mm Paukert curve using the 10mm equation to produce the results so the 10mm Stokes curve would give a more accurate comparison. The Stokes/Oppenlander model generally produces higher arcing current curves except at 13mm.

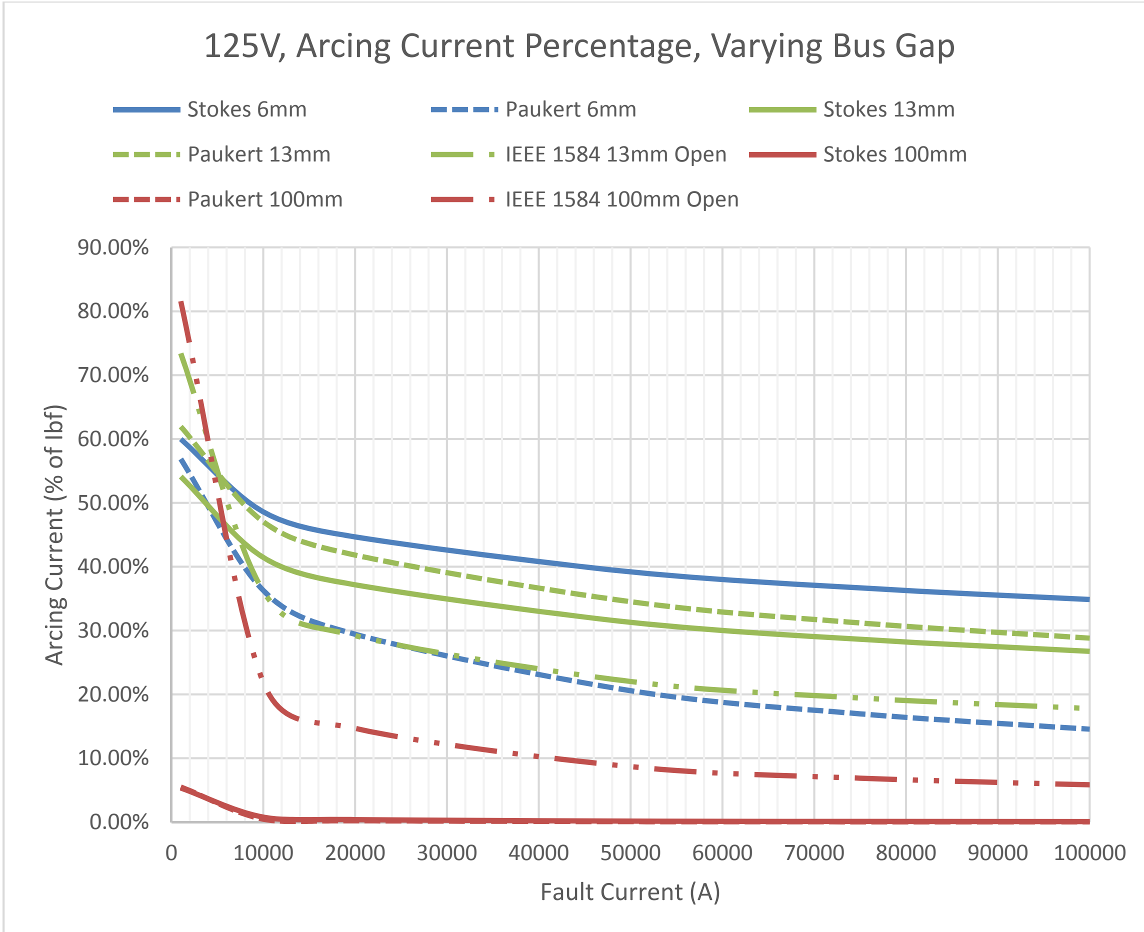



**Figure 14: Arcing Current As a Percentage of Fault Current at 125V, Bus Gaps at 6mm, 13mm, and 100mm**

Figure 15 shows more bus gap ranges. The gap range greater than 100mm was not shown since no solutions could be found, which may indicate that it is impossible to sustain an arc at this voltage for this gap width. It should be also noted that at this voltage, the Paukert equations for arc currents less than 100A were used for the 100mm gap curve since the currents were less than 100A and produced lower currents than using the equation for arc currents greater than 100A. The curves for 50mm and 100mm for both the Stokes/Oppenlander and Paukert equations showed particularly low current

values and percentages.  An IEEE 1584 6mm curve was not included since this gap value lies outside the range of applicable values.

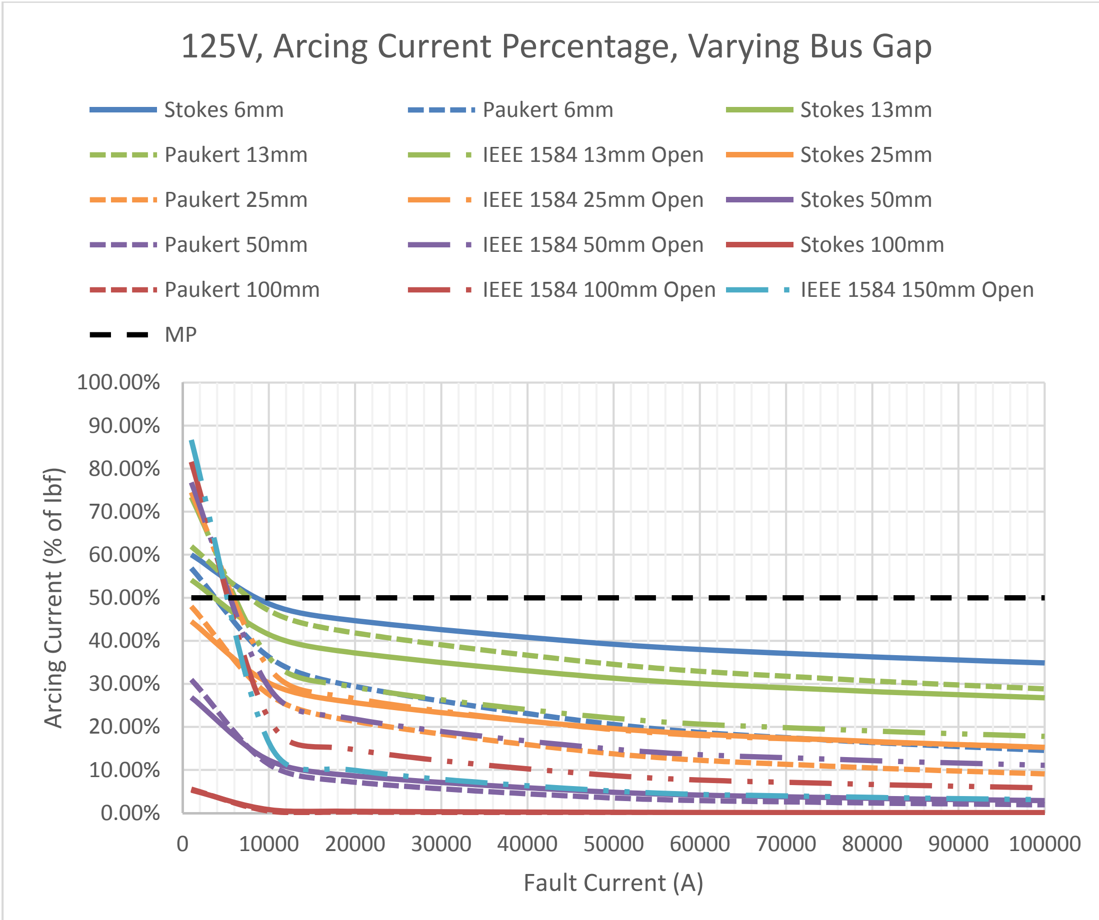



**Figure 15: Arcing Current at 125 V, Varying Bus Gap**

Though not shown on the graph, the arcing voltage also began to approach the system voltage.  These voltages and low currents indicate that it may be difficult for an arc to be sustained at this level and may provide results similar to AC equipment at 208V fed from small transformers less than 125kVA, which the IEEE 1584 deems is not a concern [4].  It should be noted that the 150mm Stokes/Oppenlander results were not

shown because they were extremely low and had limited visibility since it was practically parallel to the x-axis. Higher gap values in this graph and subsequent graphs may not be shown because a solution could not be found.

Compared to the DC curves, the curves in Figure 15 showcasing the results for the IEEE 1584 equations are not as spread out over the gap values. For a fault current of 100kA, the DC curves showed arc current percentages from the approximate range of 0% to 35% while the AC curves were in a smaller approximate range of 6% to 18%. In general, except for the "breakdown" gap values, such as 50mm and 100mm, where the currents are very low, the IEEE 1584 equations tend to produce much lower currents for a given fault current. However, the IEEE 1584 curves did show the same general inverse characteristic as the DC methodology curves. For this graph and subsequent graphs, any gap values where the IEEE 1584 curve is not shown indicates this gap was outside of the applicable range of the empirical based equations. Although the IEEE 1584 150mm curve approached zero percent arcing current as the fault current, increased, it still produced higher values than that of the Stokes/Oppenlander equation.

As the voltage increased, the arcing current increased as well essentially shifting up the curves as seen in Figure 16 which displays higher arcing current percentages than seen in the graphs for 125V. Detailed results are presented in Figure 17 through Figure 20 for 208V, 250V, 480V and 500V. Once again, the Paukert curve at 13mm showed much higher arcing currents than the 6mm curve for a given value of fault current. This curve also showed higher arcing current percentages than the Stokes 6mm curve at lower voltages, whereas the other gap values generally had the Stokes curve resulting in higher

percentage values. The currents past 10kA also decreased at a slower rate compared to 125V resulting in flatter curves past the "knee".

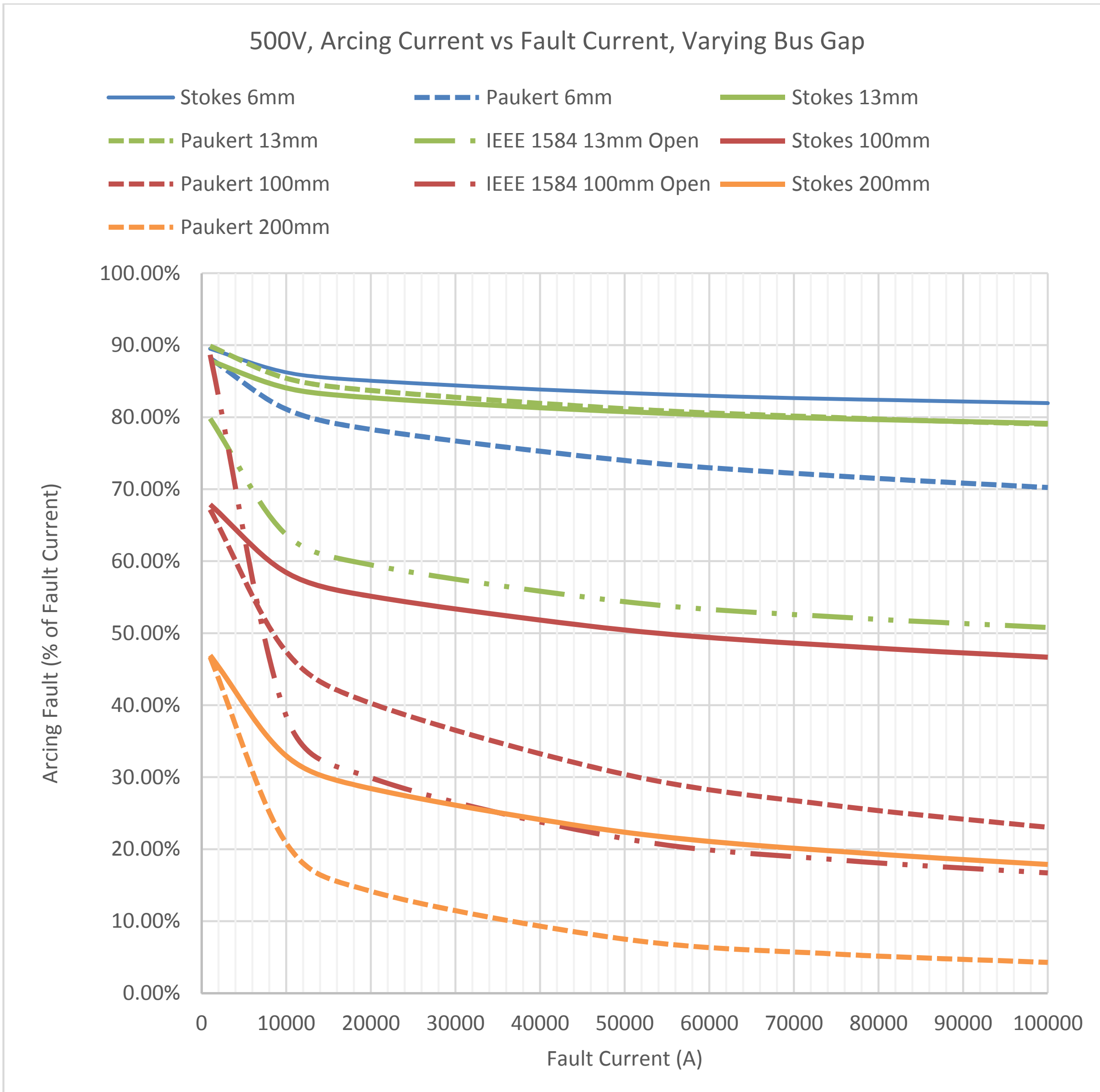



**Figure 16: Arcing Current at 500V for 6mm, 13mm, 100mm, and 200mm Bus Gaps**

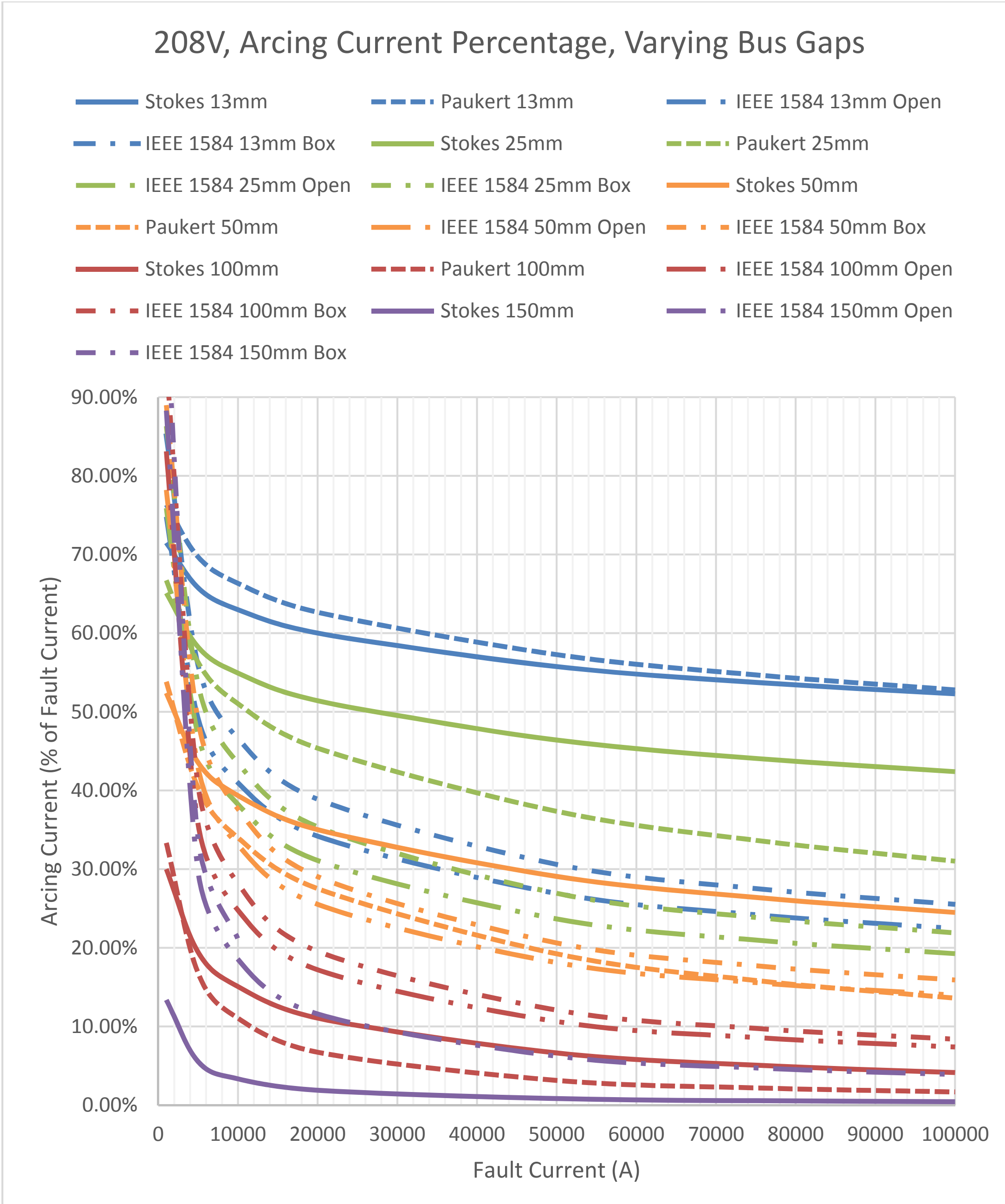



**Figure 17: Arcing Current at 208V, Varying Bus Gap**

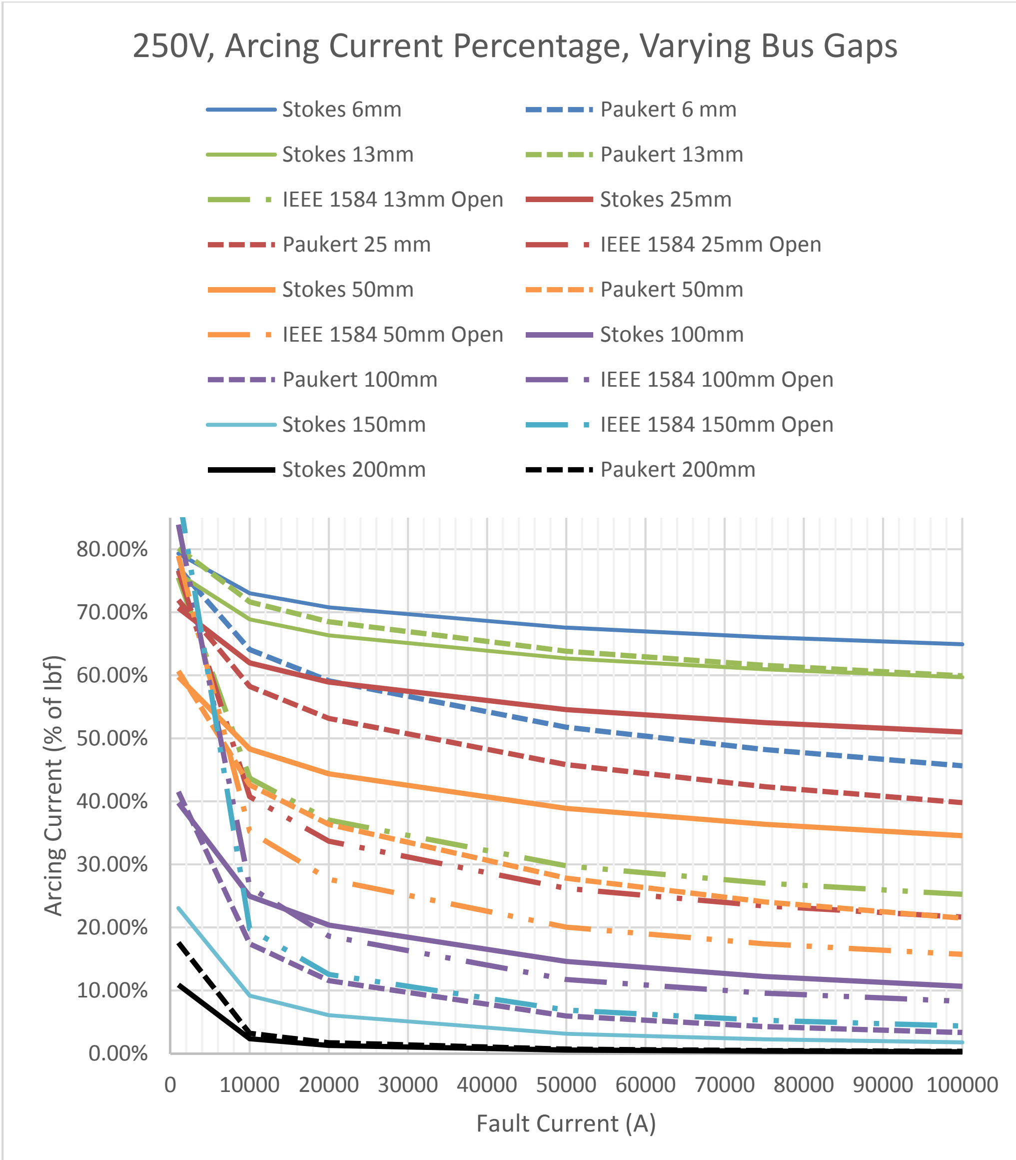



**Figure 18:Arcing Current at 250V, Varying Bus Gap**

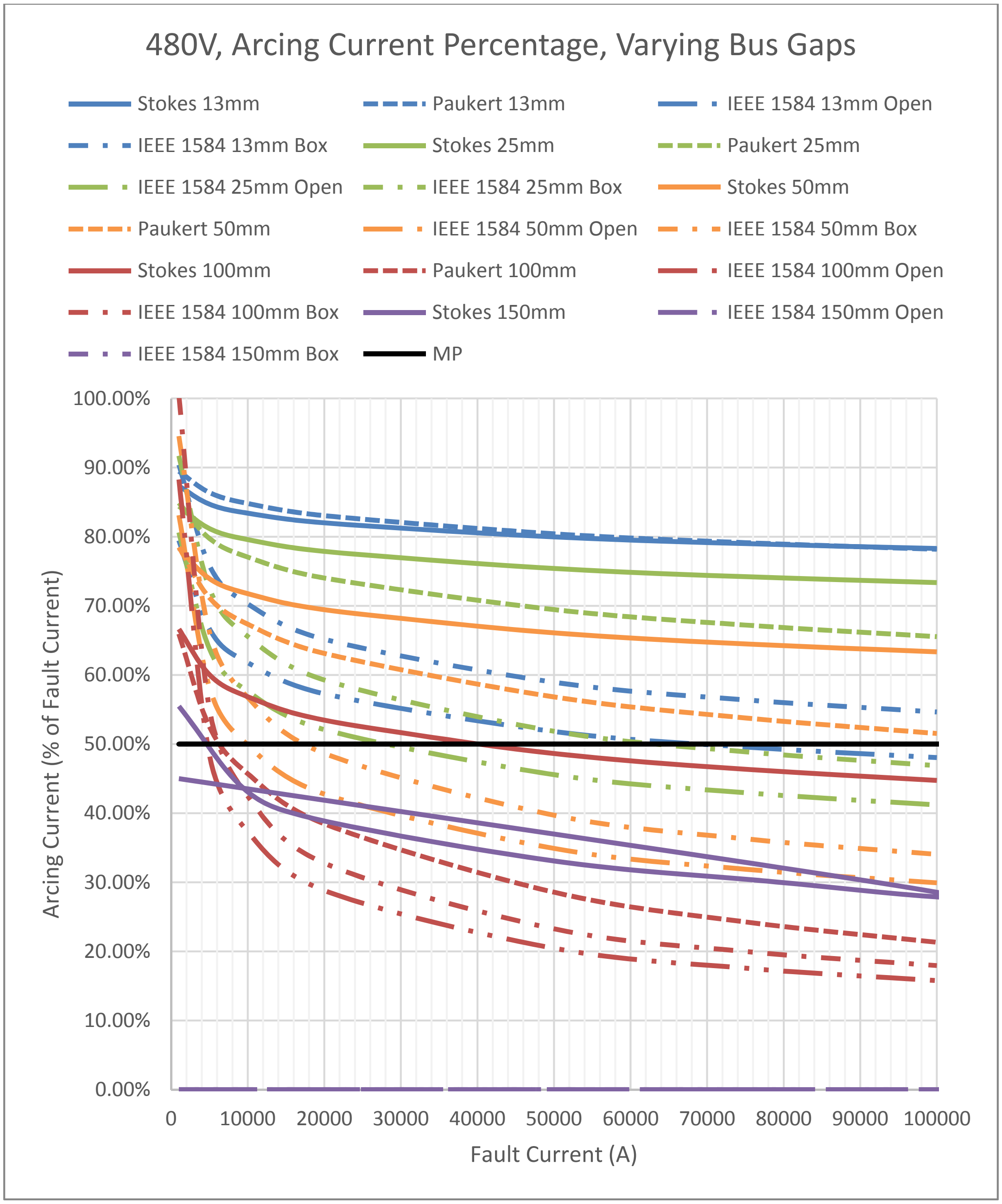



**Figure 19: Arcing Current at 480V, Varying Bus Gap**

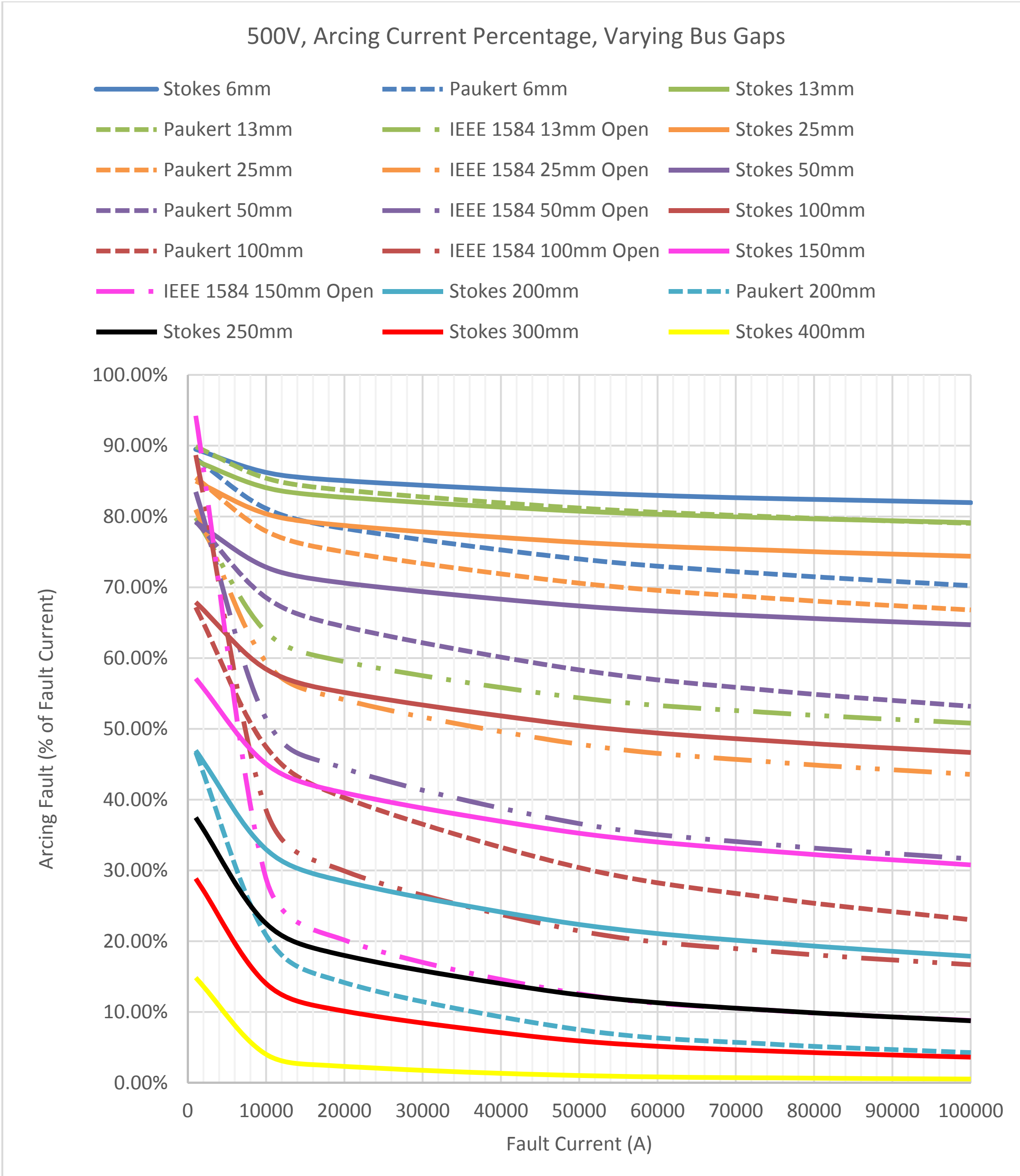



**Figure 20: Arcing Current at 500V, Varying Bus Gap**

Although the Stokes/Oppenlander curves generally showed higher arcing current percentages than the Paukert curves, for equivalent bus gap values and at currents less

than approximately 10kA, both curves showed approximately the same results with the Paukert curves actually being slightly steeper so the Paukert equations would sometimes produce higher arcing current percentages at very low currents. Past the 10kA knee is where the Paukert generally showed lower arc current percentages which agrees with the larger arcing impedance shown by Paukert mentioned in Chapter 2. In general, the small bus gap values showed bigger differences between Stokes/Oppenlander and Paukert (13mm once again being the exception) but as the bus gap value increases, the percentage difference between the two curves would decrease especially at large gap values where the arcing current percentage is particularly low.

As the voltage increases and the arc current curves shift up, results for arcs across gaps of wider length could also be seen. As mentioned earlier and seen in Figure 7 and Figure 8, a minimum arc voltage is needed to sustain the arc, with larger gap values requiring a larger minimum voltage. Thus, the formulas from Stokes/Oppenlander and Paukert may also give an indication of what bus gap value is realistic at a given voltage level. As can be seen at 125V and 250V, the bus gaps past 100mm and 200mm, respectively, no solutions could be found. Not only did these bus gap values push the limits of the calculation but also produced arc voltages that approached the system voltage.

The AC IEEE 1584 curves also shifted up with increasing system voltage. Since the general range of applicable bus gaps has been captured in these plots, new bus gap curves were not shown, e.g. IEEE 1584 curve for 200mm, but the curves did become

more spread out so that it was more similar to the DC equation curves at lower voltages as seen when comparing the curves at 500V to the curves at 125V.

Also of note, the IEEE 1584 equations showed that bus gap had minimal effect on the arcing current for small fault currents, particularly those less than 10kA. Larger bus gaps actually showed slightly higher arcing current percentages for the same amount of fault current. As the voltage increased, the bus gap had a larger effect on arcing current especially if the fault currents got closer to 10kA. Overall, as mentioned earlier, the bus gap did not have as big an impact on calculating the arc current values as it did for DC systems. The IEEE 1584 curves were not as spread out as the DC curves at the same root mean square (RMS) voltage. However, higher voltages did show more difference in the arcing currents at certain bus gap values than at lower voltages.

Unlike the DC equations, the IEEE 1584 formulae also had different results for arcing current depending on whether the arc was in an enclosure or in open air. Because arcs in enclosures see a reflecting and focusing effect, the incident energy for arcs in open air compared to arcs in enclosures is significantly different. However, the difference is not significantly greater for arcing current as seen in Figure 17 and Figure 19.

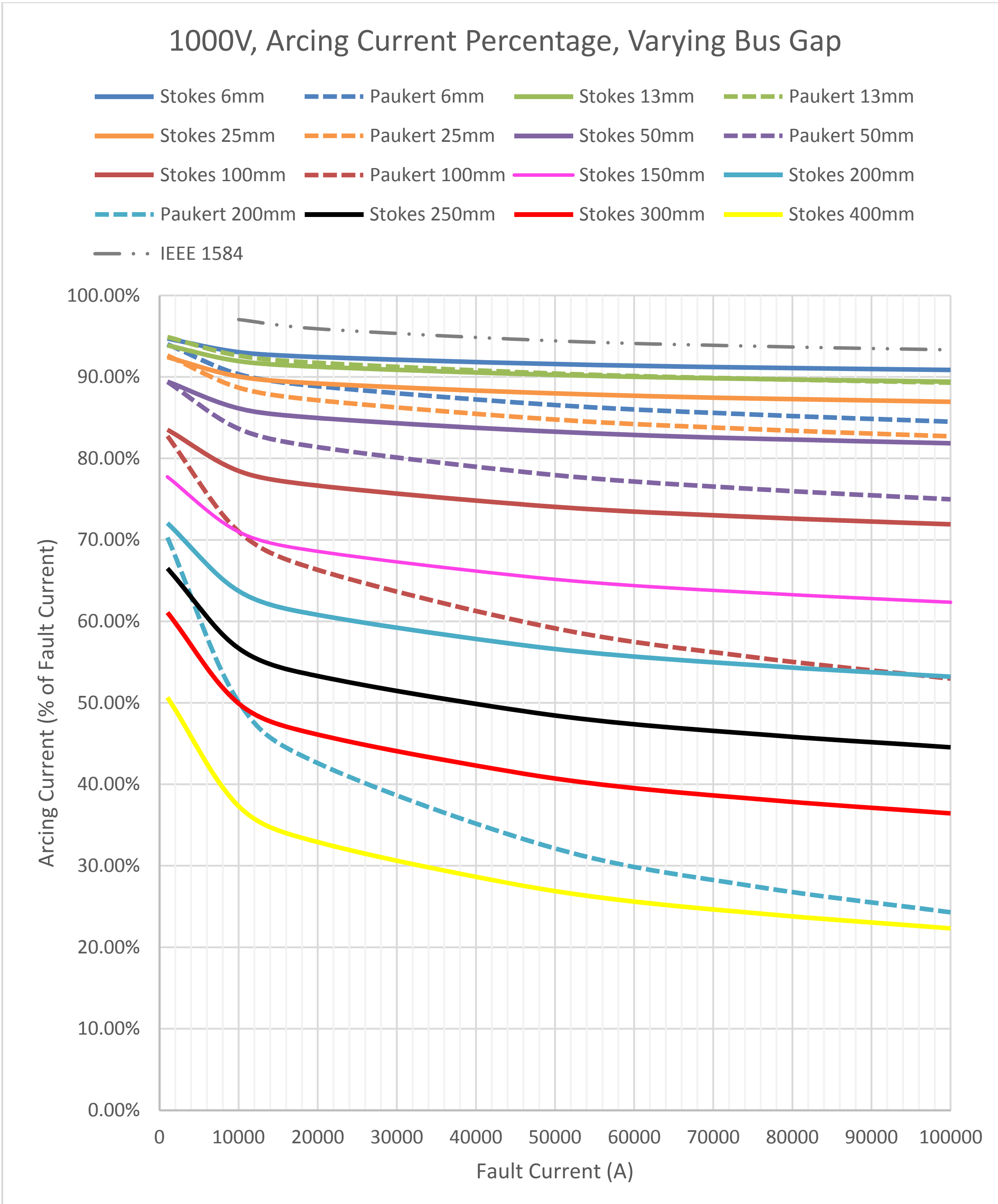



**Figure 21: Arcing Current at 1000V, Varying Bus Gap**

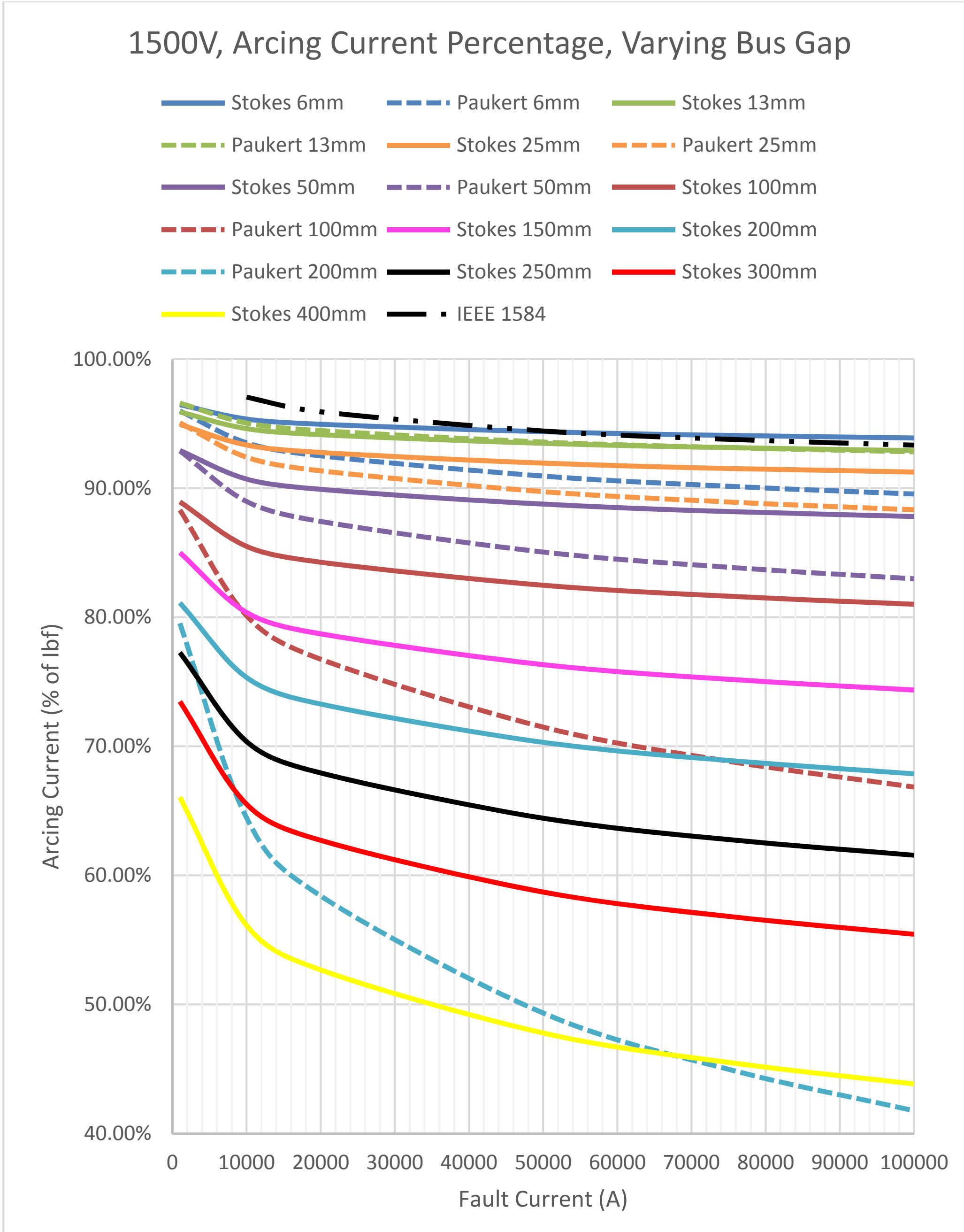



**Figure 22: Arcing Current at 1500V, Varying Bus Gap**

For voltages of 1000V and 1500V, as seen in Figure 21 and Figure 22, the arcing current curves become even less inverse and more and more flat, especially for the small

bus gap values although the Stokes/Oppenlander results showed flatter curves at higher voltages even for large gaps. For the small gap values such as 6mm and 13mm, the curves were especially flat suggesting that the fault current had little effect on the arcing current. For these small bus gaps at these voltages, the arcing current was a high percentage of the fault current. There is also closer agreement with the arcing current between the Stokes/Oppenlander and Paukert methodologies at these smaller bus gaps for high voltages.

In the IEEE methodology, the formula for calculating arc current changes at 1kV. Unlike the low voltage cases, currents at 1kV up to 15kVare not affected by open configurations or box configurations, bus gap, or system voltage (other than it only applies the range previously mentioned). While it is dependent on the bolted fault current, the effect is minimal on the results in terms of the arcing current as a percentage of bolted fault current. Overall, the arcing currents at high voltages produced are very close to the bolted fault current values.

As seen in Figure 21 and Figure 22, the small gap values at high voltage levels tend to be more in line with the IEEE 1584 equations. However, at high voltages, very small bus gaps like 6mm may not be a realistic situation as shown in Table 1, which shows the typical gap between conductors for various equipment types at different voltage ranges. At high voltages, where a switchgear would be a common type of installation, typically it has higher gap values than 6mm.

Although the methods proposed by Ammerman et al. do not specify a voltage limit, since the tests conducted by Stokes/Oppenlander and research compiled by Paukert were themselves limited in the parameters examined, it is hard to draw any solid conclusions for high voltage arcs of 1kV and above. As mentioned before, the IEEE 1584 method of calculating arcing current for AC systems at high voltages is different from low voltages. This could be the case for DC arcs as well but since no alternate equations are provided for high voltages, for now it seems that high voltage arcing current follows the general trend until more data can be obtained.

It should be noted that for high voltages and low fault currents (particularly the values calculated at 1000A), some discrepancies can be found in the IEEE 1584 equations, as calculation results can give arcing currents greater than the bolted fault current, which is impossible. The maximum available fault current at a bus cannot be exceeded since the presence of an arc means there is some added resistance to the system therefore reducing the fault current. Although tests at high voltages were limited in the range of fault current they were conducted, IEEE 1584 states the equations are valid from 700A to 106kA [4], however the currents in the lower end of that range can result in arc currents greater than the fault current. Arc flash calculation software will work around the issue by capping the arcing current at the maximum although this is inaccurate since this would suggest that arc resistance is equal to zero, in which case it would not exist in the first place. As an aside, this shows that the IEEE 1584 equations are not perfect themselves and can be improved.

As an alternative way of looking at the data, Figure 23 through Figure 25 present the arcing current with a constant bus gap and varying voltage. As seen earlier, the arcing curent as a percentage of fault current increases as the voltage increases.

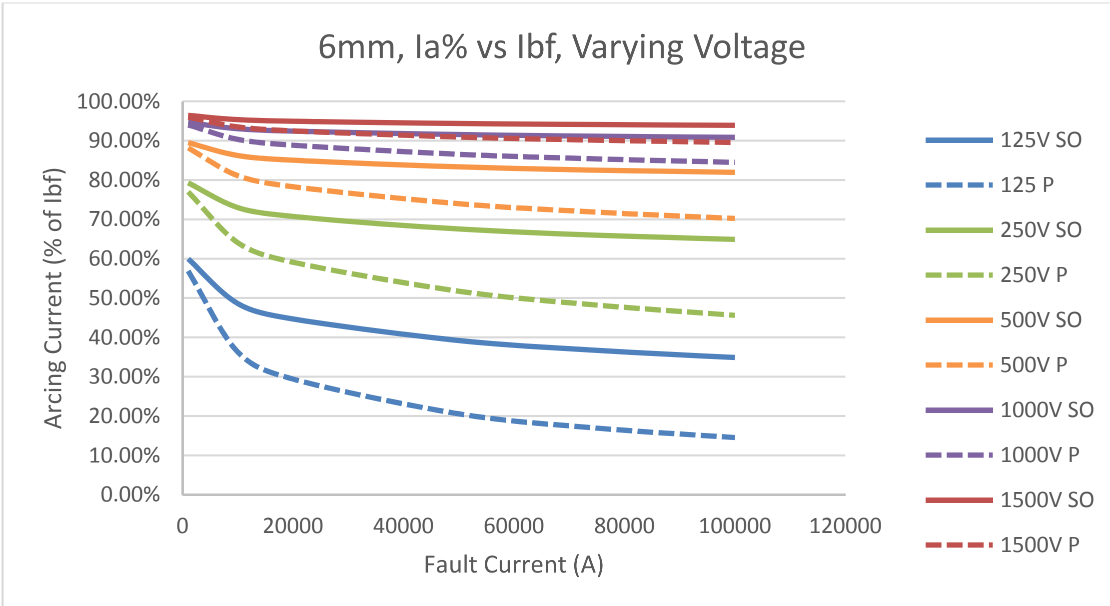



**Figure 23: Arcing Current for 6mm, Varying Voltage**

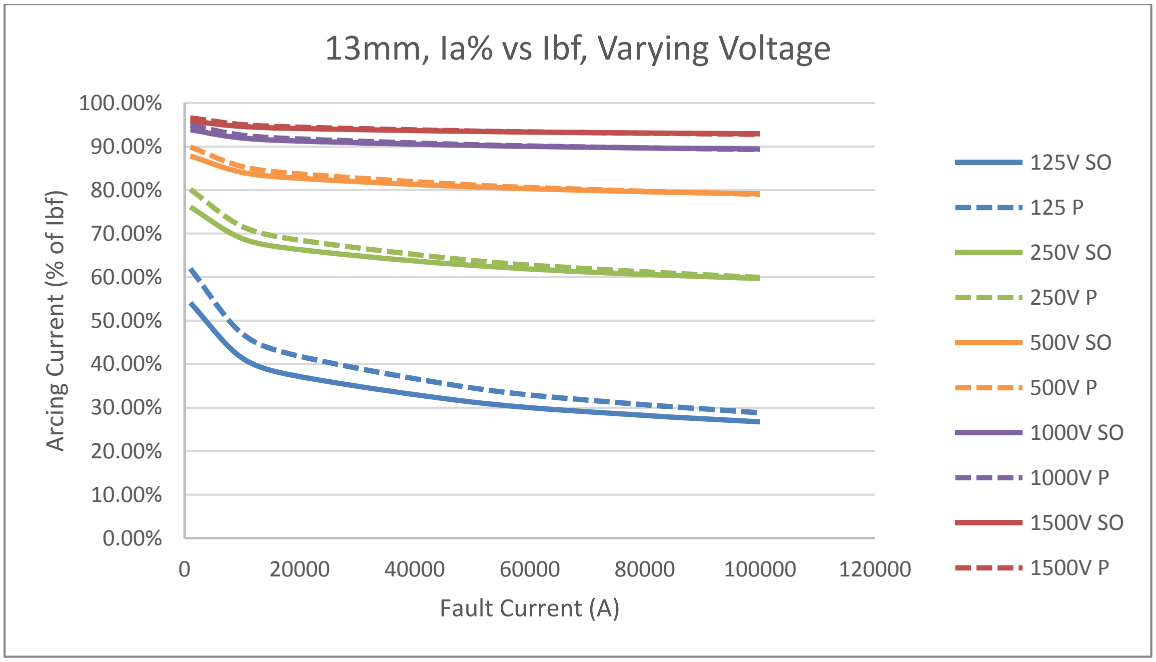



**Figure 24: Arcing Current for 13mm, Varying Voltage**

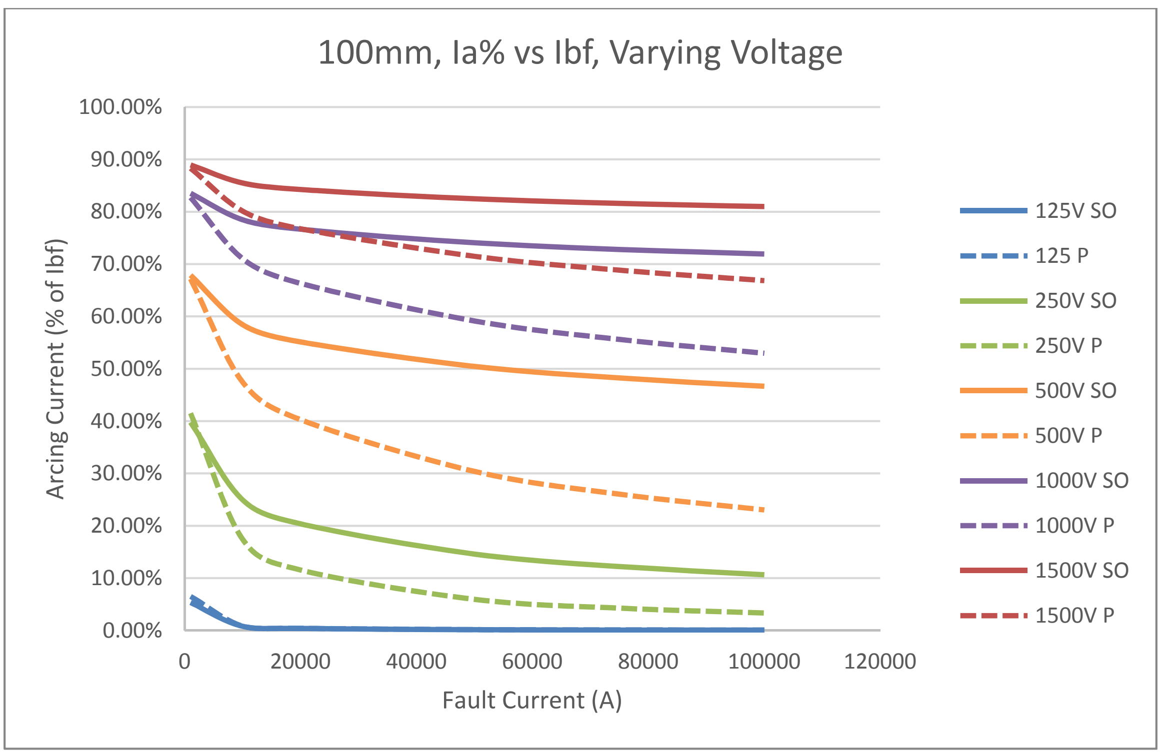



**Figure 25: Arcing Current for 100mm, Varying Voltage**

Across all voltage levels, the most consistent values between Stokes/Oppenlander and Paukert is seen at a bus gap of 13mm. Briefly mentioned before however, the equations used to calculate the 13mm Paukert results were based off the 10mm equation per the ETAP guide. A look at Figure 26 and Figure 27 below shows the difference in Stokes/Oppenlander results between 10mm and 13mm at 125V and 1000V, respectively.

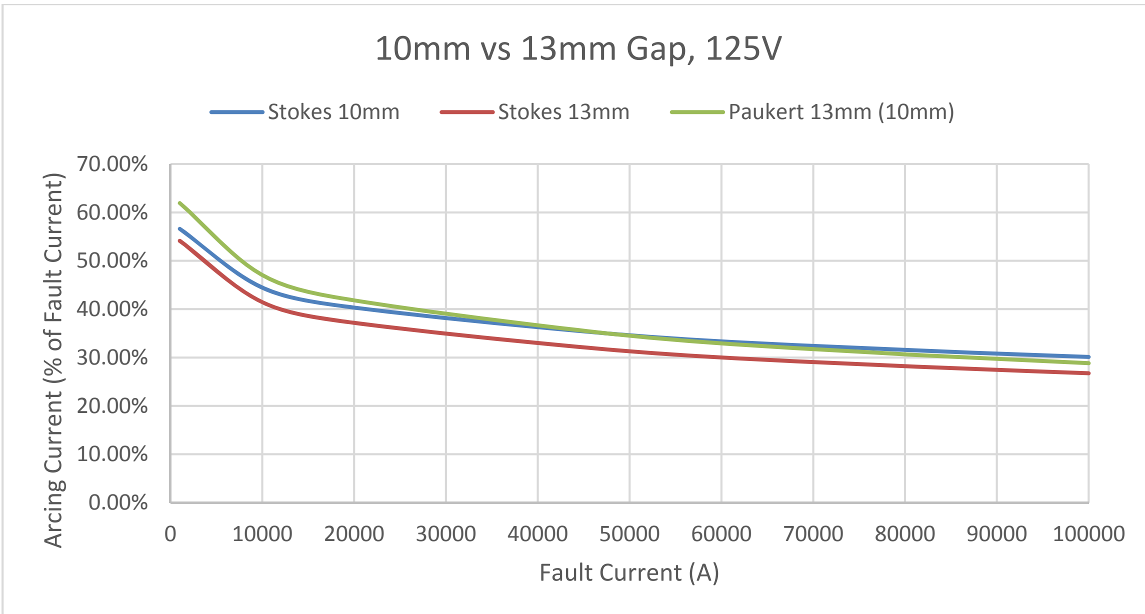



**Figure 26: Comparison of 10mm and 13mm Stokes/Oppenlander Curves to Paukert at 13mm (10mm), 125V**

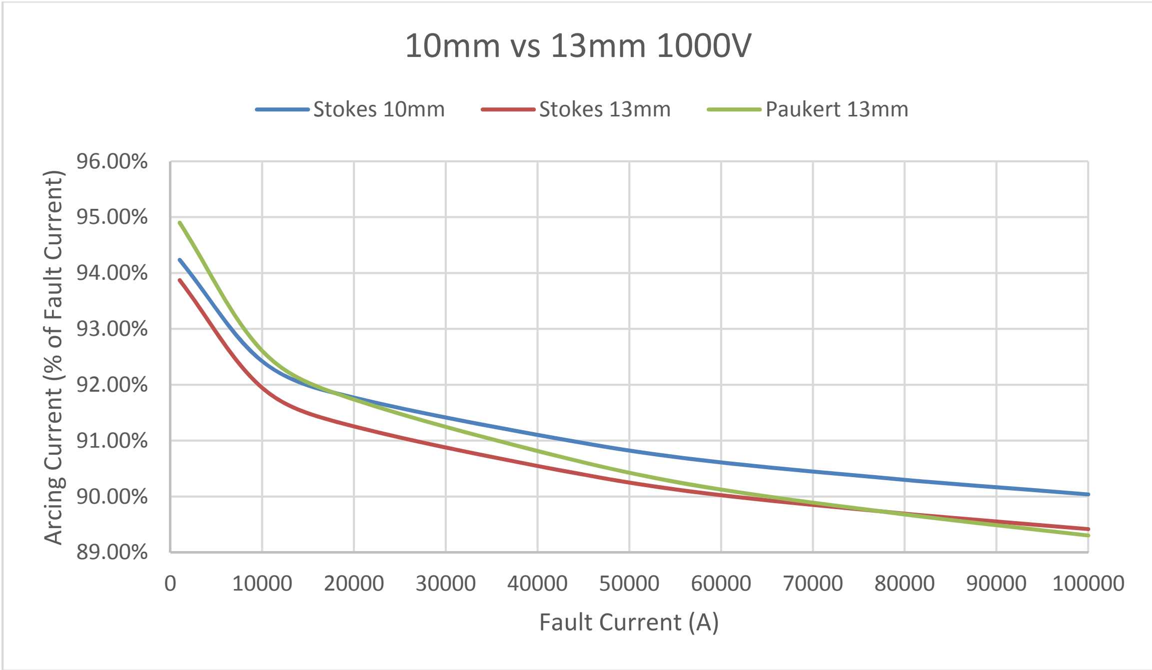



**Figure 27: Comparison of 10mm and 13mm Stokes/Oppenlander Curves to Paukert at 13mm (10mm), 1500V**

As seen, the Paukert curve shows better agreement with the Stokes/Oppenlander 10mm curve at 125V. At 1000V, the Paukert curve follows the Stokes/Oppenlander 10mm curve for low fault currents up to 20kA, but starts to converge with the 13mm curve from approximately 70kA and above. Despite the small differences at either voltage level, it is safe to say the Paukert equations are most accurate at the bus gaps for which they were specifically modelled. In this case, since 10mm and 13mm have a small gap difference between them, the results would be very similar but for a bigger gap difference such as 100mm and 150mm, it would definitely show less accuracy to use the Paukert 100mm equations.

Reviewing the previous results so far shows that the arc currents for both AC and DC can vary wildly depending on the voltage and gap value. Although there is little research performed on DC arcs, the existing semi-empirical equations out there do capture the nonlinear nature of arcs more accurately than the Maximum Power method based on the comparison to the AC IEEE 1584 results. Although there are certain parameters where the arcing current is close to 50% for almost all fault current values, the results show this is only under a narrow set of conditions.

Ultimately, the general shape of the curve is very similar between Stokes/Oppenlander and Paukert but they are shifted up and down depending on the bus gap value. Both models overall capture the nonlinear nature of DC arc resistance however they show great differences in how the bus gap is accounted for. For instance, at 1500V, the Paukert 100mm curve and the Stokes/Oppenlander 200mm curve have more similar characteristics compared to the Paukert 100mm and Stokes/Oppenlander 100mm or the Paukert 200mm and Stokes/Oppenlander 200mm. However, this is not something proportional or that scales as seen earlier with the Paukert 13mm (10mm) and Stokes/Oppenlander 13mm having extremely similar curves.

Similar comments can be made for a comparison made between AC and DC results. However, because the IEEE 1584 equations generally result in lower arc currents than the DC equations at the same RMS voltage, the similarities in the curves has to happen across different voltages unlike Stokes/Oppenlander and Paukert, which show similar curves at the same voltage but different bus gaps.

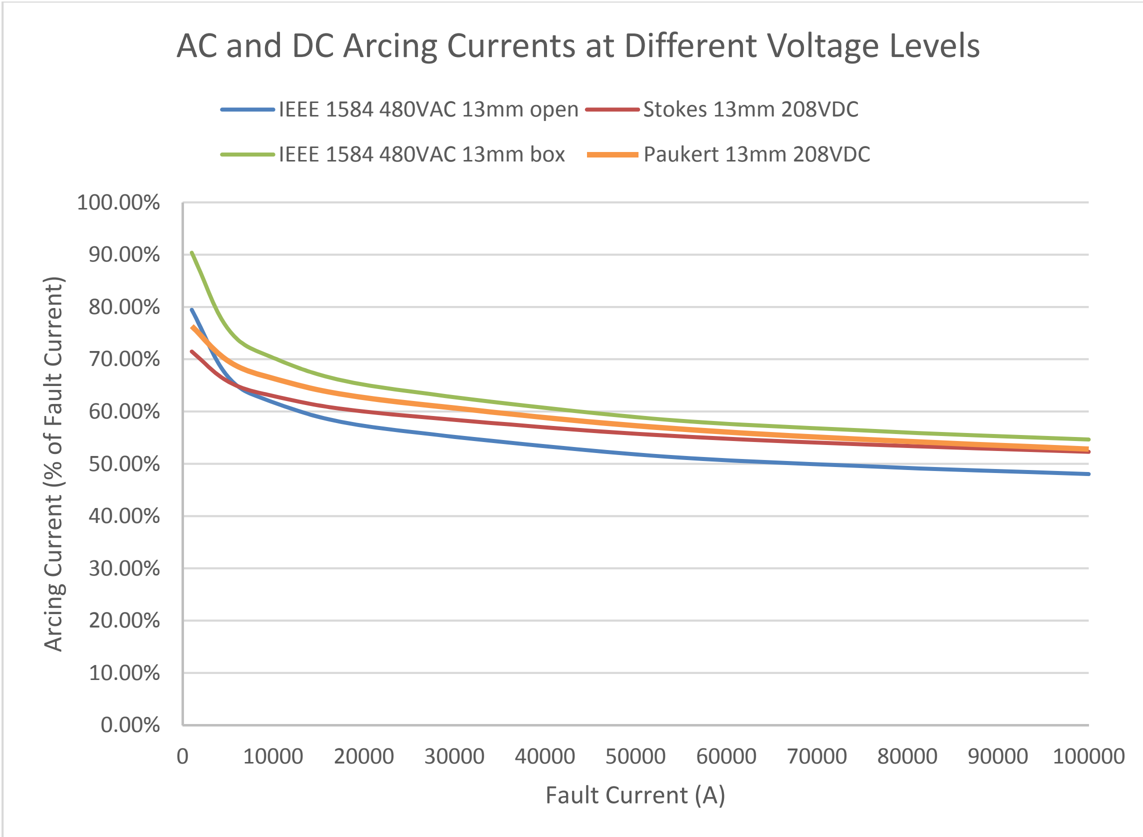



**Figure 28: Similar Arc Current Results Between AC and DC at 13mm**

As shown in Figure 28 above, it would seem that for equal fault current, certain levels of voltage and bus gaps for DC produce the same amount of arcing current as different levels of AC voltage, in this case, 208VDC and 480VAC. Since DC values are equal to their RMS values, and therefore produce more energy than AC under equal parameters, it makes sense that a DC voltage of a lower RMS value produces roughly the equivalent amount of a higher AC RMS voltage. However, this proportion of voltages is not something that is equally reproduced across bus gaps as seen in Figure 29 for 25mm, which shows a bigger difference in AC and DC than for 13mm.

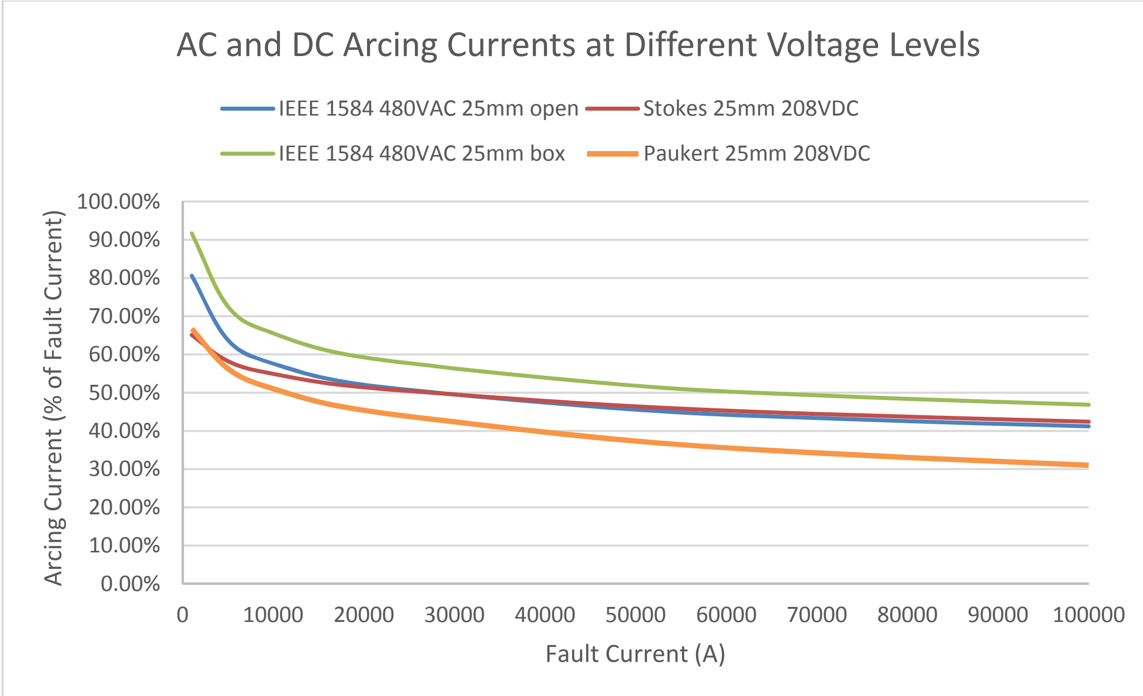



**Figure 29: DC and AC Arc Current Comparison at 25mm**

To summarize, generally Stokes/Oppenlander model produces higher arcing currents than Paukert at the same gap values, the exception being 13mm. While both the Stokes/Oppenlander and Paukert curves became more flat as voltage increased, especially at small gap values, the curves by Paukert would show a more inverse characteristic at large bus gap values and the arcing current would decrease relatively rapidly as the fault current increased.

The AC equations presented by IEEE 1584 also displayed the same general curve characteristic as the DC models presented by Ammerman et.al. however the curves were shifted much further down, thus the AC arc currents were a much smaller percentage of the fault current than the DC arc currents, for equal bus gap and fault current (except at

low voltages where large bus gaps result in much smaller amounts of arc current). Unlike the DC models, the IEEE 1584 equations produce different arcing currents depending on whether the arc is in open-air or an enclosure, with all other parameters being the same (bus gap, system voltage, fault current). Although an arc in an enclosure results in significantly higher in incident energy, the arcing current is only slightly higher.

IEEE 1584 also changes the formula for calculating arcing current for voltages in the range of 1kV to 15kV and the arc current is influenced solely by the amount of available fault current. Arcing currents in this higher voltage region produce arcing currents that are very close to the bolted fault current.

### 4.2. Relative Power vs Fault Current

After creating the power maps, it was shown that for each voltage level, there was a gap value or range of gap values where the calculated power was within 90% of the maximum power value for the majority of fault current levels examined. In general, for gap values that were below or above the gap range, this condition is where Stokes/Oppenlander and Paukert methods would be significantly lower than the Maximum Power method. Some of the gap values at both the small and large extremes (depending on the voltage level) showed extremely low power and may indicate that sustaining an arc at that voltage level and bus gap may not even be feasible.

At 125V, as seen in Figure 30, the majority of bus gap values did not produce relative power values that were within 90% of the theoretical maximum power for fault currents greater than 10kA. For the approximate range of 10kA to 18kA, using the

Stokes/Oppenlander 6mm method would produce very similar power results to the Maximum Power method.

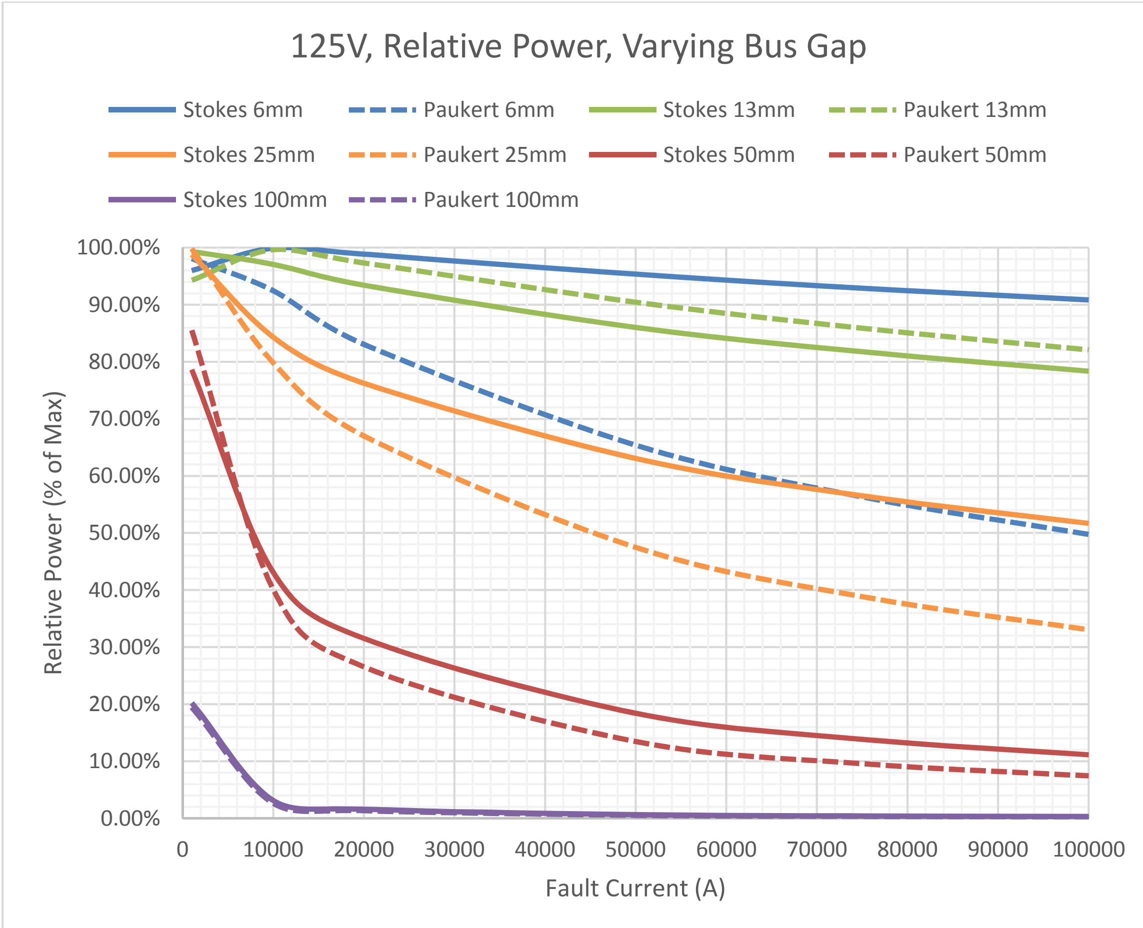



**Figure 30: Relative Power at 125V, Varying Bus Gap**

As seen in Figure 31 at 208V and higher voltages however, there are gap values from either Stokes/Oppenlander or Paukert which are almost in tune with the Maximum Power method.  Although there are many gap values at 208V that produce close to maximum power for some current range, the Stokes/Oppenlander 25mm shows relative

power very close to 100% for almost all levels of fault current. At each of the fault current points examined, the relative power was within 90% of the maximum.

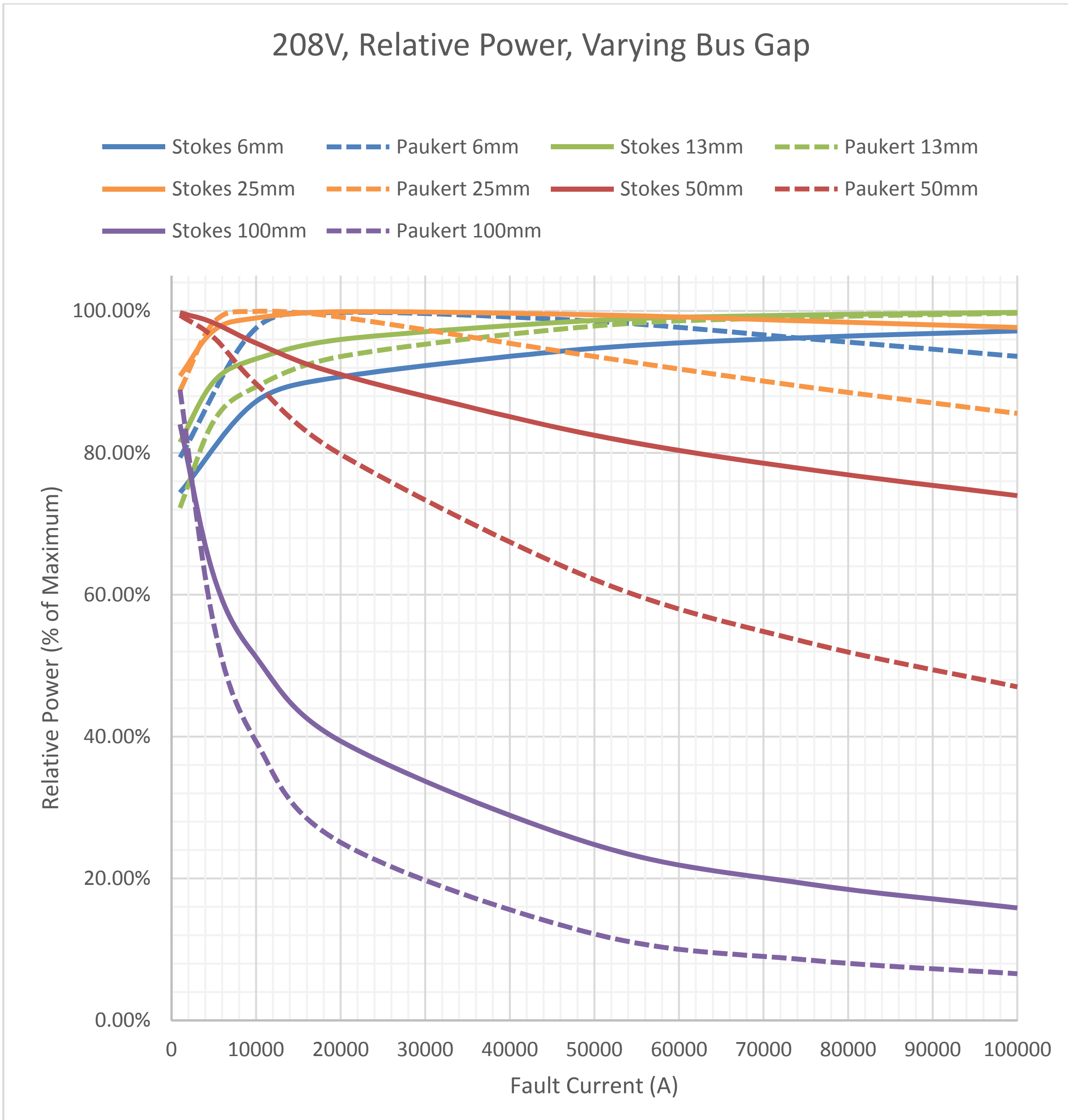



**Figure 31: Relative Power at 208V, Varying Bus Gap**

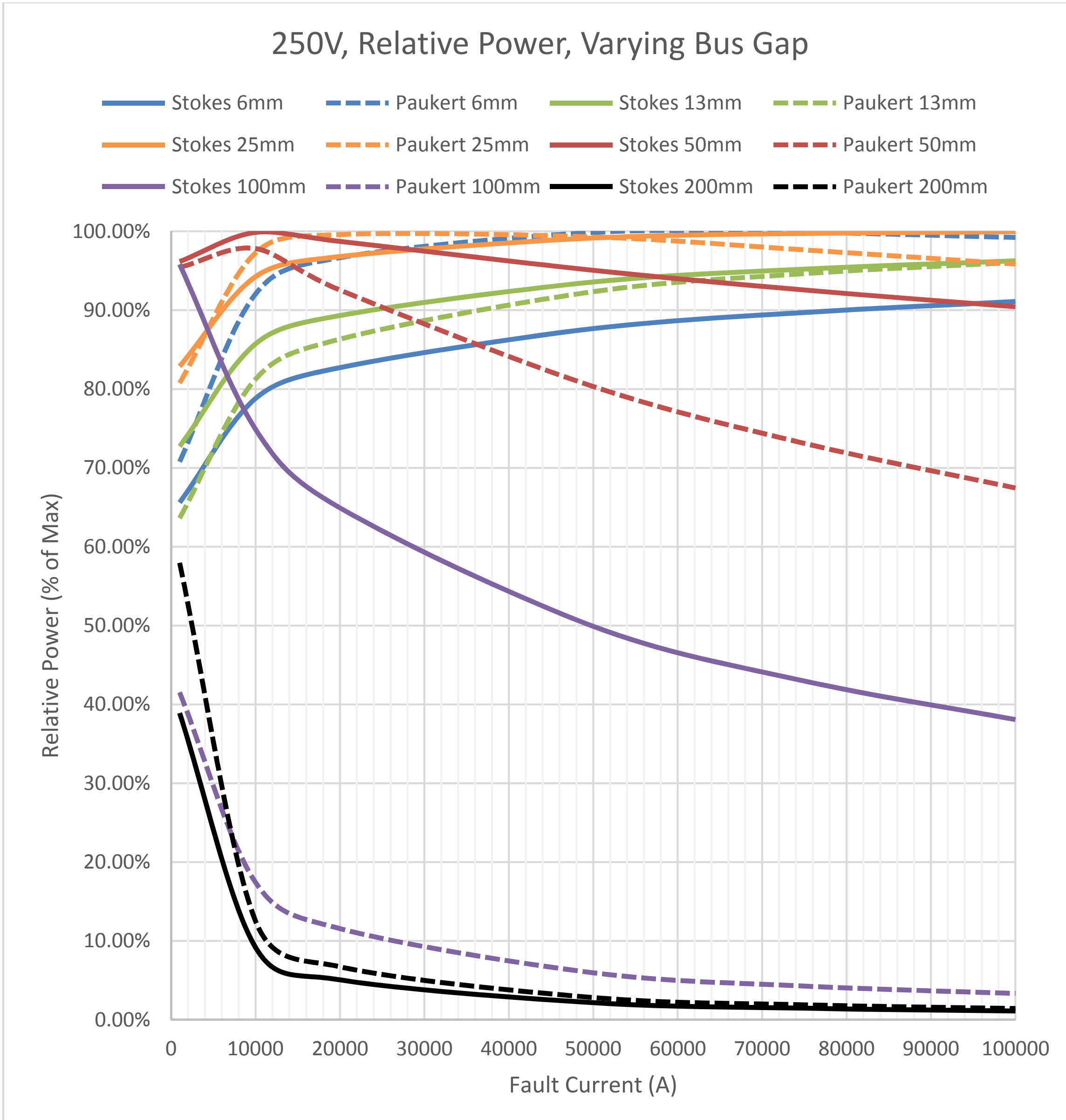



**Figure 32: Relative Power at 250V, Varying Bus Gap**

Increasing voltages could result in significantly different shaped relative power curves. For instance, looking at the difference between 208V and 250V in Figure 31 and Figure 32, the Stokes/Oppenlander curves at 100mm vary quite greatly. Past 10kA, the 250V results show significantly higher relative power for the 100mm curve than at 208V.

The 13mm curves for both Stokes/Oppenlander and Paukert show much closer agreement to Maximum Power at 208V than they do at 250V.  Also at 250V, solutions could be found for 200mm curves which was not the case at 208V.  Overall, it seemed like the voltage had a greater effect on Stokes/Oppelander curves than it did Paukert curves.

Generally, as the voltage increased, the higher the optimal gap values in tune with Maximum Power would be.  Gap values above or below this would result in curves with regions that had significantly less power.  For instance, at 208V and 250V, the gap value that resulted in power that was very similar to the theoretical maximum was 25mm.  Gap values below this exhibited a similar fractional power function curve except was shifted downward.  Gap values above this showed more inverse curves with decreasing relative power as current increased.  Moving to Figure 33 and Figure 34 at 480V and 500V showed 100mm (for Stokes/Oppenlander) being the optimal gap value for maximum power with higher gap values showing inverse characteristics.

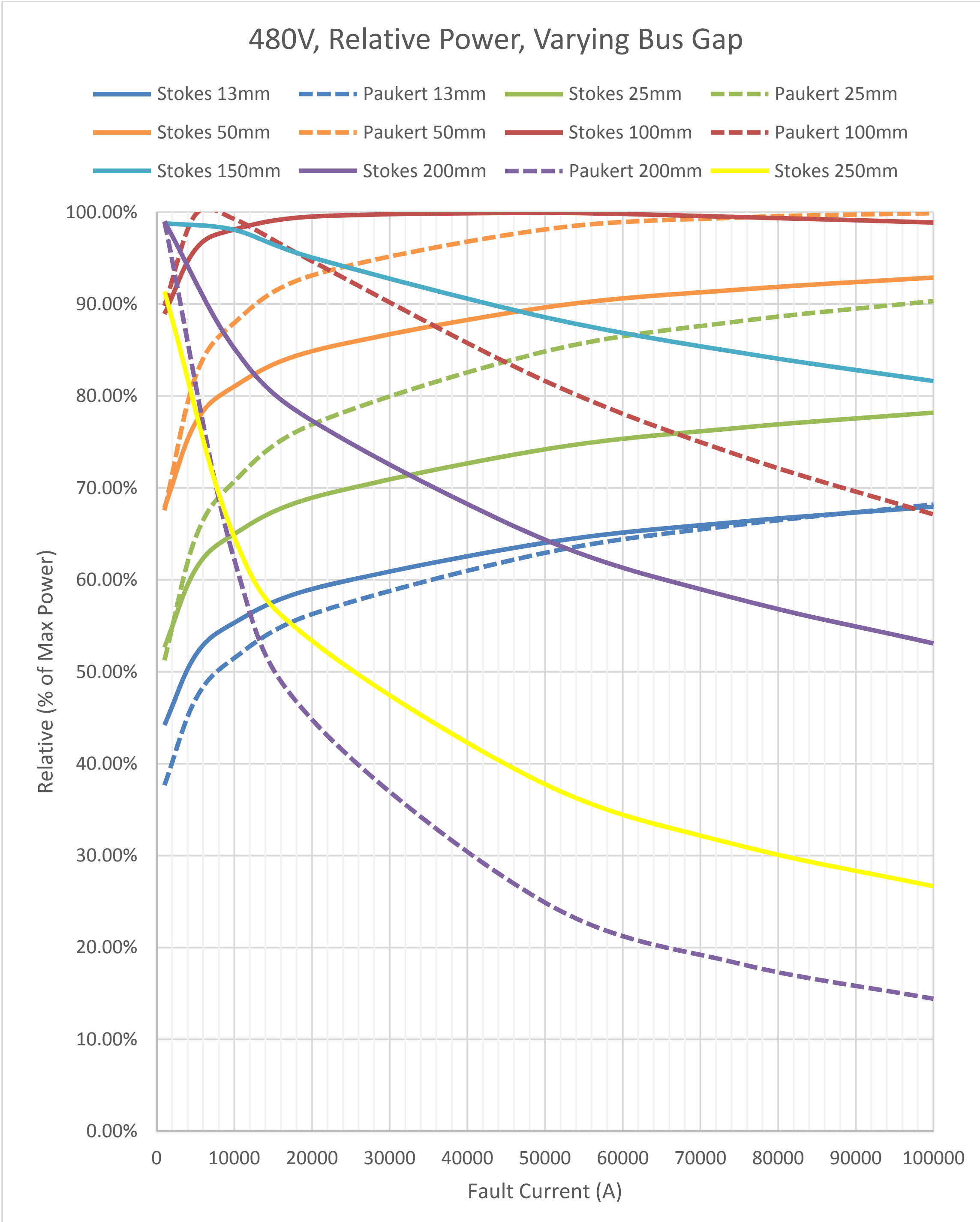



**Figure 33: Relative Power at 480V, Varying Bus Gap**

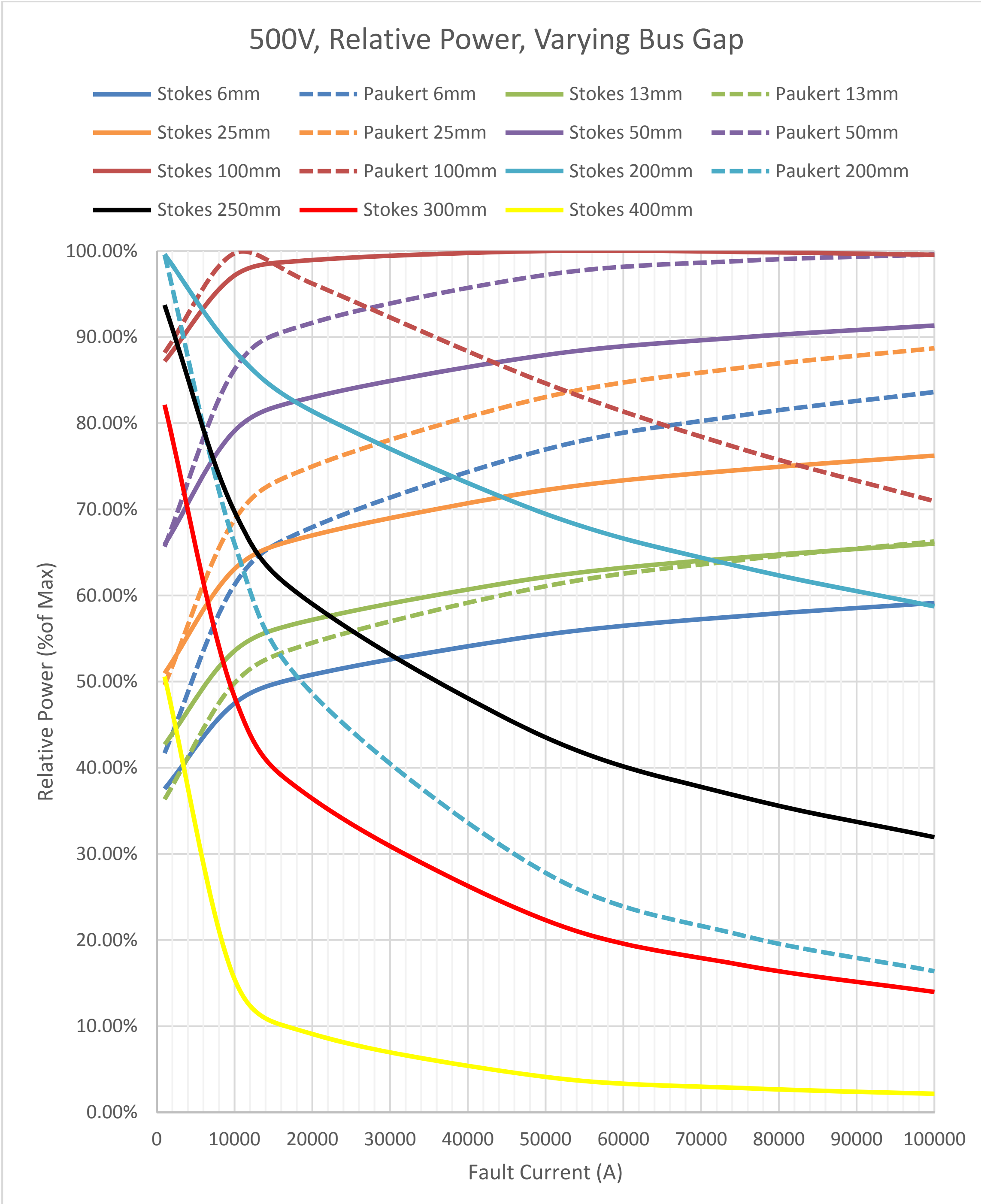



**Figure 34: Relative Power at 500V, Varying Bus Gap**

At 1000V, in Figure 35, the small gaps such as 6mm exhibited a similar curve shape to the optimal gap of 250mm (for Stokes/Oppelander) but shifted much further down resulting in significantly lower power values. Some of the gap values past 250mm would show increasing relative power at first but then decrease after a certain point. In Figure 36 at 1500V, all gap values exhibited similar shaped curves.

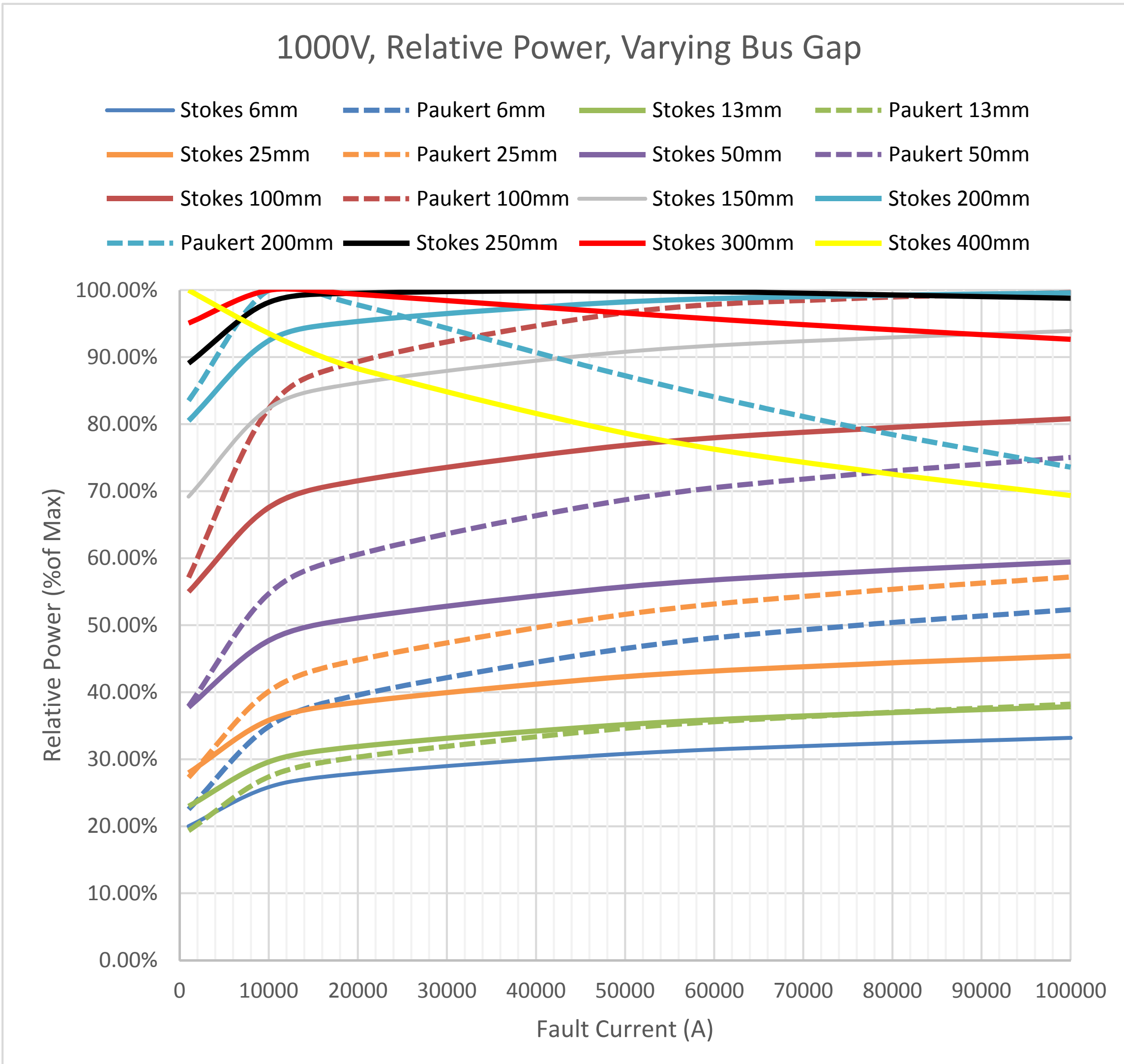



**Figure 35: Relative Power vs Fault Current, 1000V, Varying Bus Gap**

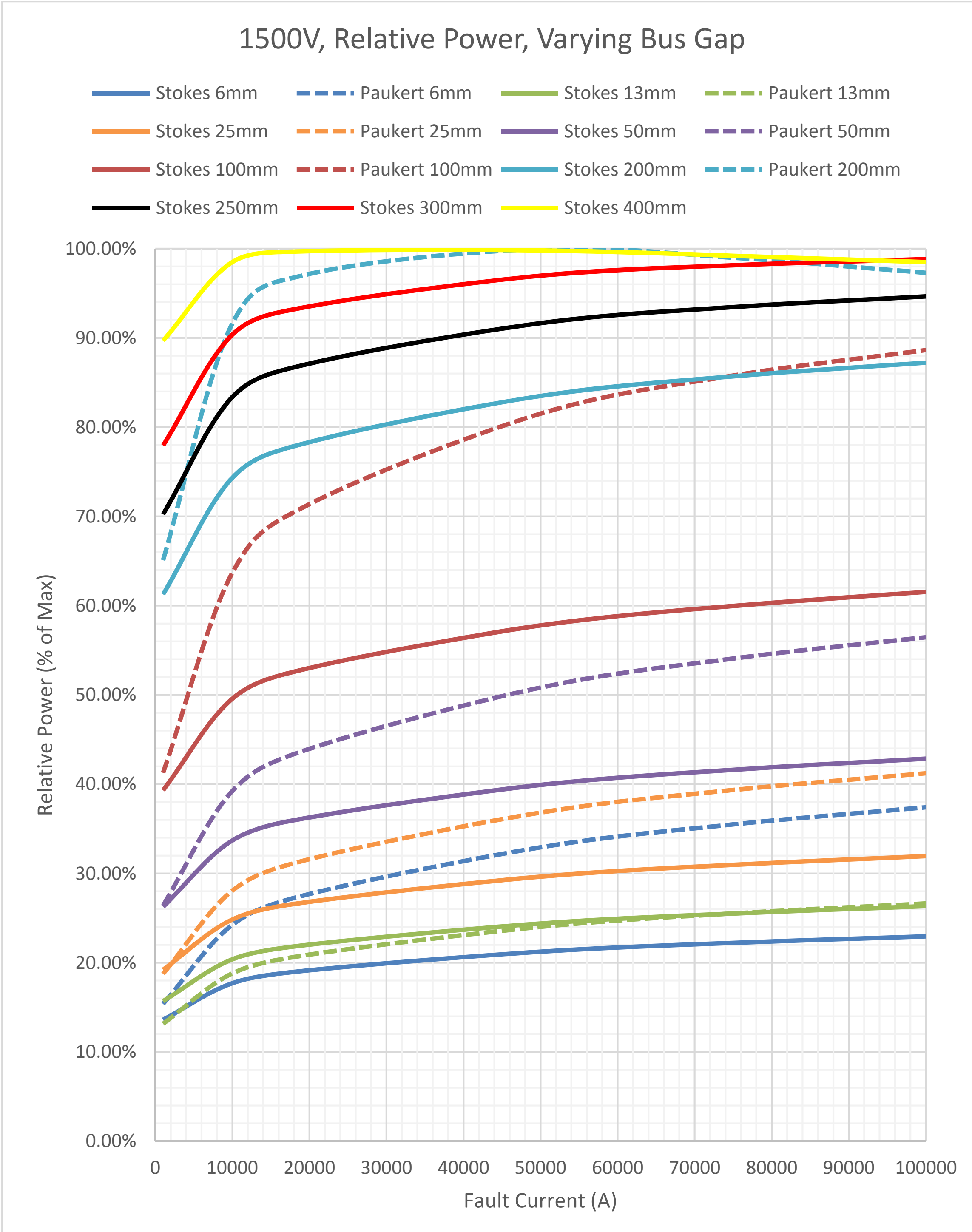



**Figure 36: Relative Power vs Fault Current, 1500V, Varying Bus Gap**

For curves showing decreasing power as fault current increases, this further supports the idea that at these gap values, it may be difficult to sustain an arc at that voltage level.  The low power corresponds to the arcing current curves discussed in the previous section that approached zero percent as the fault current increased.

While the Stokes/Oppenlander equations generally resulted in higher arcing current values than the Paukert equations, with relative power the Paukert equations generally produce the higher values.  However, the Stokes/Oppenlander curves tend to be more “stable” as the curves are more flat and do not increase or decrease as greatly as the Paukert curves.

An alternative way of looking at it, Figure 37 through Figure 44 present the same information but show the voltage at each gap value that produces similar results to the Maximum Power method.  Here, it is easier to see which voltages are supported at each gap value.

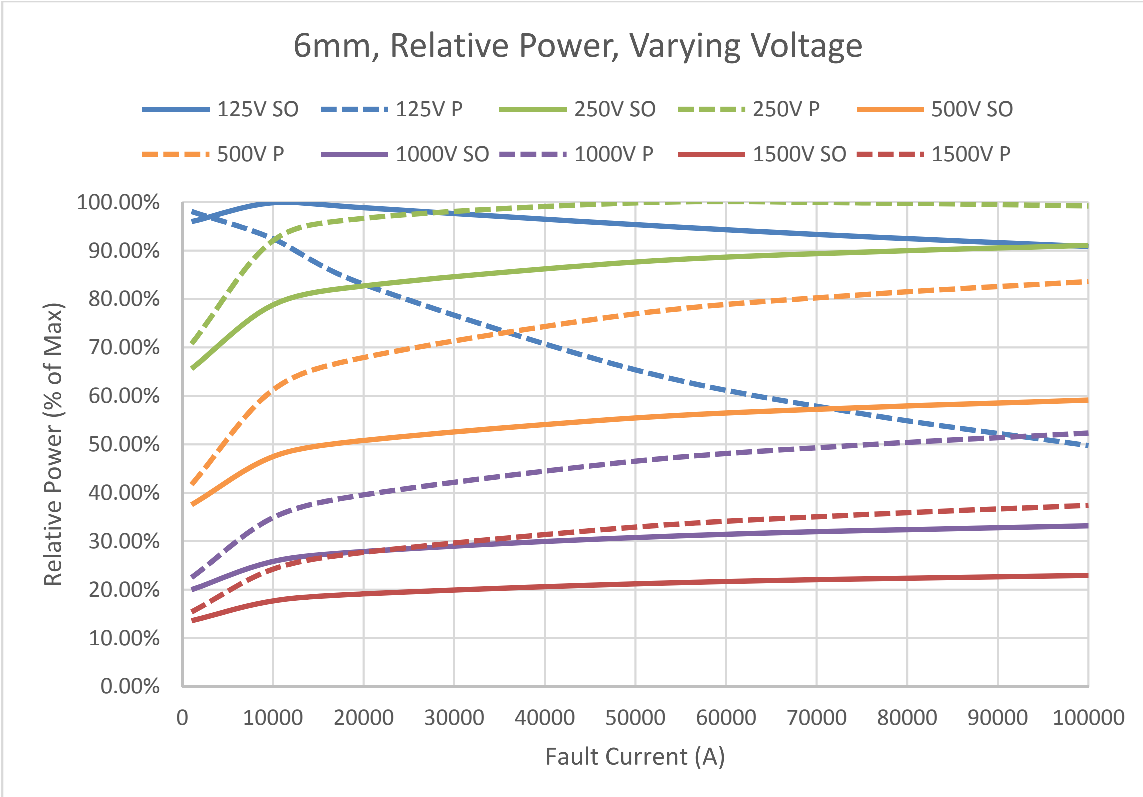



**Figure 37: Relative power of Stokes/Oppenlander and Paukert at 6mm**

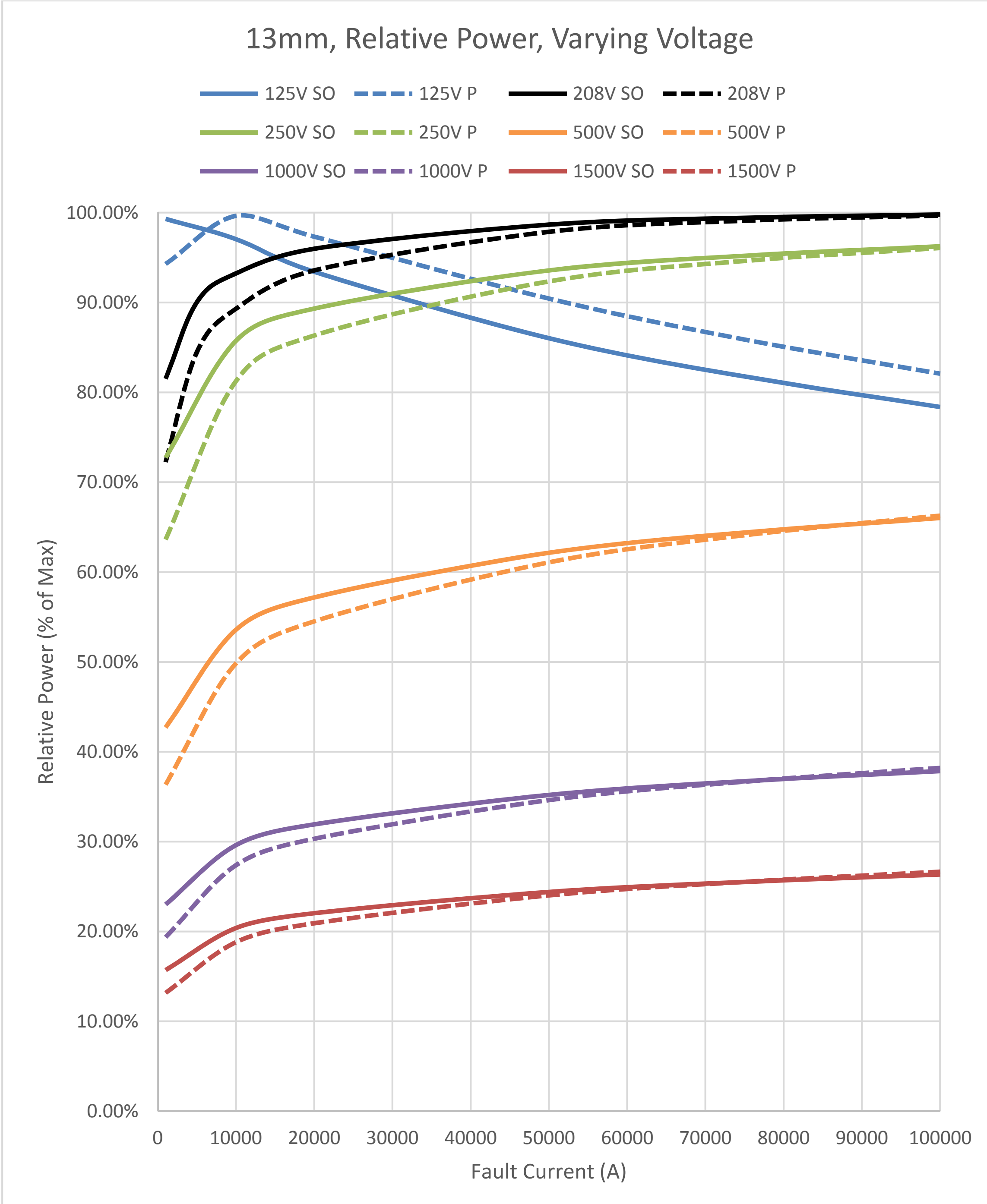



**Figure 38: Relative power of Stokes/Oppenlander and Paukert at 13mm**

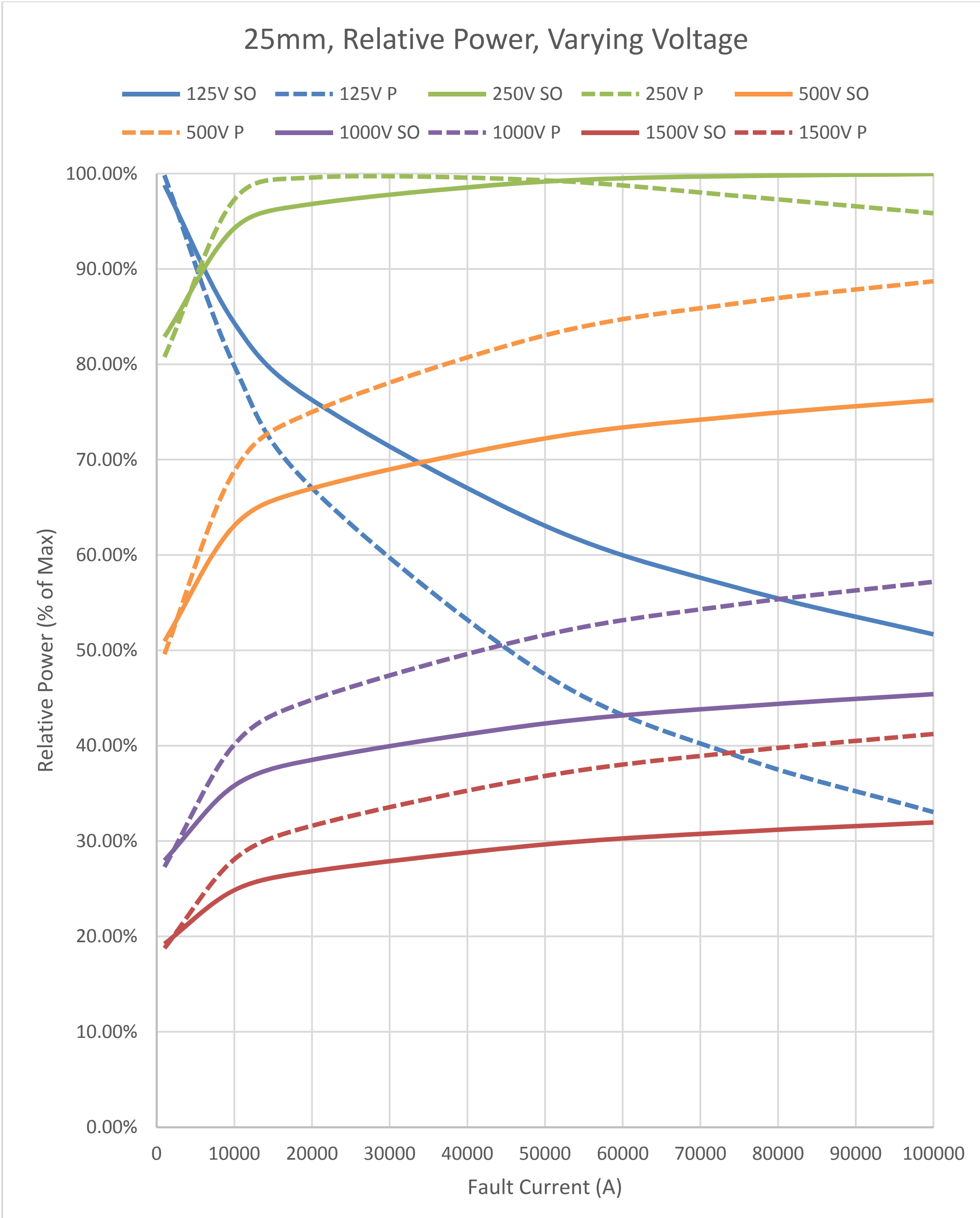



**Figure 39: Relative power of Stokes/Oppenlander and Paukert at 25mm**

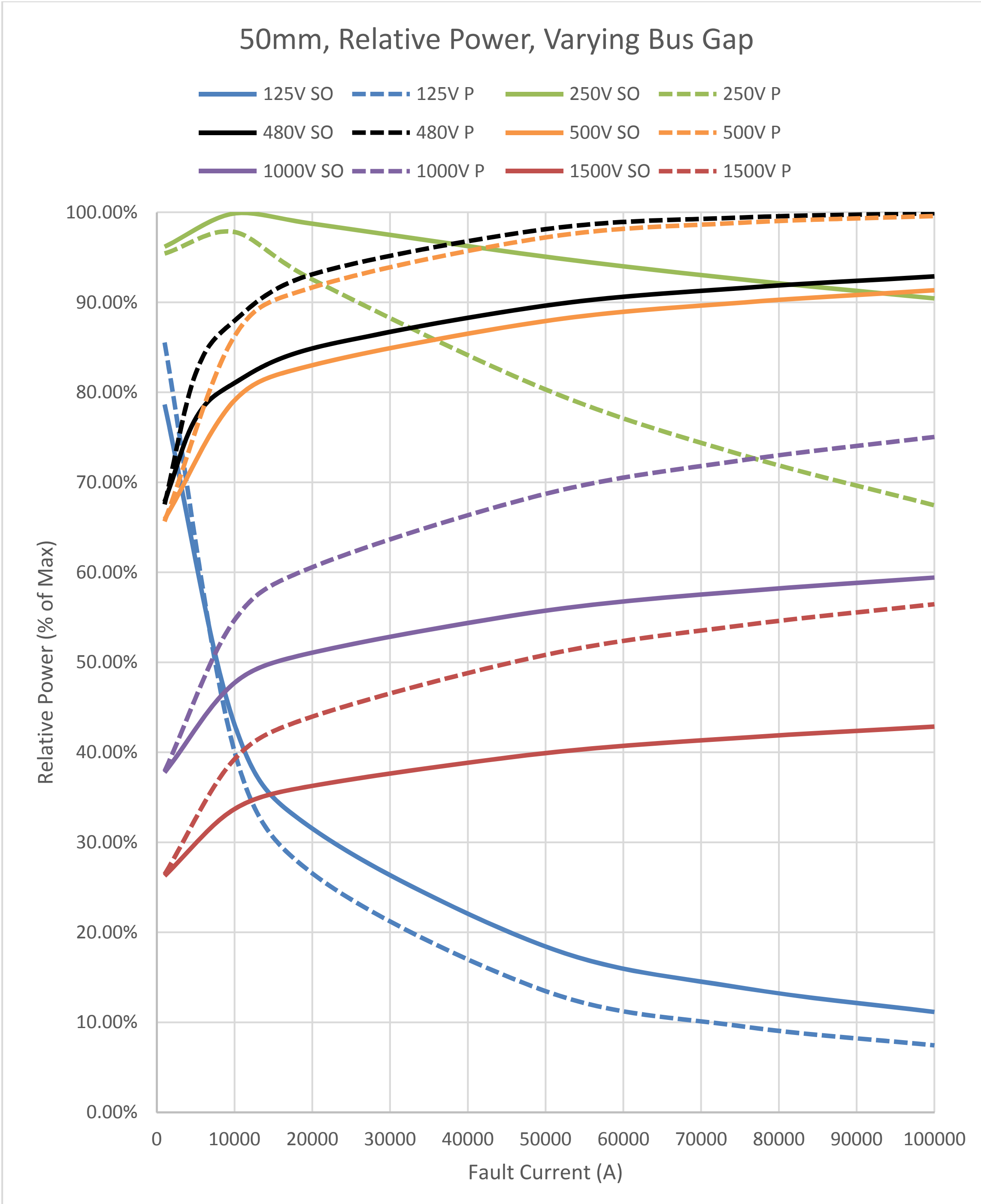



**Figure 40: Relative power of Stokes/Oppenlander and Paukert at 50mm**

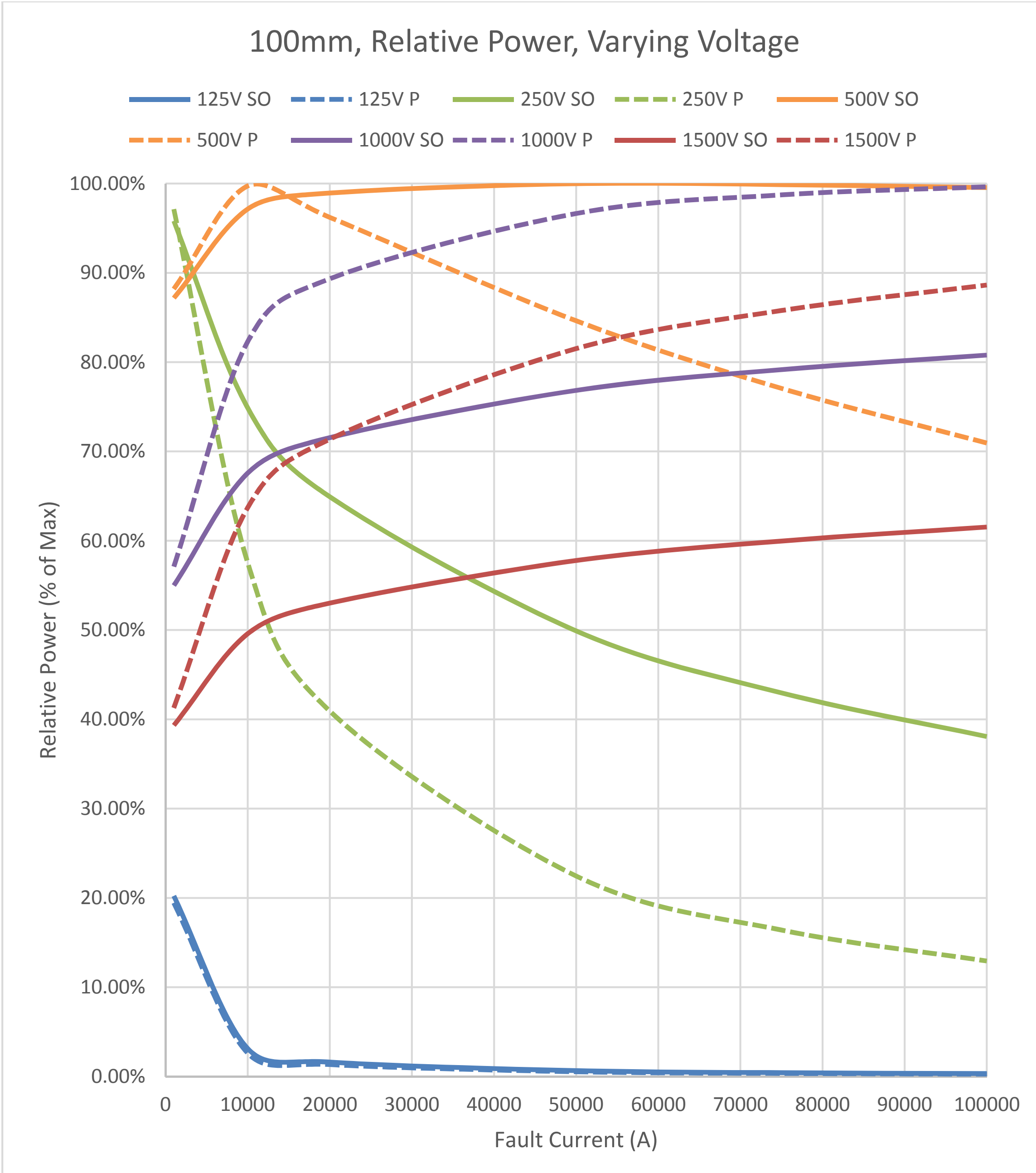



**Figure 41: Relative power of Stokes/Oppenlander and Paukert at 100mm**

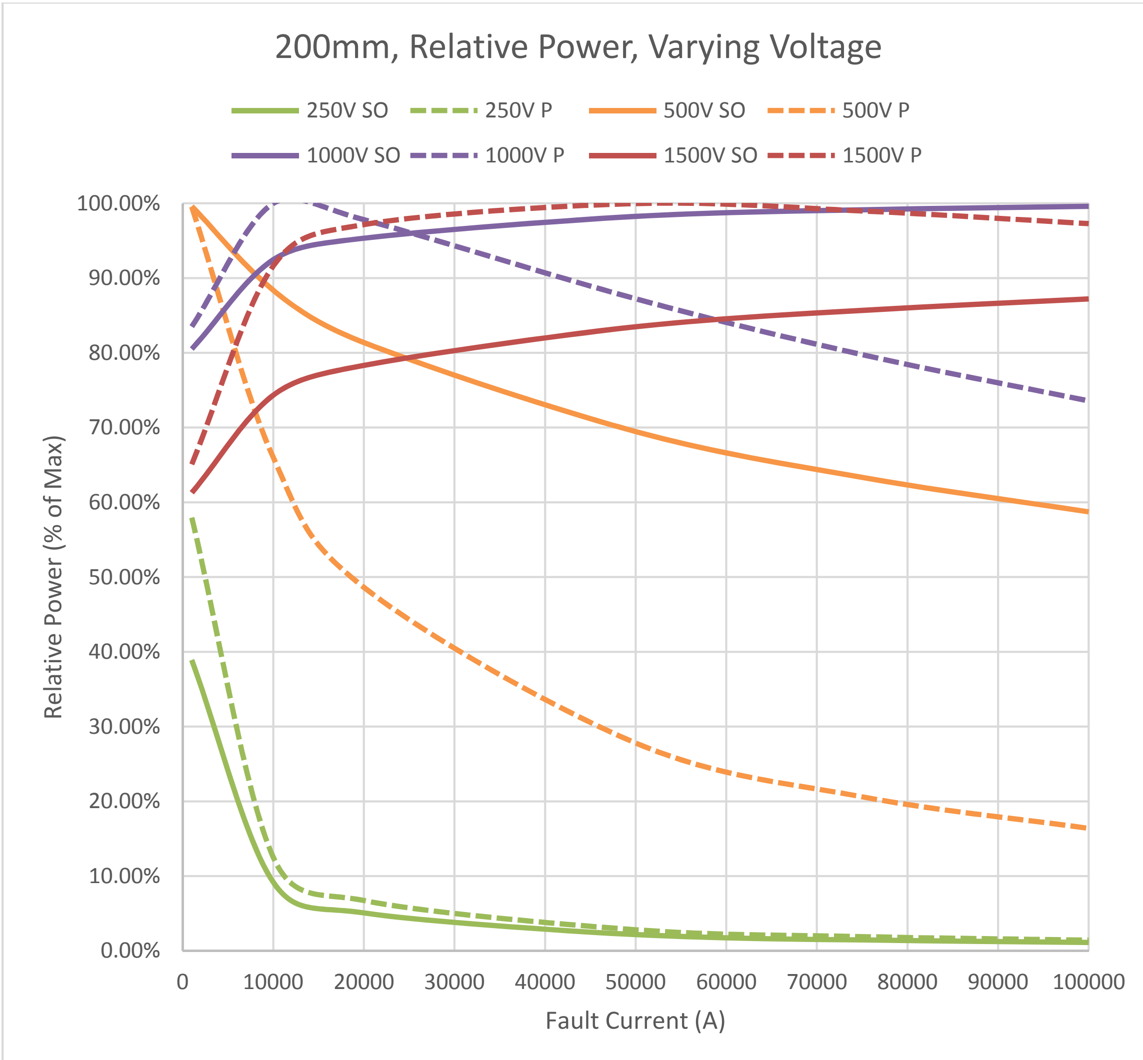



**Figure 42: Relative power of Stokes/Oppenlander and Paukert at 200mm**

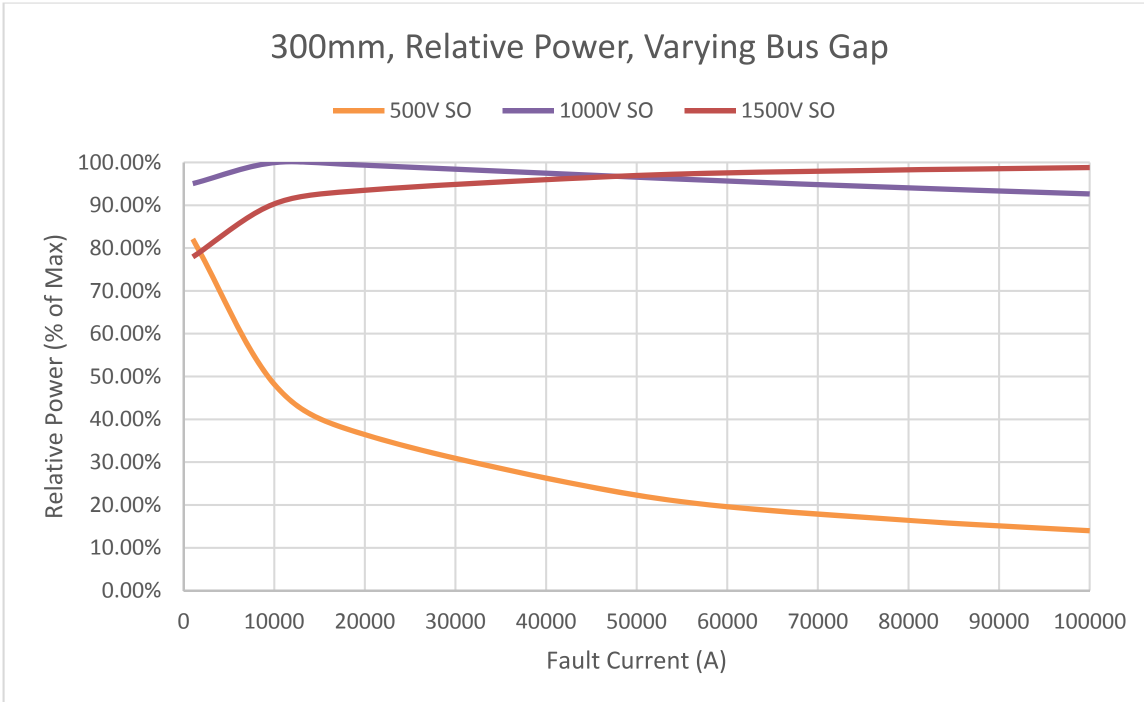



**Figure 43: Relative power of Stokes/Oppenlander and Paukert at 300mm**

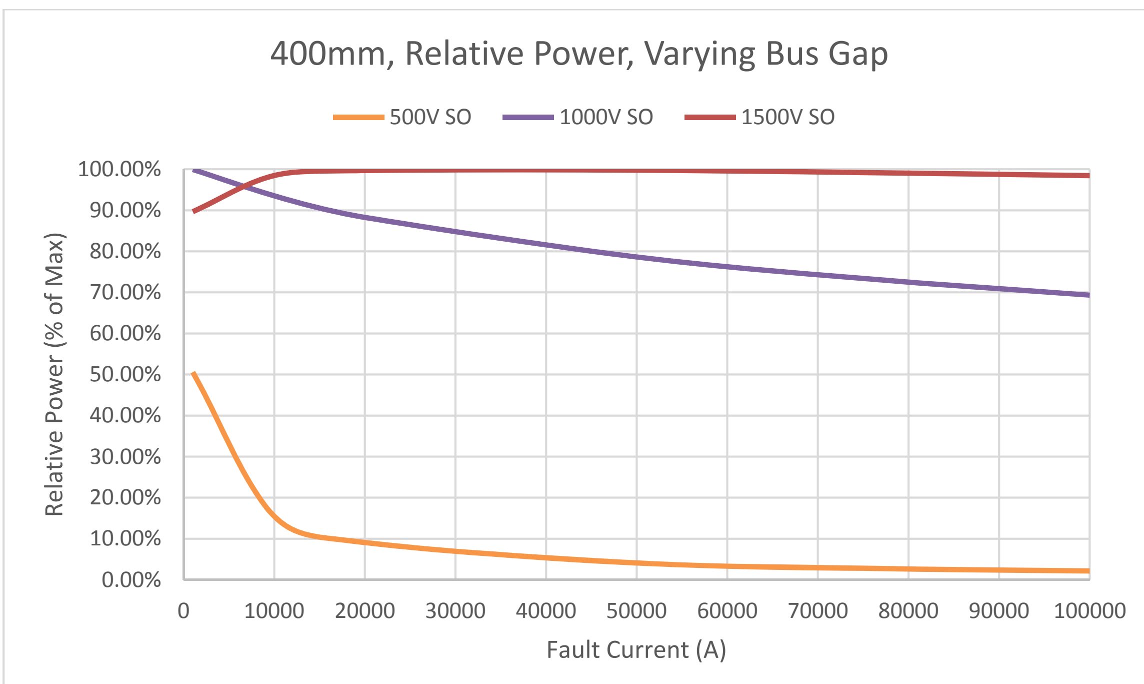



**Figure 44: Relative power of Stokes/Oppenlander and Paukert at 400mm**

One area where the Maximum Power method and the methodologies by Stokes/Oppenlander and Paukert agree is regarding the amount of arcing current in relation to the amount of power delivered to the arc. In general, when the arcing current was within 45 - 55% of the bolted fault current, this is when the power was close to the maximum as seen in Figure 45 through Figure 47 below. This was true at all voltage levels. In general, it appears that the smaller bus gaps showed relative power close to 100% at arc currents that were closer to 45% of the fault current while larger bus gaps exhibited the same at arc currents closer to 55% of the fault current. Currents both above and below the range of 45% - 55% showed considerably less power.

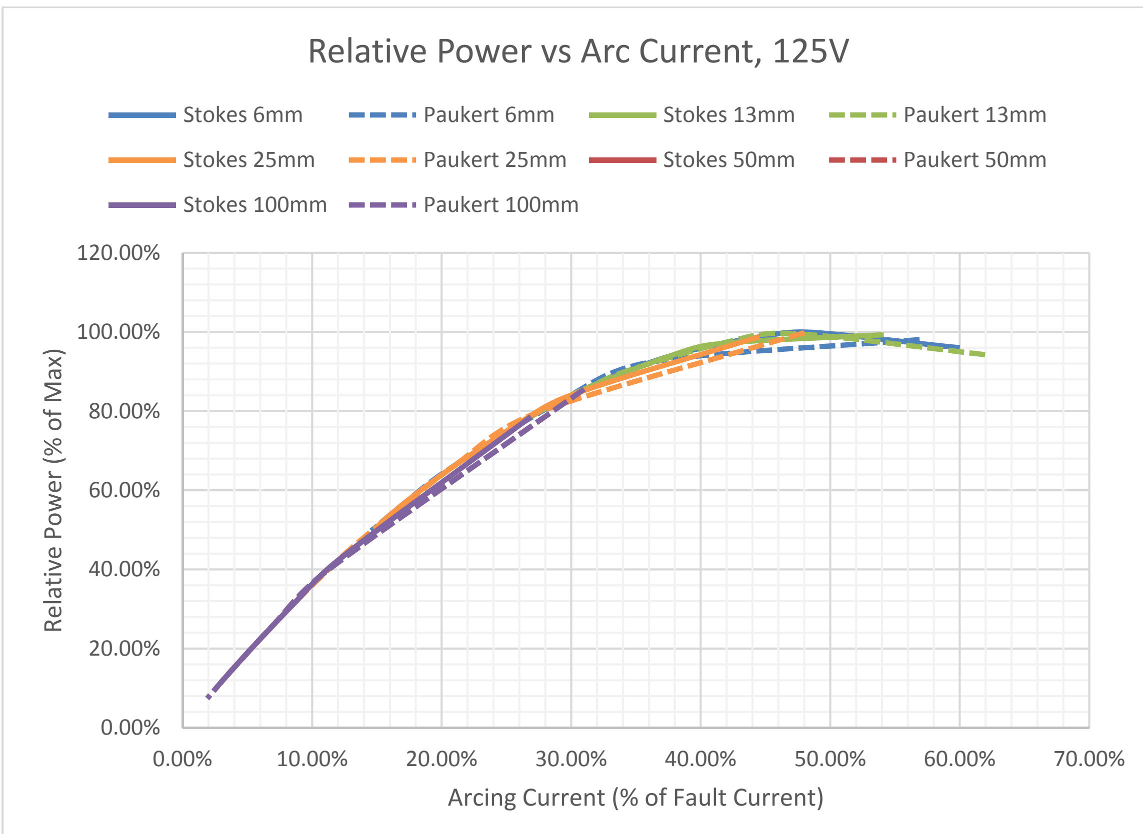



**Figure 45: Relative Power Compared to Arc Current at 125V**

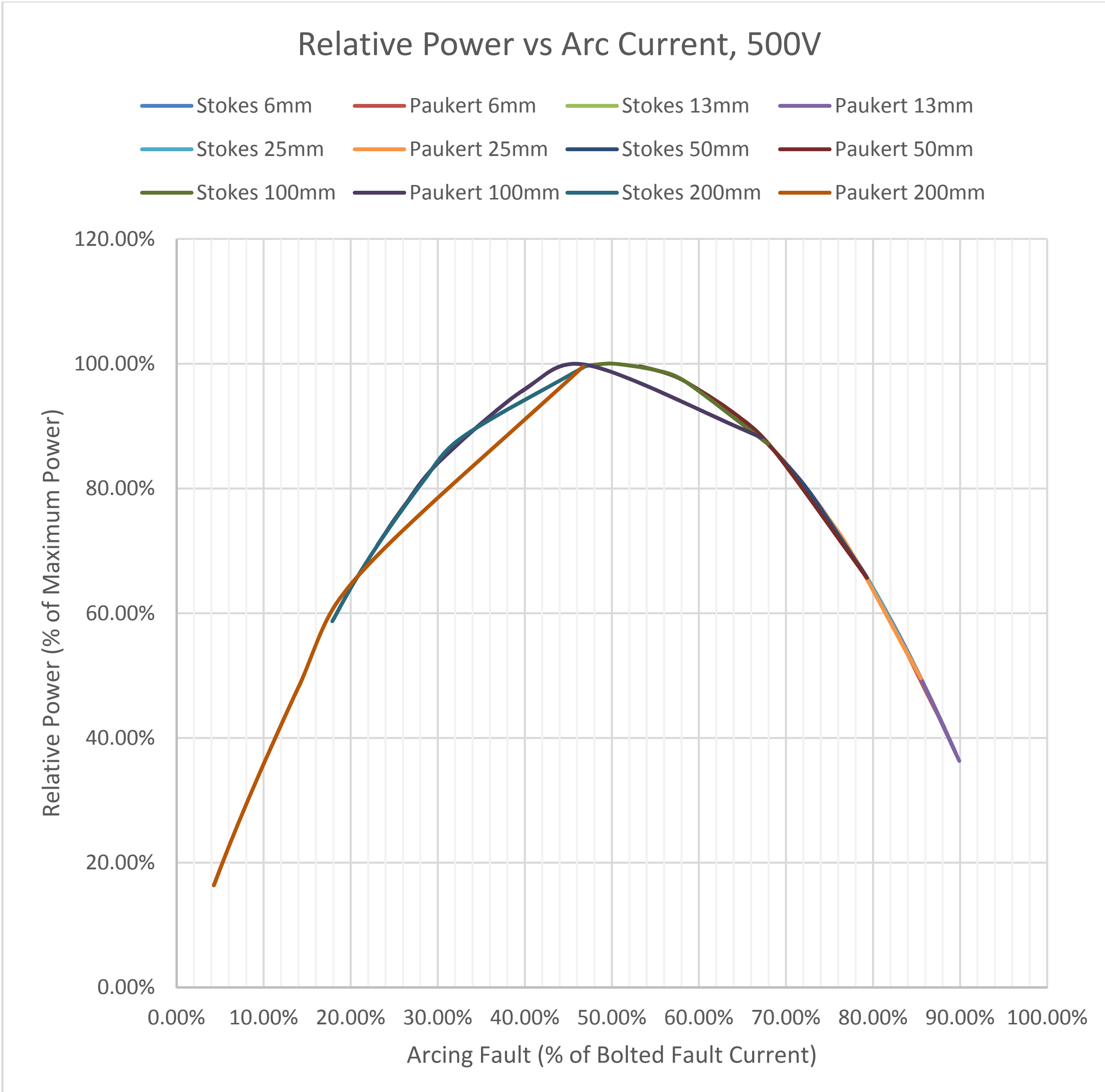



**Figure 46: Relative Power Compared to Arc Current at 500V**

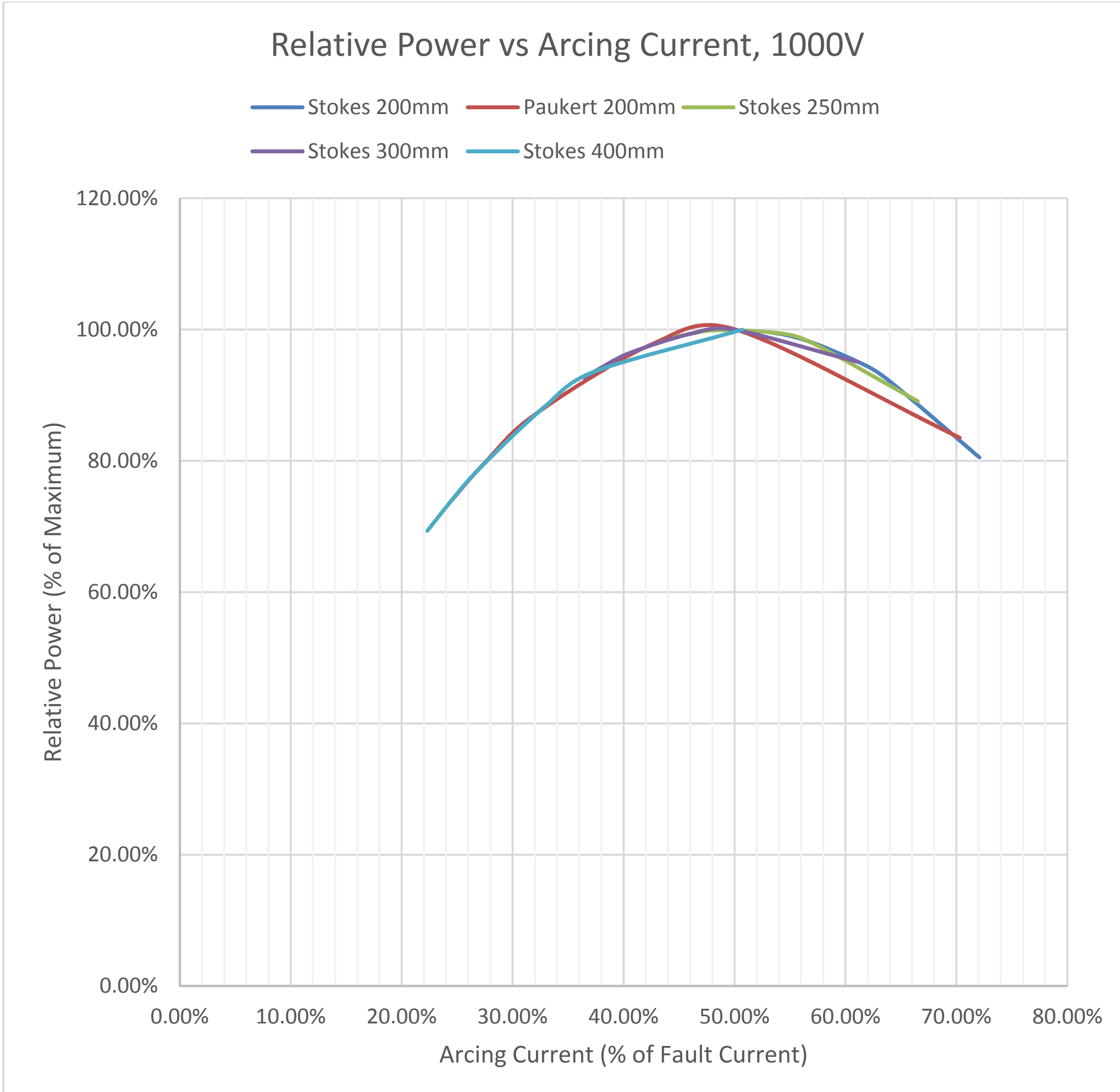



**Figure 47: Relative Power Compared to Arc Current at 1000V**

Since each of the DC calculation methodologies produces different arc currents depending on the gap value and voltage, care must be taken when considering which method to use, particularly when the circuit breaker or fuse can clear faults or currents in less than two seconds. Although one method may produce roughly equivalent power to one or two of the other methods for equal fault current, system voltage, and gap value, if

the arcing current of another method is much lower such that the protective device cannot clear the fault quickly, this may result in a higher incident energy even if the power is lower.

## 4.3. Incident Energy Comparison

Because the majority of arcs analyzed are in enclosures, initially the incident energy in enclosures was compared. In order to calculate the incident energy, first the arc energy was calculated using the following equation:

$$\mathbf{E_{arc} = V_{arc} I_{arc} t_{arc} * 0.239 = P_{arc} t_{arc} * 0.239} \quad (4\text{-}1)$$

where $E_{arc}$ is the arc energy (cal), $V_{arc}$ is the arcing voltage (V), $I_{arc}$ is the arcing current (A), $P_{arc}$ is the arc power (W), and $t_{arc}$ is the arcing time (sec). This value is then plugged into Equation 2-19 using the panelboard values from Table 3 for a and k, with a distance of 18in for d:

$$\mathbf{E_1 = k \frac{E_{arc}}{a^2+d^2} \; (arc-in-a-box)} \quad (4\text{-}2)$$

However, as seen in Figure 48, the equations for incident energy themselves actually have their own effect on the magnitude of results. Compared to Figure 30, it would be expected that the incident energy using the Stokes/Oppenlander method for equipment with a 6mm bus gap and a fault current of around 12kA would be roughly equal to that of the Maximum Power method. However, because Doan proposed to use a multiplier of three for arc-in-a-box situations, this results in rather conservatively high incident energy. This can be problematic because at approximately 22kA, the incident energy exceeds 40 cal/cm$^2$ which is the NFPA 70E limit where no NFPA recommended

PPE exists and de-energized work is recommended. However, for a range of about 20kA to 30kA, the Stokes method at 6mm produces power that is within 5% of the maximum power. Since this method results in incident energy that is well below 40 cal/cm$^2$, the methods proposed by Ammerman et al. for calculating incident energy suggest that the arc flash hazard can be partially mitigated with PPE while the method by Doan does not. The multipliers that Ammerman et al. use for calculating the incident energy in an enclosure are based of research performed for IEEE [2] so using these values is not completely unfounded. Parsons suggest an alternative multiplier to use instead of three as Doan proposed, which would be 2.74 for low voltage switchgear and 1.52 for low voltage panelboards per IEEE 1584 [11] which produces similar values, at least for panelboards, as seen later in the examples.

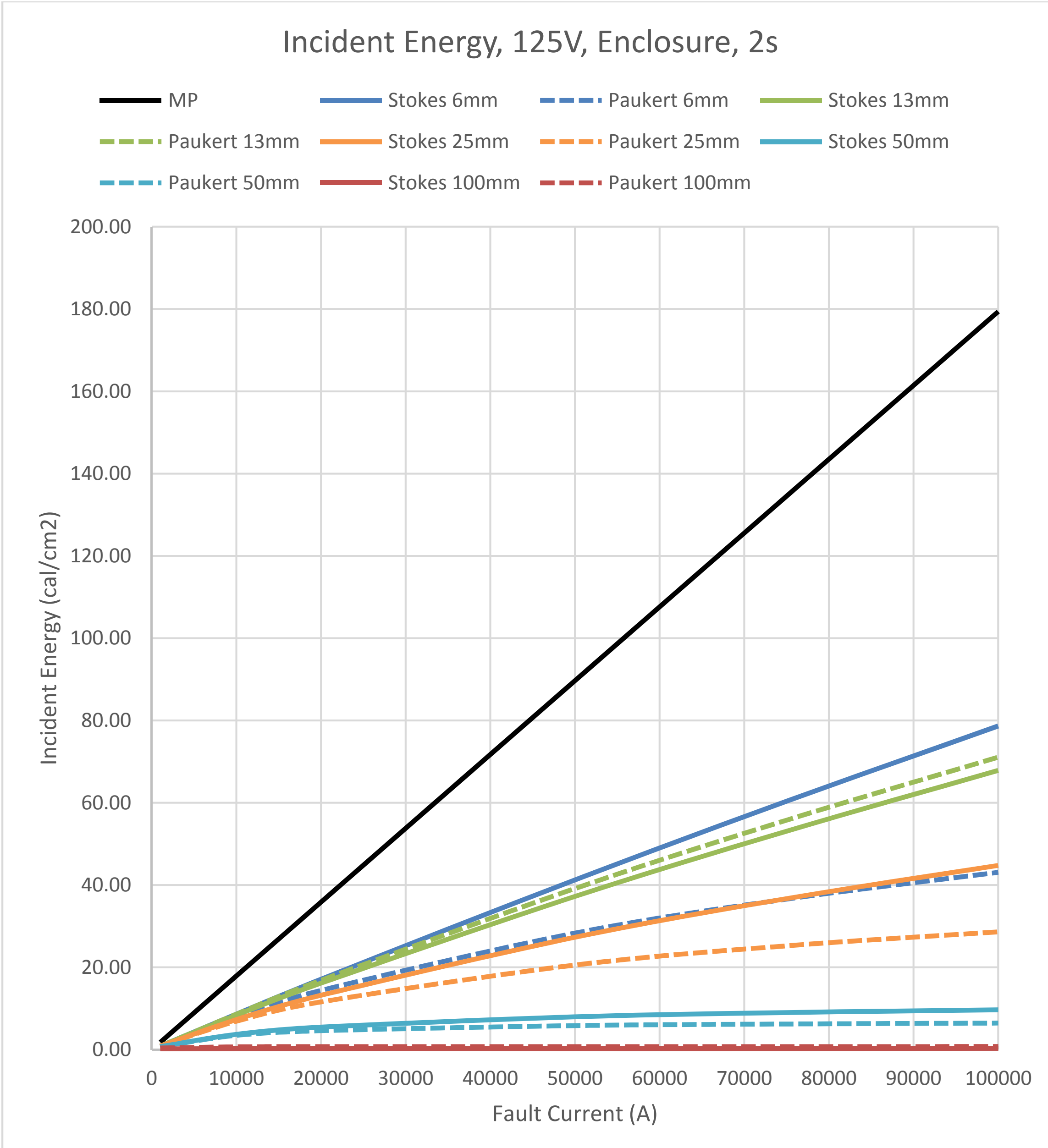



**Figure 48: Incident Energy at 125V, Various Gap Values for Arcs in Enclosures.**

It has been shown in the AC test results from IEEE 1584 that arcs in enclosures have heat reflected which concentrates and thus increases the incident energy. With the

dilemma previously mentioned, it is clear that some work and research needs to be done to accurately capture the multiplier effect caused by arc-in-a-box situations as there is quite a significant difference between the multipliers proposed by Doan and those by Ammerman et al (which are an extension of work done by Wilkins). However, since that is a project on its own and is outside the scope of this thesis, this will be left to future work. In the meantime, the incident energy will be compared using open air situations and Equation 2-18 since this provides the base energy levels and is not influenced by any multipliers.

For the incident energy comparisons, all results were calculated using a working distance of 18 inches and arc time of 2 seconds since 18 inches is the typical working distance for panelboards and two seconds is the assumed maximum arcing time per IEEE 1584 standards. This is under the assumption that two seconds is the worst case scenario, as it is enough time for either personnel to leave the arc flash boundary and avoid the rest of the hazard or for an arc blast to push the person away from the incident [4].

Although 2 seconds provides the worst case scenario for equal fault currents, it must be remembered that the arc time is based on the amount of arc current that flows through the protective device. Since not all three methodologies will always produce the same amount of arcing current for a given fault current, it is possible that one method could produce more incident energy since the protective device clearing the fault cannot sense the current quickly enough as shown in Figure 49 below. For a fault current of approximately 50kA and arc time of 1.5 seconds, this will produce the same amount of energy as a fault current of approximately 75kA with an arc time of 1 second.

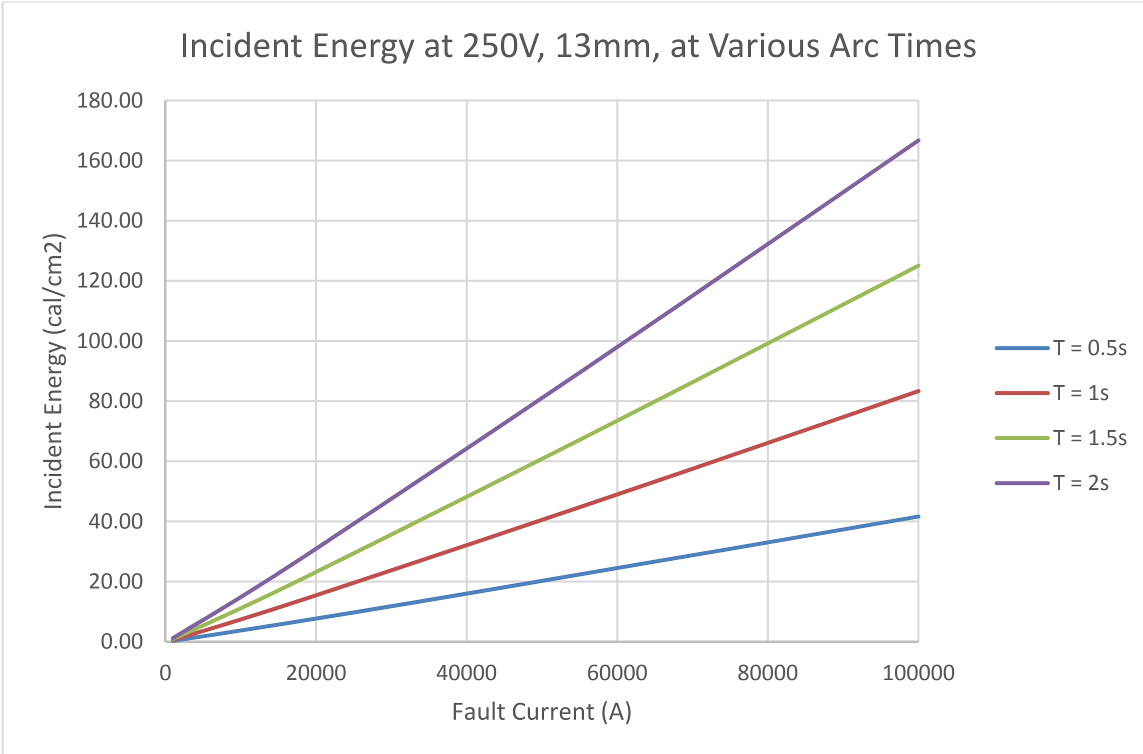



**Figure 49: Incident energy at 250V and 13mm comparing various arcing times based on the Stokes/Oppenlander method**

Comparing the incident energy for arcs in open-air shows results that are more aligned with the results comparing relative power. The incident energy results confirmed what the results from the relative power maps showed, with the bus gap curves at particular voltage levels showing close to maximum power producing very similar incident energy calorie levels to the Doan method.

The open air incident energy results in Figure 50 through Figure 54 confirm the results seen in the relative power maps. For instance, in Figure 50, the 6mm equations show very similar results to the Maximum Power method while the 100mm equations show close to zero cal/cm$^2$. At 250V, where 6mm through 50mm all produce relative

power values within 90% for certain current ranges (depending on the methodology), Figure 51 showed that these gap values produced incident energy values close to the Doan method.

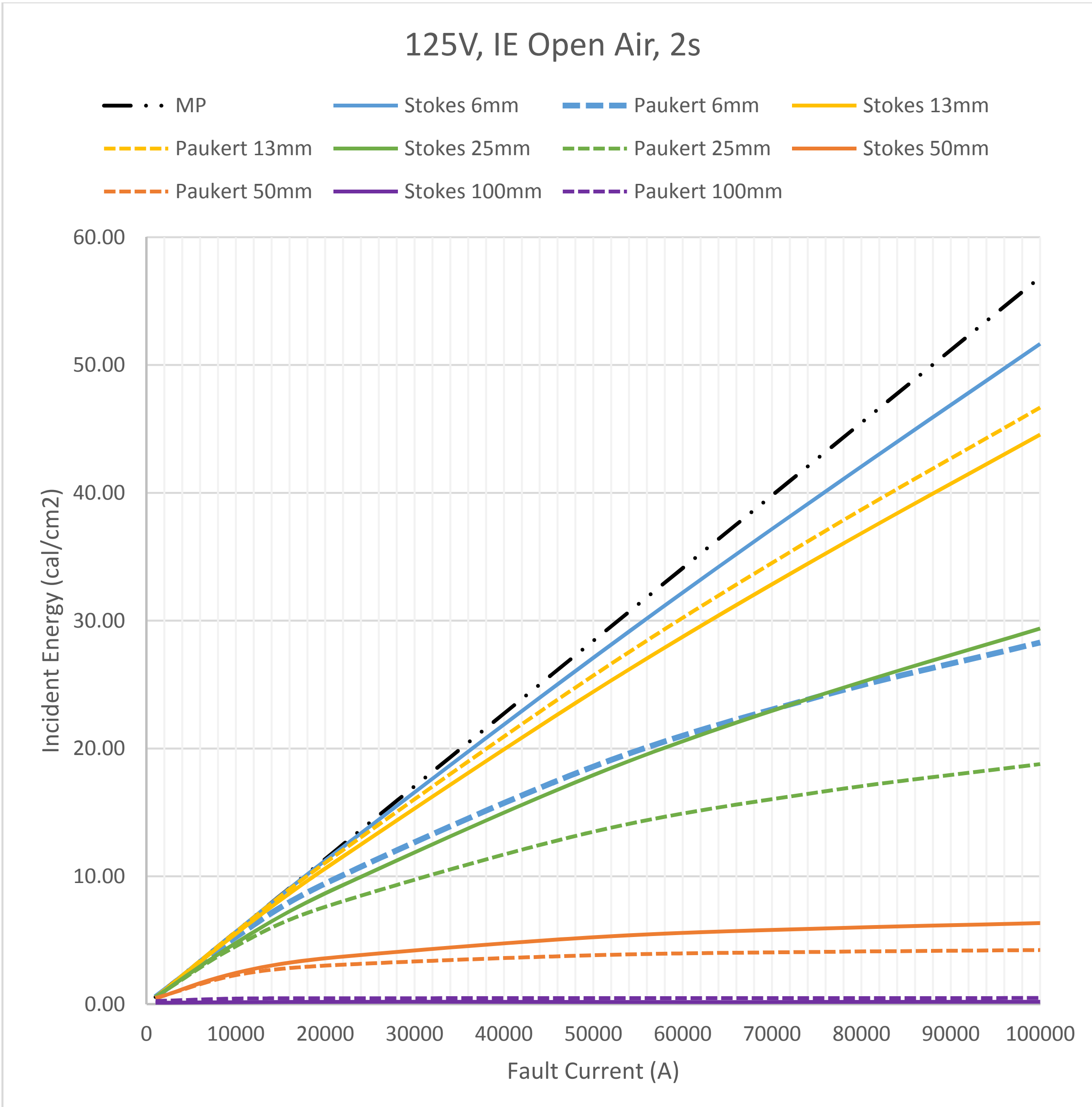



**Figure 50: Incident Energy Comparison, 125V, Open Air**

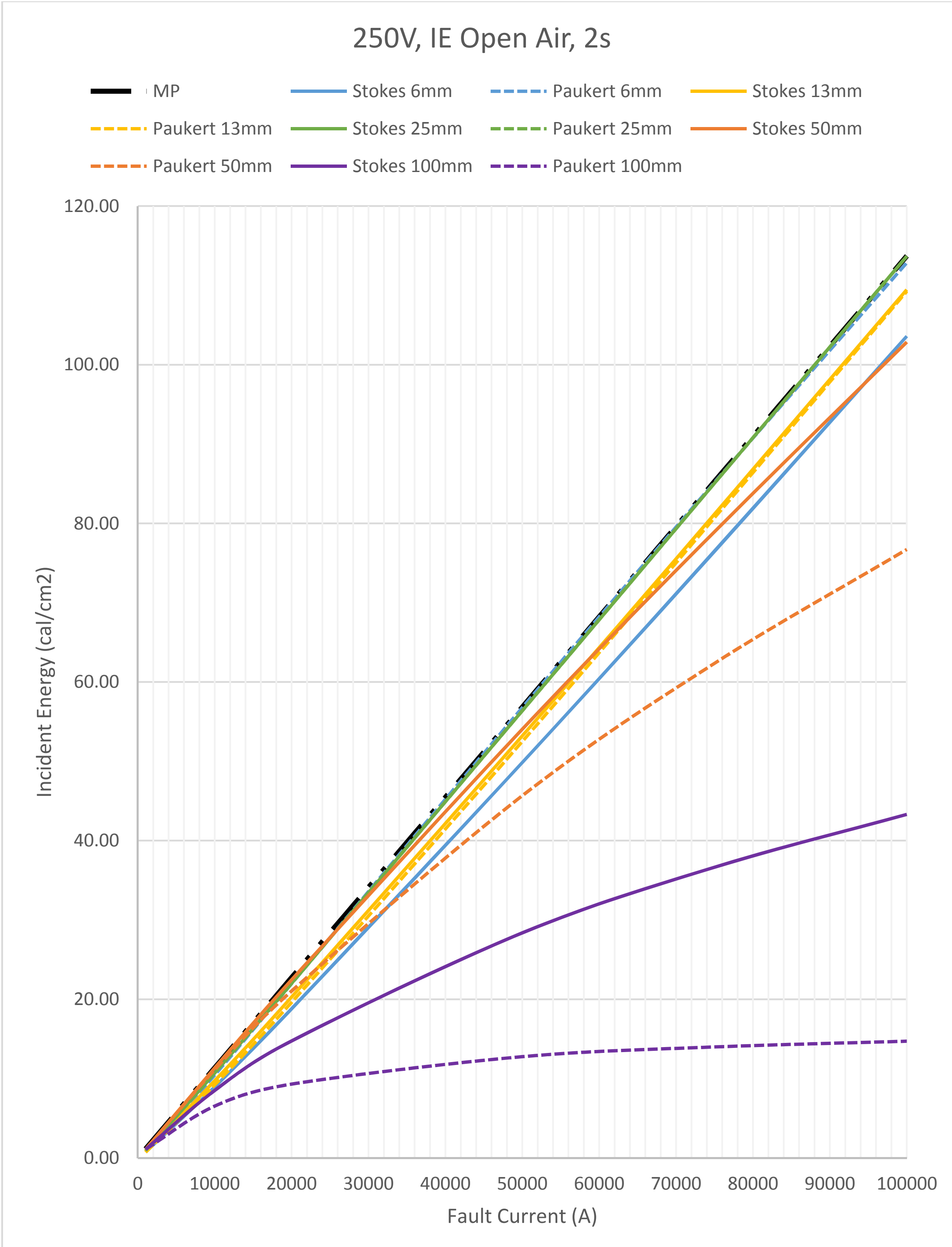



**Figure 51: Incident Energy Comparison, 250V, Open Air**

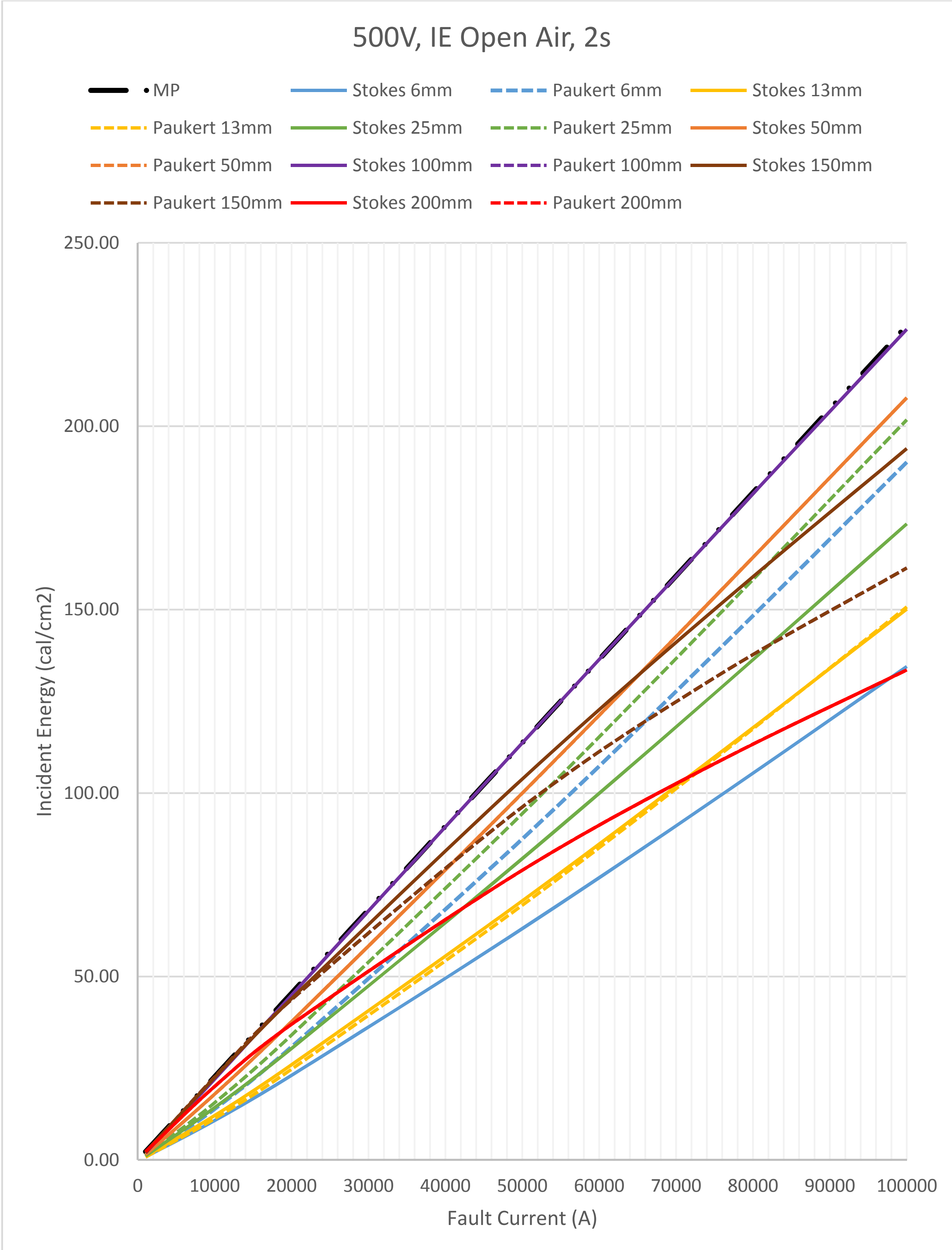



**Figure 52: Incident Energy Comparison, 500V, Open Air**

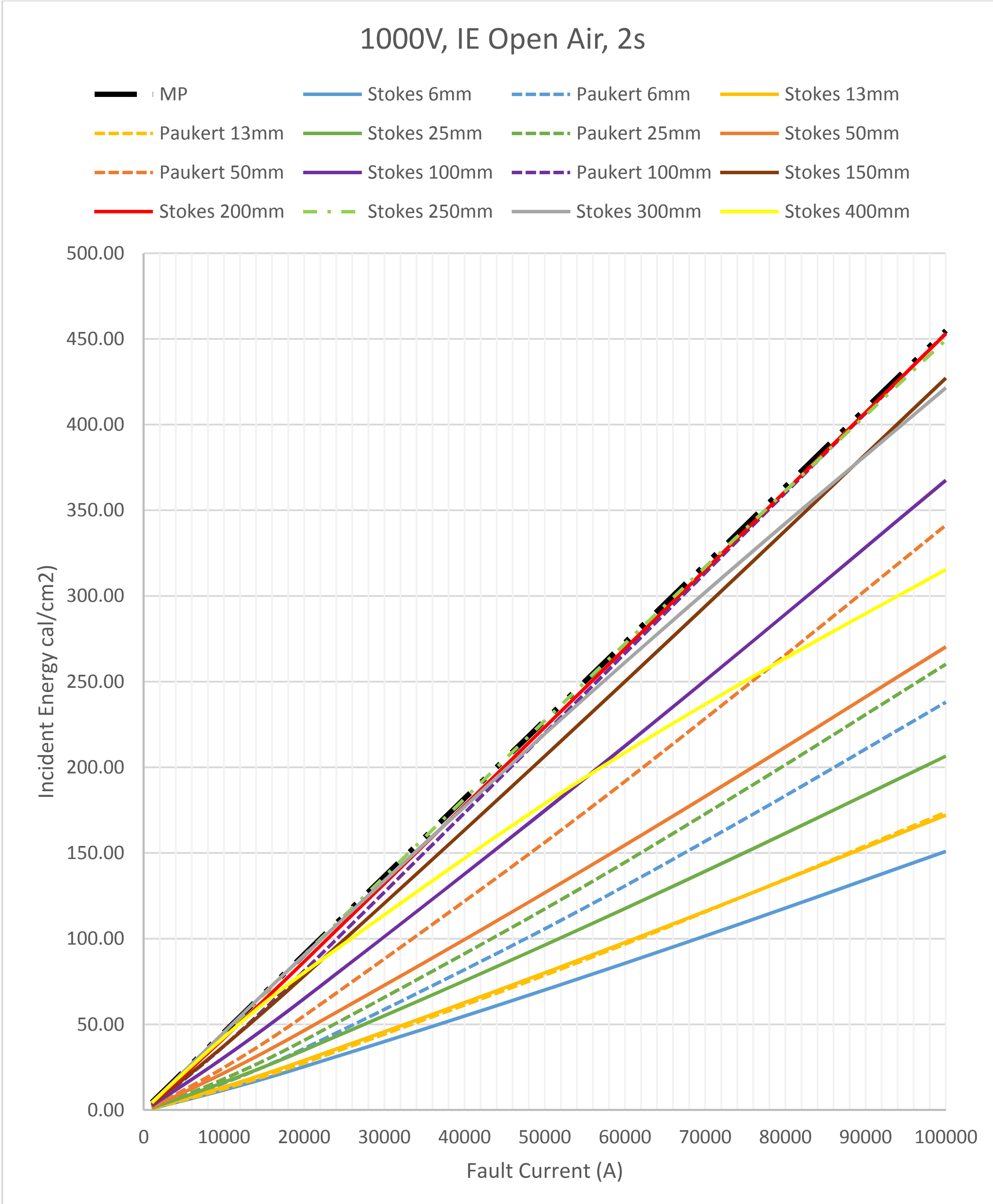



**Figure 53: Incident Energy Comparison, 1000V, Open Air**

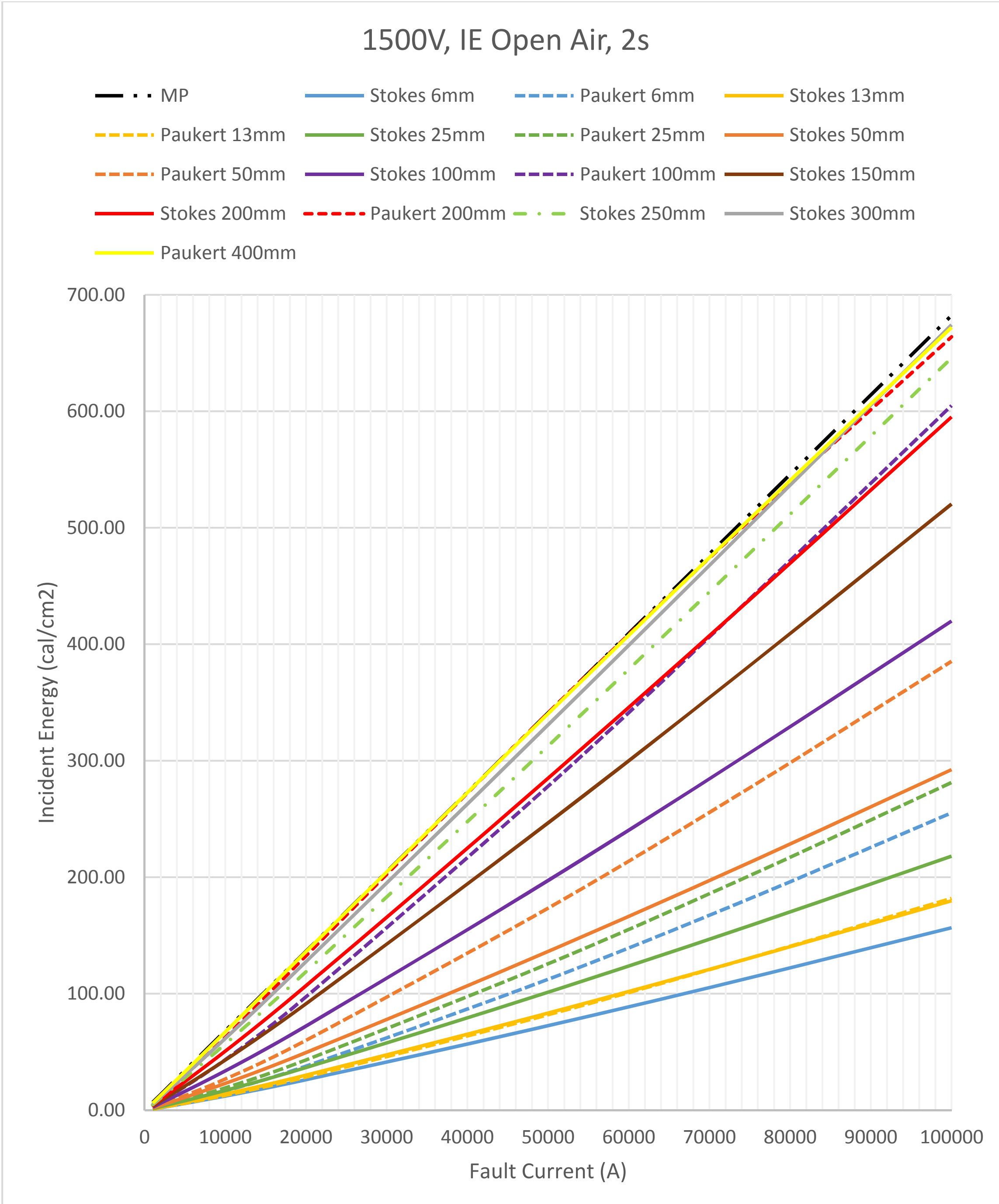



**Figure 54: Incident Energy Comparison, 1500V, Open Air**

The graphs also show some important information regarding the calculation of incident energy. In general, the two methods showed the greatest deviance from

Maximum Power at high fault currents, especially as the voltage increases. Even at areas where the Stokes/Oppenlander and Paukert methods may yield much lower incident energy levels, if the fault current is high enough, regardless of which method is applied, the incident energy levels are above 40 cal/cm$^2$ where de-energized work is recommended. For instance, in Figure 52, even though the 200mm curve produces almost half the incident energy at 100kA, both results are well above the 40 cal/cm$^2$ limit. Although it is always recommended to produce the most accurate values possible, from a logistical standpoint, all three methods would yield the same result for the end-user.

However, slight deviations can be extremely significant at lower incident energy levels since the PPE incident energy threshold ranges are much smaller at low levels. A difference of 4 cal/cm$^2$ may not have as big an impact on the PPE worn at higher incident energy levels, especially 8 cal/cm$^2$and above, but a 4 cal/cm$^2$ difference would change the amount of PPE required quite significantly for values less than 8 cal/cm$^2$.

It should also be mentioned that although the graphs show multiple bus gap levels, not all may be applicable as they may be outside the value or range of values that is typical for different types of equipment as seen in the IEEE tables.

Looking at the AC comparison of the measured results to the theoretical Lee (Equation 2-1) results in Figure 55 through Figure 57, the measured results showed fairly good agreement with the Lee equations especially as the voltage increased. The 25mm curves showed particularly good agreement which is significant since 25mm is the typical bus gap for panel type enclosures, which is perhaps the most common type of equipment installation. Note that some of the curves actually had greater incident energy values

than the theoretical Maximum Power results as the low voltage IEEE 1584 equations for calculating incident energy in open air have their own multipliers so this could result in higher incident energy than the theoretical maximum.

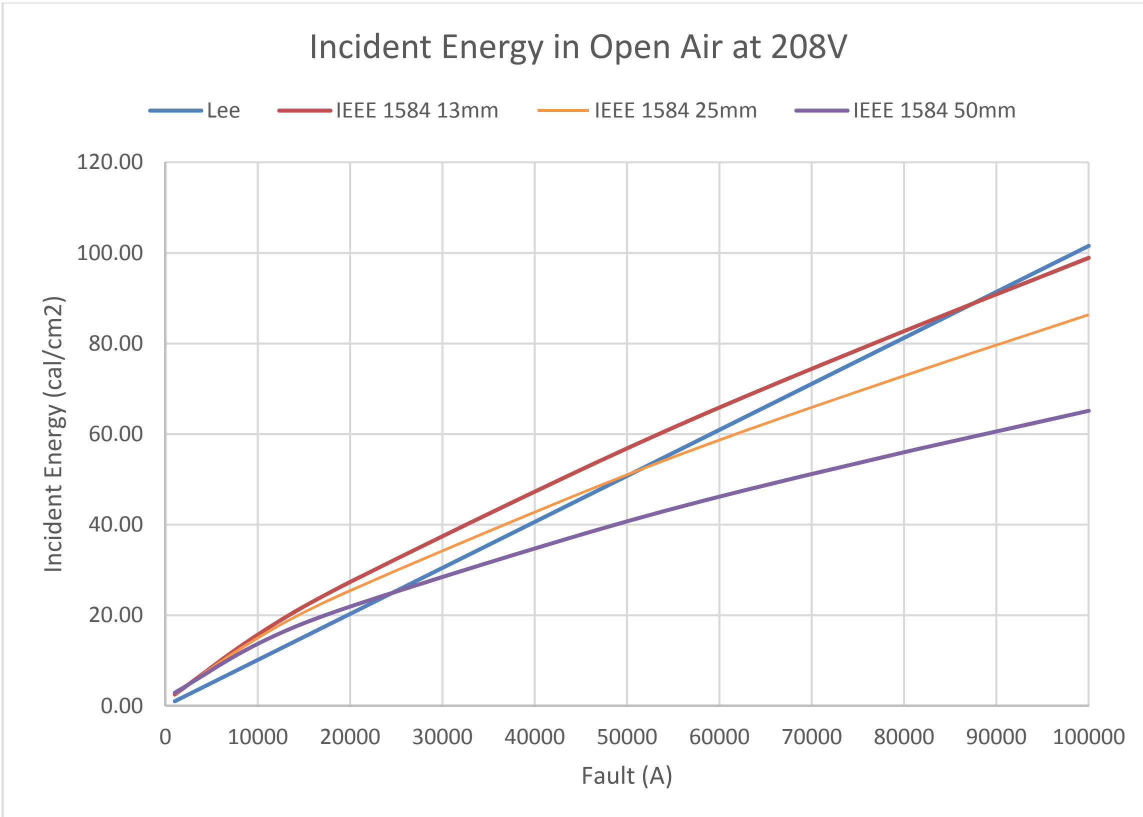



**Figure 55: Incident energy in open air at 208V, comparing measured IEEE 1584 results to theoretical Lee equation.**

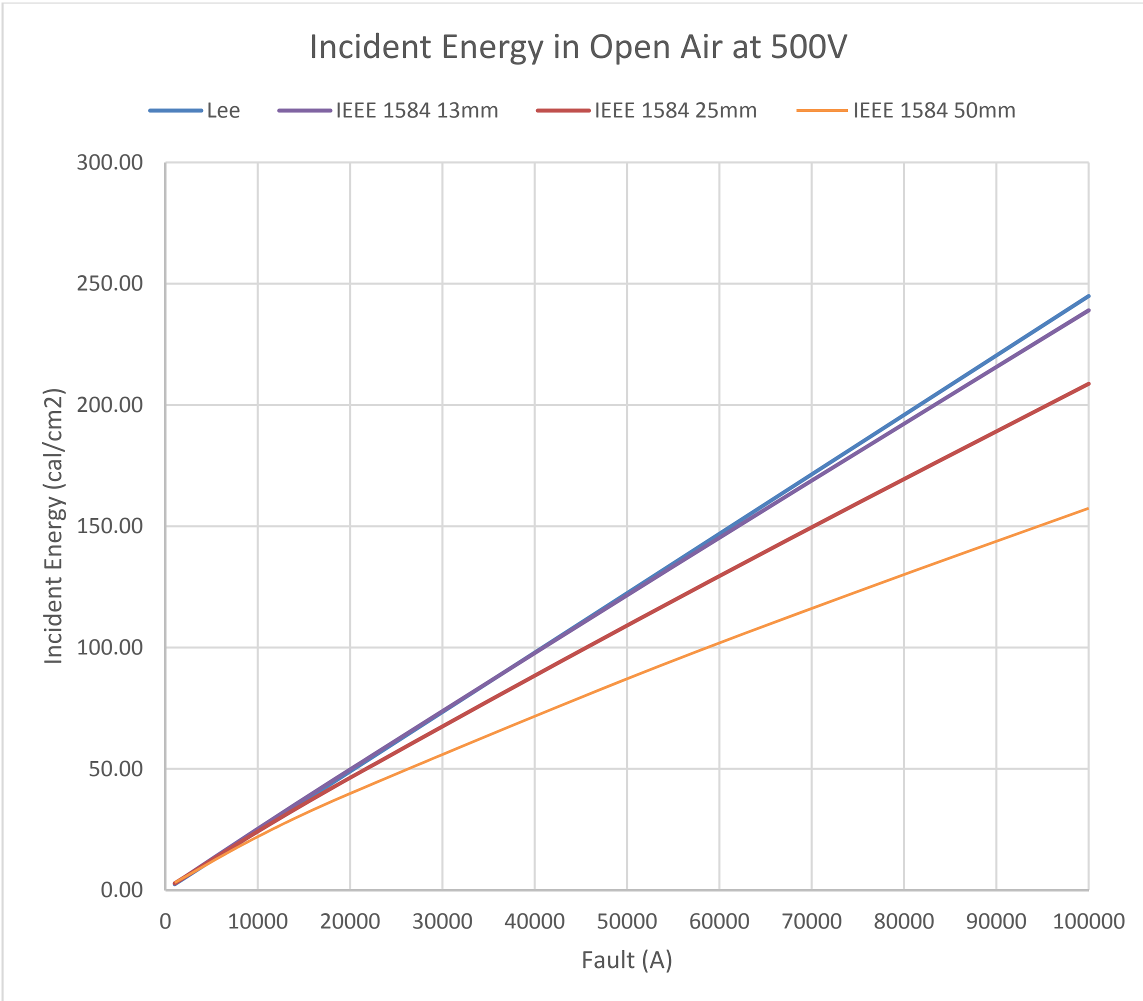



**Figure 56: Incident energy in open air at 500V, comparing measured IEEE 1584 results to theoretical Lee equation.**

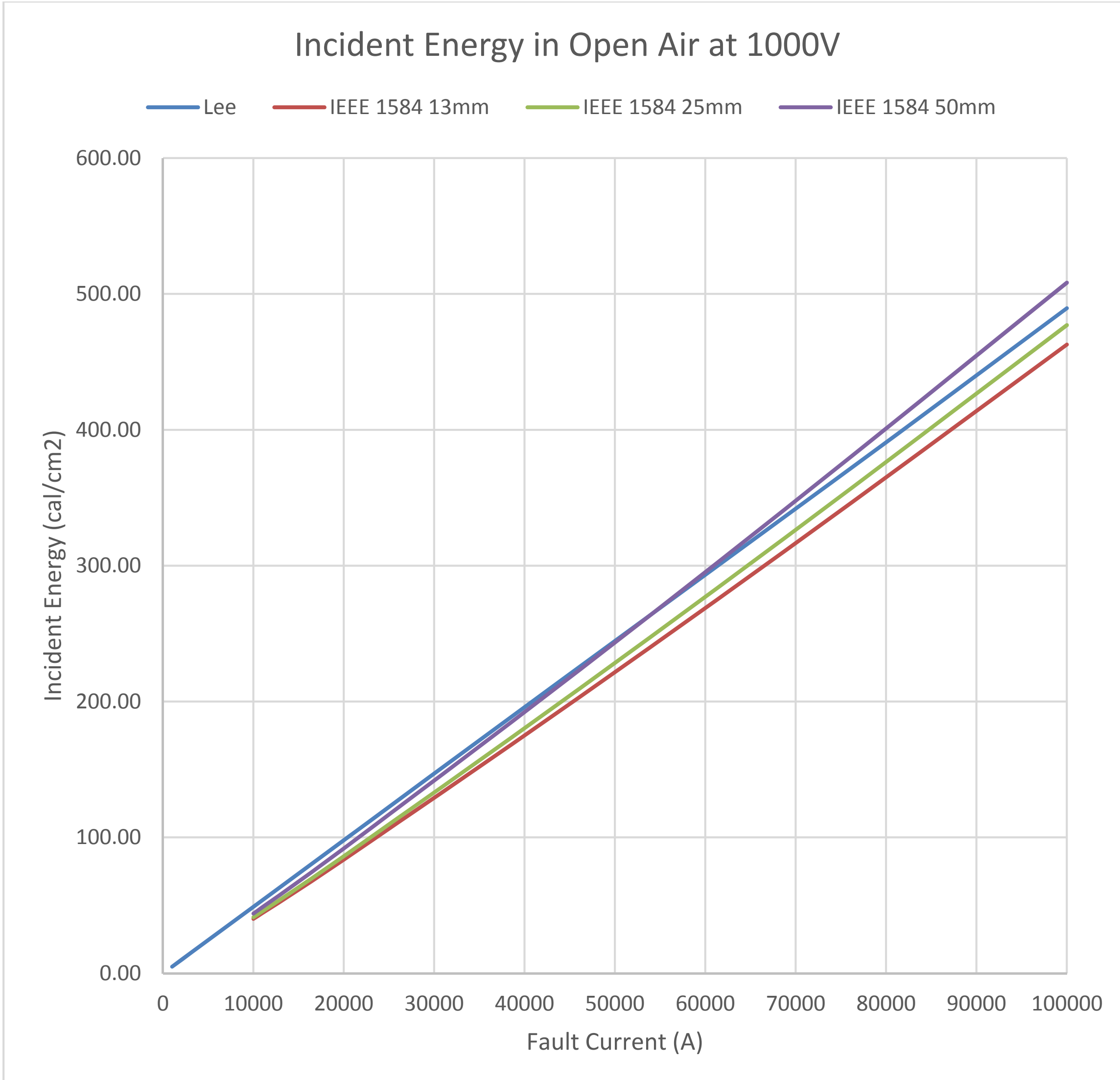



**Figure 57: Incident energy in open air at 1500V, comparing measured IEEE 1584 results to theoretical Lee equation.**

For the IEEE 1584 results in open air at low voltage, only the gap values of 13mm, 25mm, and 50mm were shown because, as seen in Table 1, the typical bus gap for low voltage open air calculations is anywhere from 10mm to 40mm.

As seen earlier with the arcing current, the bus gap did not affect the AC results as widely as it does for DC.  Even at 1000V, the incident energy results from 6mm to 400mm were all over the place while the AC results were fairly close together.

Once the voltage exceeded 1kV however, the incident energy for the measured results was quite lower than the theoretical maximum indicating that Lee's equation is particularly conservative at high voltages as seen in Figure 58.  For the IEEE 1584 equation results, a bus gap of 102mm was used since this is the typical value for open-air and is the only gap value shown.

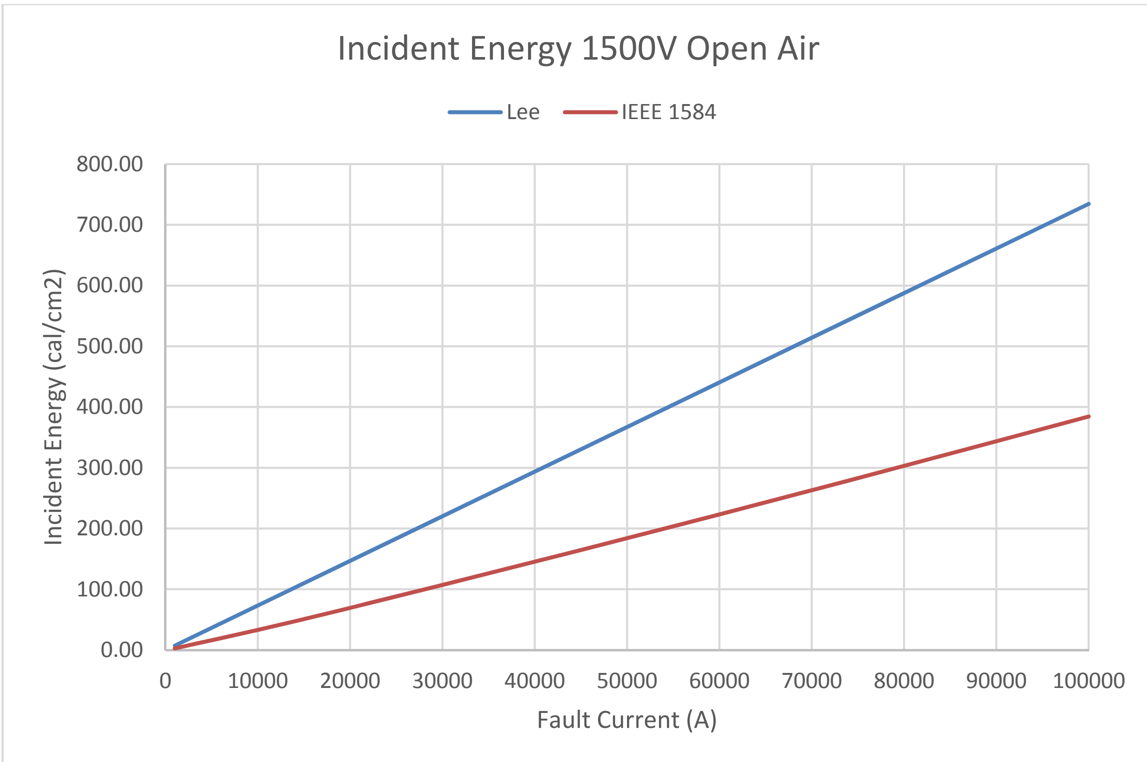



**Figure 58: Incident energy in open air at 1500V, comparing measured IEEE 1584 results to theoretical Lee equation.**

Overall, the open-air results for the DC methodologies showed agreement with the relative power maps.  While the IEEE 1584 AC incident energy graphs showed fairly close agreement at all voltages and levels, the DC results were all over the map although some of the gap values shown may not be typical in the type of installation.  The AC results showed that Lee's equation was very conservative at voltages greater than 1kV and that measured values were actually much lower.  This could be the same case for DC but without further testing it cannot be verified and no conclusive statement can be made.

Just as important as selecting the methodology to perform the calculations is the multiplier used to calculate the incident energy for arc-in-a-box situations.  The times three multiplier proposed by Doan has been shown to be very conservative.

### 4.4. Example Cases

This section examines previous DC arc flash studies performed by SEES.  These studies were previously performed using either the Maximum Power method or using the NFPA 70E tables.  These cases will be re-evaluated using the Stokes/Oppenlander and Paukert methodologies proposed by Ammerman et al.  A different multiplier as proposed by Parsons will also be explored for the Maximum Power method.

In order to protect customer confidentiality, the electrical single-lines will not be provided, however, all the necessary specifications and input data will be shown.

#### 4.4.1. Example 1

One facility had a UPS where the customer required a DC arc flash analysis to determine the PPE required when performing maintenance. At the time the study was conducted, the following parameters were known or assumed.

System voltage = 480V

Bolted fault current = 24,005A

Working distance = 45.72cm (18in for panelboards)

Arcing time = 2 sec

Bus gap = 25mm

Using the Maximum Power Method gave the following results:

$$\mathbf{E_{max\,power} = 3 * 0.005 * \left(V_{sys}^2 / R_{sys}\right) * \frac{T_{arc}}{D^2} = 3 * 0.005 * \left(\frac{480^2}{480/24005}\right) * \frac{2}{45.72^2}}$$

$$\cong \mathbf{165\ \frac{cal}{cm^2}} \qquad (4\text{-}3)$$

After the analysis however, the circuit breaker information was received which was thermal magnetic. For currents in the instantaneous region at the breaker's highest setting, above 5,000A, the breaker could clear the fault at a maximum of 0.025 seconds. Using this new information, the analysis was re-evaluated first using the Maximum Power method. Since the arcing current using this method is half of the bolted fault current, this would result in an arcing current of approximately 12,000A, which falls into

the instantaneous region. Using this new arcing time and a multiplier of 1.52 as suggested by Parsons yields:

$$\mathbf{E = 1.52 * 0.005 * \left(V_{sys}^2/R_{sys}\right) * \frac{T_{arc}}{D^2} = 1.52 * 0.005 * \left(\frac{480^2}{480/24005}\right) * \frac{0.025}{45.72^2}}$$

$$\mathbf{\cong 1.047\ \frac{cal}{cm^2}} \qquad \text{(4-4): Maximum Power method using multiplier of 1.52}$$

As seen, having the breaker information resulted in a huge decrease in the incident energy. The values went from levels where it is recommended to perform the work de-energized (as no NFPA 70E recommended PPE is available over 40 cal/cm$^2$) to levels where PPE can be worn. Looking at the maps that have been created, at 480V, 25mm gap, and fault current of approximately 24kA, the Stokes/Oppenlander and Paukert would provide results that are approximately 69% and 77%, respectively, of the Maximum Power method. Next, the analysis will be performed using Stokes/Oppenlander. For a fault of 24,005A, under this methodology it would result in an arcing current of approximately 18,579A and arc voltage of 108.49V, which again falls into the breaker's instantaneous region. Calculating the energy of the arc:

$$\mathbf{E_{arc} = P_{arc}t_{arc} * 0.239 = V_{arc}I_{arc}t_{arc} * 0.239 = 108.49 * 18579 * 0.025 * 0.239}$$

$$\mathbf{= 12,043\ cal} \qquad \text{(4-5)}$$

Using Equation 2-18 proposed by Ammerman and the values in Table 3 for a panelboard to calculate the incident energy provides the following result:

$$\mathbf{E = k\frac{E_{arc}}{a^2 + d^2} = 0.127\frac{12043}{10^2 + 45.72^2}}$$

$$= \mathbf{0.69831}\ \frac{\mathbf{cal}}{\mathbf{cm^2}} \qquad \text{(4-6): Stokes/Oppenlander using Ammerman equation}$$

For comparison, rather than using the multipliers by Ammerman, the multipliers proposed by Parsons with Equation 2-18 for open-air yields similar results:

$$\mathrm{E} = 1.52\frac{\mathrm{E_{arc}}}{4\pi \mathrm{d}^2} = 1.52\frac{12043}{4\pi 45.72^2}$$

$$= \mathbf{0.6969}\ \frac{\mathbf{cal}}{\mathbf{cm^2}} \qquad \text{(4-7): Stokes/Oppenlander Parsons multiplier}$$

This method results in approximately 33% less incident energy. Using this method results in PPE that would only need to be rated for up to 1.2 cal/cm$^2$, which was formerly known as Category 0. As seen in Table 5, this does not require any special arc rated clothing and consists of the normal PPE that is typically worn when on an industrial jobsite.

Lastly, this case is examined using the Paukert method. This methodology results in an arcing current of 17,564A, which falls into the instantaneous region, and an arc voltage of 128.79V.

$$\mathbf{E_{arc} = V_{arc}I_{arc}t_{arc} * 0.239 = 128.79 * 17564 * 0.025 * 0.239}$$

$$\mathbf{= 13,515\ cal} \qquad \text{(4-8)}$$

Using the Ammerman equations to find the incident energy yields:

$$\mathbf{E = k\frac{E_{arc}}{a^2 + d^2} = 0.127\frac{13515}{10^2 + 45.72^2}}$$

$$= \mathbf{0.783699}\ \frac{\mathbf{cal}}{\mathbf{cm^2}}$$ (4-9): Paukert using Ammerman equation

As expected, this methodology results in slightly higher incident energy than the results from Stokes/Oppenlander, however both results would not require personnel to wear special arc-rated clothing.

### 4.4.2. Example 2

The next case examines another UPS system. The parameters of the system are listed below:

System voltage = 768V

Bolted fault current = 14,403A

Working distance = 45.72cm (18in for panelboards)

Arcing time = 2 sec

Bus gap = 25mm

The initial analysis using the Maximum Power method provides the results below:

$$\mathbf{E_{max\,power}} = \mathbf{3} * \mathbf{0.005} * \left(\frac{\mathbf{768^2}}{\mathbf{768/14403}}\right) * \frac{\mathbf{2}}{\mathbf{45.72^2}} \cong \mathbf{159}\ \frac{\mathbf{cal}}{\mathbf{cm^2}} \quad (4\text{-}10)$$

These results show that there is no PPE recommended by the NFPA that will provide sufficient protection and de-energized work is recommended. In this case, the clearing time of the protective device was unknown so using the arcing current to pick a method would be irrelevant since the worst case scenario of two seconds was assumed.

However, although the voltage level of 768V was not examined in this paper, the relative power levels of a 25mm gap between 500V and 1000V at a fault current of 14kA are seen to be significantly lower than 100%. This is expected since as seen before, the higher voltages would have all three methods producing approximately equal power levels at higher gap values. Under the Stokes/Oppenlander methodology, the resulting arcing current is 12,463A with an arc voltage of 103.41V. Calculating the energy of the arc:

$$\mathbf{E_{arc} = V_{arc} I_{arc} t_{arc} * 0.239 = 103.41 * 12463 * 2 * 0.239}$$

$$\mathbf{= 616{,}045\ cal} \qquad \text{(4-11)}$$

Using the energy equation proposed by Ammerman, the following result for incident energy was obtained:

$$\mathrm{E} = \mathrm{k}\frac{\mathrm{E_{arc}}}{\mathrm{a^2 + d^2}} = 0.127\frac{616045}{10^2 + 45.72^2}$$

$$\mathbf{= 35.72\ \frac{cal}{cm^2}} \qquad \text{(4-12): Stokes/Oppenlander using Ammerman equation}$$

As expected, the Stokes/Oppenlander method yields much lower incident energy levels. Taking a look at the Paukert model, which results in an arcing current of 12,150A and arc voltage of 120.08V:

$$\mathbf{E_{arc} = V_{arc} I_{arc} t_{arc} * 0.239 = 120.08 * 12150 * 2 * 0.239}$$

$$\mathbf{= 697{,}388\ cal} \qquad \text{(4-13)}$$

Using the Ammerman equation to find incident energy:

$$E = k\frac{E_{arc}}{a^2 + d^2} = 0.127\frac{697388}{10^2 + 45.72^2}$$

$$= \mathbf{40.44}\ \frac{\mathbf{cal}}{\mathbf{cm^2}} \qquad \text{(4-14): Paukert using Ammerman equation}$$

In this case, only the Stokes/Oppenlander model results in incident energy levels where recommended PPE can be worn during energized work. However, since the Paukert results are based off the 20mm equation, it is likely that the incident energy is actually lower than calculated since voltages between 500V and 1000V showed bus gaps at 100mm to 250mm with curves that resembled maximum power so the relative power would be less than that at 25mm. That being said, the Stokes/Oppelander results are very close to the 40 cal/$cm^2$ limit for PPE, so recommending that de-energized work is performed for this piece of equipment is not a particularly conservative recommendation.

## 5. Conclusion

Although the NFPA 70E states that the Maximum Power Method has been shown to be highly conservative, comparison with the Stokes/Oppenlander and Paukert methods shown that this isn't always the case under certain conditions. At each voltage there is a certain gap value where fault currents from approximately 10,000A and above will produce similar results to the Maximum Power Method. Gap values above or below this value are where the models by Stokes/Oppenlander and Paukert provide more accurate depictions of the arc behavior.

Equally as important as choosing the methodology is the way one accounts for arcs in enclosures. Situations where the power produced by all three methods is more or less equal will produce vastly different arc-in-a-box incident energy results (for the same arcing time and working distance). This is because the multiplier of three proposed by Doan results in a conservatively high incident energy. Although some believe this should be higher and question if it is based on test data or is just an arbitrary value [12], using the method proposed by Ammerman et.al. [2] or Fontaine [12] is advised since these multipliers are based on some testing done. Alternatively, the multipliers proposed by Parsons [11] based on AC testing will produce similar results to the equation proposed by Ammerman, at least for panelboards.

Even with extensive testing, there are hazards with DC equipment that are not normally faced with AC systems that also must be considered. For instance, working on batteries also presents a chemical hazard. Even if the PPE is manufactured to provide some sort of protection against an arc flash event, the PPE is not necessarily rated to handle the acidic corrosion. Additionally, with batteries, the power cannot simply be

turned off.  Another issue is with PV arrays, which are current sources.  PV arrays also follow their own V-I model as seen in Figure 59 below.  Because of this, it is possible, that arcs in these situations may behave differently than the ones examined so far.

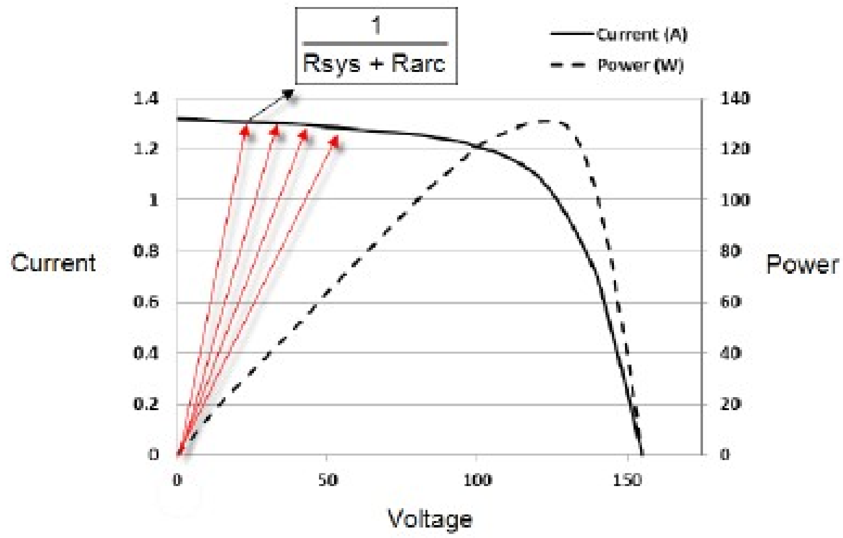



**Figure 59: V-I Characteristics of a Solar Panel [11]**

For regions where Stokes/Oppenlander and Paukert produce vastly different arcing currents, it is wise to examine the results using both methods if there is a protective device which can clear the arcing currents in less than two seconds.  Since the Paukert model tends to result in lower arcing currents anywhere from approximately 10%-30%, it is possible that this current could be low enough that the breaker will not trip fast enough to clear the fault resulting in higher incident energy.  Because there is not enough information to say which of the two models is more valid, it would be prudent to use the results with the higher incident energy as the worst case scenario until further data is obtained.

Care must also be taken when using Paukert to evaluate equipment where the bus gap does not exactly match one of the levels for Paukert's proposed equations. Of course, it can be expected that the Paukert methodology is most accurate at the designated bus gap levels rather than the intermediary values. As seen in Figure 27, the differences can be quite small for small bus gaps but the difference may be of concern at small voltages. Although Stokes/Oppenlander does not have this issue with discrete gaps, it would be wise to compare both methods since they can produce significantly different values if they produce very different arcing currents at the same fault level. Some sort of sensitivity analysis can be performed to estimate the accuracy of the results as was done in Example 2 previously.

One situation where it is hard to draw solid conclusions is for voltages of 1000V and greater. Although the trend for higher voltages tends to follow what was examined for lower voltages, this is because it follows the same equations. However, as seen in the AC results, the equations change when calculating arcing current and incident energy at 1000V and higher. Thus, it cannot be a definitive statement that the relative power follows the same trend for voltages at 1kV and greater until further testing has been performed. Also seen with the AC results, the research performed in the IEEE 1584 tests shows that the actual incident energy results are much lower than the theoretical equations from Lee's work. Even the Maximum Power method proposed by Doan is stated to be limited up to 1000V so it is hard to say exactly how accurate the results at 1500V are.

Based on the relative power maps created, the table below was created to give a quick look based on all the parameters examined where the Stokes/Oppenlander and

Paukert results were within 90% of the Maximum Power method.  The ranges of fault current in the table shown are only approximate and values within +/- 500A could fall in the range.  For situations where the parameters are outside the ranges shown in the table, it is may be worth examining Stokes/Oppenlander or Paukert where applicable. However, the data for 1500V is informational only.  Some instances shown in the table may not actually be realistic, for instance, at 480V for a 200mm gap, the current is limited to 3kA before the relative power is less than 90%.  Fault current magnitudes tend to be higher than 3kA so for this bus gap it may require to always use the other two methodologies.

**Table 8: Parameters Where Relative Power is at Least 90%**

| Voltage | Bus Gap | Fault Current Range | Method |
|---|---|---|---|
| 125 | 6mm | Up to 100kA | S/O |
| | | Up to 12kA | P |
| | 13mm | Up to 33kA | S/O |
| | | Up to 50kA | P |
| | 25mm | Up to 6kA | S/O |
| | | Up to 5kA | P |
| 208 | 6mm | From 18kA to 100kA | S/O |
| | | From 6kA to 100kA | P |
| | 13mm | From 5kA to 100kA | S/O |
| | | From 11kA to 100kA | P |
| | 25mm | Up to 100kA | S/O |
| | | From 2kA to 70kA | P |
| | 50mm | Up to 23kA | S/O |
| | | Up to 10kA | P |
| 250 | 6mm | From 80kA to 100kA | S/O |
| | | From 9kA to 100kA | P |
| | 13mm | From 24kA to 100kA | S/O |
| | | From 36kA to 100kA | P |
| | 25mm | From 6kA to 100kA | S/O |
| | | From 6kA to 100kA | P |
| | 50mm | Up to 100kA | S/O |
| | | Up to 25kA | P |
| | 100mm | Up to 7kA | S/O |
| 480 | 50mm | From 54kA to 100kA | S/O |
| | | From 13kA to 100kA | P |

| | | | |
|---|---|---|---|
| | 100mm | From 2kA to 100kA | S/O |
| | | Up to 30kA | P |
| | 150mm | Up to 42kA | S/O |
| | 200mm | Up to 6kA | S/O |
| | | Up to 3kA | P |
| 500 | 50mm | From 14kA to 100kA | S/O |
| | | From 72kA to 100kA | P |
| | 100mm | From 4kA to 100kA | S/O |
| | | From 2kA to 36kA | P |
| | 150mm | Up to 60kA | S/O |
| | 200mm | Up to 8kA | S/O |
| | | Up to 3.5kA | P |
| | 250mm | Up to 2kA | S/O |
| 1000 | 100mm | From 22kA to 100kA | P |
| | 150mm | From 44kA to 100kA | S/O |
| | 200mm | From 8kA to 100kA | S/O |
| | | From 4kA to 100kA | P |
| | 250mm | From 2kA to 100kA | S/O |
| | 300mm | Up to 100kA | S/O |
| | 400mm | Up to 16kA | S/O |
| 1500 | 200mm | From 9kA to 100kA | P |
| | 250mm | From 38kA to 100kA | S/O |
| | 300mm | From 10kA to 100kA | S/O |
| | 400mm | From 2kA to 100kA | S/O |

As mentioned earlier, the data in the table for 1500V is informational only as it is hard to give a definitive statement of arcing behavior at high voltages. The IEEE 1584 equations used to calculate arcing current and incident energy at 1000V and greater changed to reflect the test results. Although there is not much correspondence between the AC measured results and the DC semi-empirical models, there still exists the possibility that the nature of arcs at high voltages could change for DC as well. Since the Maximum Power Method is also limited up to 1000V, it is recommended that for voltages greater than 1kV work is performed while de-energized.

Unsurprisingly, it is extremely hard to draw conclusions based on comparing the DC semi-empirical results to the measured AC results. Although the arcing current as a percentage of fault current shows the same general inverse trend in both AC and DC, the values seen in the AC results show much less arc current than DC for a given fault current value except at high voltages. The DC results also showed a much wider variance on the arcing current depending on the bus gap while AC arc current was not as greatly affected by bus gap especially at low voltages and bus gap actually had no effect at high voltages.

Future work would include actual testing over an extensive range of fault currents, bus gap values, system voltages, equipment type, and other aspects not considered in this analysis such as horizontal vs vertical electrodes, electrode material, etc. The analysis performed and the results obtained were all assuming a very simple circuit with one source. However, AC arc flash analysis can be a much more complex process than simply using the equations proposed by IEEE 1584 as a system can be more

difficult to analyze when there are multiple sources involved. In AC arc flash analysis, since the nature of arcs is unpredictable, it is also common to calculate a lower current, often at 85% of the original arcing current, to examine if this lower current would produce a higher arcing time and therefore possibly more incident energy. These types of situations were not examined and are left for future work. Though only slightly different, the IEEE 1584 equations also produce calculate different arcing currents for arc-in-a-box situations compared to open air arcs (for voltages less than 1000V). DC calculations however, only produce one level of arcing current regardless of the equipment housing.

As mentioned earlier, testing must also be done to establish accurate multipliers that capture the amount of incident energy for arc-in-a-box situations. Fontaine has proposed a detailed method to calculate the appropriate multiplier that requires an iterative process [12] that is not explored in this paper. This method and how it compares to the multipliers proposed by Ammerman could be analyzed further.

What little test data that exists shows that there is much work that needs to be performed. One paper by Cantor et al. shows the test data in the particular setup as being much lower than even the Stokes/Oppenlander method for low voltages of 130V and 260V [13] while Kinetrics has shown the test data to agree with the Ammerman results at the tested voltage of 600V [11].

As a final disclaimer, the results of this thesis should not be used as a substitute for the methods proposed by standards such as IEEE 1584 or the NFPA 70E.

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# APPENDIX

## A.1 Excel Program Reference

This section details the formulas and methods used in the Excel program to calculate the results. For calculating, the results for Stokes/Oppenlander and Paukert methods, the basic format is used below:

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | GAP (mm) | | | | |
| 3 | System V | | | | |
| 4 | Bolted FC | | | | |
| 5 | System R | #DIV/0! | | | |
| 6 | Ia | | #DIV/0! | | |
| 7 | Calc Ra | #DIV/0! | Check. Should match B11 | | |
| 8 | va | 0.00 | | | |
| 9 | Ia(calc) | #DIV/0! | Check. Should match B6 | | |
| 10 | err(ia) | #DIV/0! | This should be < 1% | | |
| 11 | Formula Ra | #DIV/0! | | | |
| 12 | | | | | |
| 13 | Ia (% of Ib) | #DIV/0! | | | |
| 14 | | | | | |
| 15 | Parc | 0 | Watts | | |
| 16 | Arcing Time | | seconds | | |
| 17 | Earc | 0 | Joules | | |
| 18 | Working Dist | | in | | |
| 19 | IE (open air) | #DIV/0! | cal/cm2 | | |
| 20 | IE (panel) | 0 | cal/cm2 | | |

**Figure 60: Excel Spreadsheet for calculating Stokes/Oppenlander and Paukert Methods**

The yellow cells indicate the inputs: bus gap (mm), voltage (V), bolted fault current (A), arcing time (s), and working distance (in). The orange cells indicate the outputs: Ia or arcing current (A), va or arcing voltage (V), Ia as a percentage of Ib, the

bolted fault current (%), Parc or the arc power (W), and the IE or incident energy in cal/cm$^2$ for both open-air and panel enclosures.

Cells B8 and B11 use the formulas from the Ammerman paper. For Stokes/Oppenlander:

$$\mathbf{B8 = (20 + 0.534 * B2) * B6\hat{}0.12} \qquad (0\text{-}1)$$

$$\mathbf{B11 = (20 + 0.534 * B2) * B6\hat{}0.12} \qquad (0\text{-}2)$$

The following are for the Paukert method for each bus gap. For 6mm:

$$\mathbf{B8 = 14.13 * B6\hat{}0.211} \qquad (0\text{-}3)$$

$$\mathbf{B11 = 14.13 * B6\hat{} - 0.789} \qquad (0\text{-}4)$$

For 13mm:

$$\mathbf{B8 = 16.68 * B6\hat{}0.163} \qquad (0\text{-}5)$$

$$\mathbf{B11 = 16.68 * B6\hat{} - 0.837} \qquad (0\text{-}6)$$

For 25mm:

$$\mathbf{B8 = 20.11 * B6\hat{}0.19} \qquad (0\text{-}7)$$

$$\mathbf{B11 = 20.11 * B6\hat{} - 0.81} \qquad (0\text{-}8)$$

For 50mm:

$$\mathbf{B8 = 28.35 * B6\hat{}0.194} \qquad (0\text{-}9)$$

$$\mathbf{B11 = 28.35 * B6\text{^} - 0.806} \qquad (0\text{-}10)$$

For 100mm:

$$\mathbf{B8 = 34.18 * B6\text{^}0.241} \qquad (0\text{-}11)$$

$$\mathbf{B11 = 34.18 * B6\text{^} - 0.759} \qquad (0\text{-}12)$$

For 200mm:

$$\mathbf{B8 = 52.63 * B6\text{^}0.264} \qquad (0\text{-}13)$$

$$\mathbf{B11 = 52.63 * B6\text{^} - 0.736} \qquad (0\text{-}14)$$

To solve both these equations simultaneously, the SOLVER function in Excel is used. Before explaining the parameters of the SOLVER function, first the cells B9 and B10 will be explained. Cell B9 uses basic circuit theory and Ohm's law to calculate the arcing current, which is the system voltage (cell B3) divided by the total resistance or the sum of the system resistance (cell B5) plus the arcing resistance (cell B7). The formula for B9:

$$\mathbf{B9 = B3/(B5 + B7)} \qquad (0\text{-}15)$$

The cell B10 is the err(ia) or arcing current cell, which compares the arcing current in cell B6 to the calculated value in B9. Ideally, this value should be as close to zero as possible. The formula for B10 is given by:

$$\mathbf{B10 = ABS(B6 - B9)/ABS(B6)} \qquad (0\text{-}16)$$

Now that the cells necessary to find the arcing current have been defined, the SOLVER parameters are shown below.

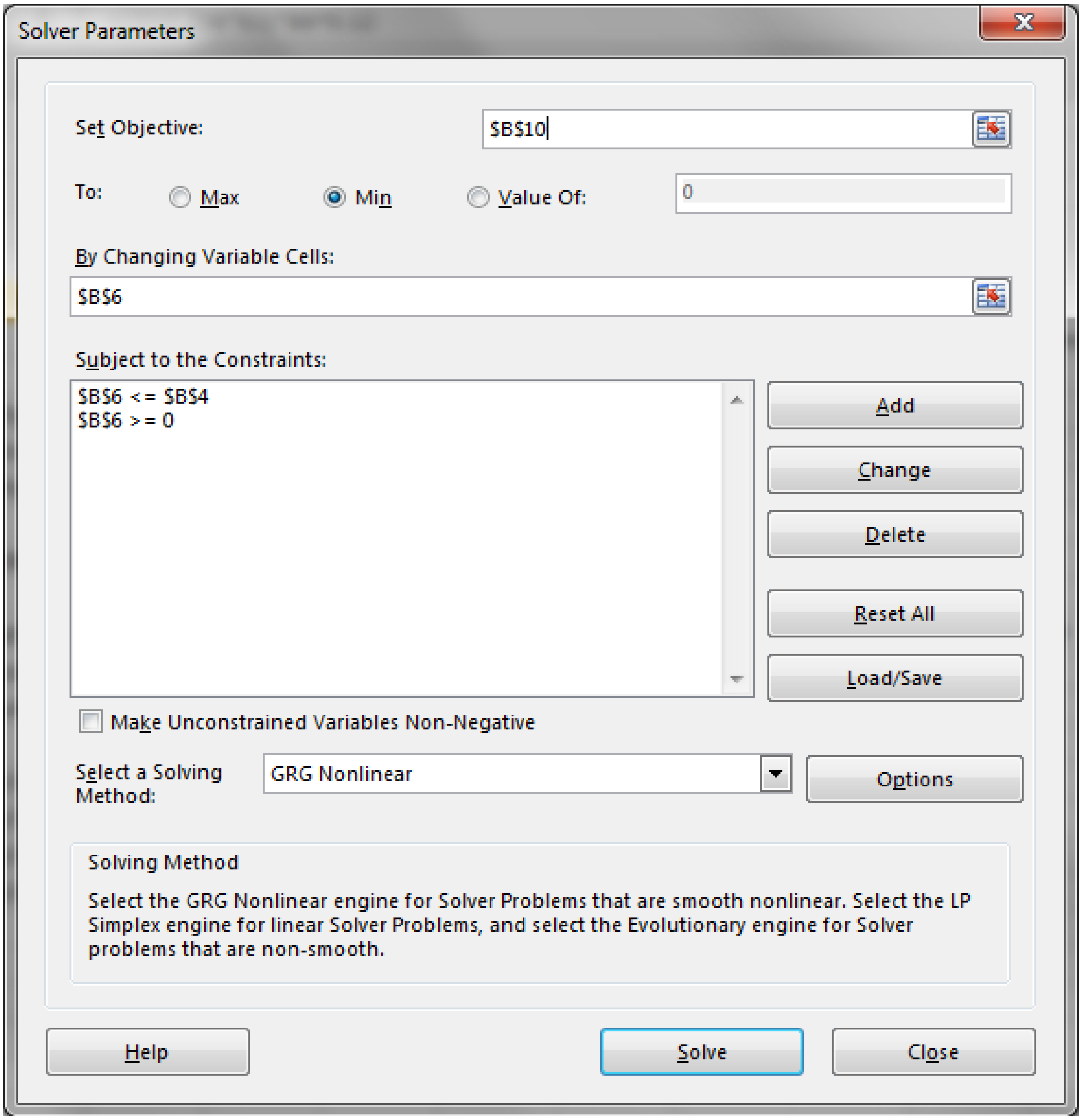



**Figure 61: SOLVER Parameters to Solve for Arcing Current**

The goal as mentioned before is to set the cell B10, or arcing current error, to as close to zero as possible. This is done by changing the arbitrary value of the arcing

current cell B6. Since the arcing current is less than the fault current (cell B4), but greater than zero (otherwise this would imply there is no arcing resistance), it is subjected to the constraints seen in Figure 61. Note that the SOLVER constraints only allow using the less than or equal to/greater than or equal to operators which is why they are being used rather than less than/greater than operators.

Cell B7 is merely used as a check to make sure the values agree with what is in B11. Using Ohm's law, it divides the calculated arc voltage by the arc current as seen below.

$$\mathbf{B7 = B8/B6} \qquad \text{(0-17)}$$

The arcing current percentage is calculated by dividing the arc current by the fault current:

$$\mathbf{B13 = B6/B4} \qquad \text{(0-18)}$$

The arcing power is calculated by multiplying the arc voltage and arc current:

$$\mathbf{B15 = B8 * B6} \qquad \text{(0-19)}$$

While the arc energy is the product of the power and arcing time:

$$\mathbf{B17 = B15 * B16} \qquad \text{(0-20)}$$

The incident energy is calculated by converting the energy to Joules and using the Ammerman equations. For open-air:

$$\mathbf{B19 = B17 * 0.239/(4 * PI() * (\$B\$18 * 2.54)\hat{}2)} \qquad \text{(0-21)}$$

For panel enclosures:

$$\mathbf{B20 = B17 * 0.239 * 0.127/(10\text{^}2 + (B18 * 2.54)\text{^}2)} \qquad \text{(0-22)}$$

A similar setup is seen for Maximum Power.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | Max Power Model | | | | |
| 2 | | | | | |
| 3 | System V | | | | |
| 4 | Bolted FC | | | | |
| 5 | System R | #DIV/0! | | | |
| 6 | Ia | 0 | #DIV/0! | | |
| 7 | Calc Ra | #DIV/0! | | | |
| 8 | va | 0 | | | |
| 9 | | | | | |
| 10 | | | | | |
| 11 | | | | | |
| 12 | | | | | |
| 13 | Ia (% of Ib) | #DIV/0! | | | |
| 14 | | | | | |
| 15 | IE (open air) | #DIV/0! | cal/cm2 | | |
| 16 | IE (panel) | #DIV/0! | cal/cm2 | | |
| 17 | Power | 0 | | | |
| 18 | Arcing Time | | seconds | | |
| 19 | Working Dist | | in | 0 | cm |

**Figure 62: Excel Setup for Maximum Power Method Calculations**

This time, the SOLVER function is not needed and since the arc current and arc voltage are half of the fault current and system voltage, respectively:

$$\mathbf{B6 = B4/2} \qquad \text{(0-23)}$$

$$\mathbf{B8 = B3/2} \qquad \text{(0-24)}$$

For the Max Power method, the equations for calculating the incident energy are those proposed by Doan. To find the incident energy of an arc in open-air, the cell B15 is given by:

$$\mathbf{B15 = 0.005 * (\$B\$3\text{^}2/\$B\$5) * \$B\$18/\$D\$19\text{^}2} \qquad (0\text{-}25)$$

Finding the incident energy in a panel is the same as open-air except with a multiplier of 3:

$$\mathbf{B16 = 3 * 0.005 * (\$B\$3\text{^}2/\$B\$5) * \$B\$18/\$D\$19\text{^}2} \qquad (0\text{-}26)$$

For the Lee equations, it is very similar to the Maximum Power Method using Doan's equations.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | Lee Eqns | | | | |
| 2 | | | | | |
| 3 | System V | | | | |
| 4 | Bolted FC | | | | |
| 5 | System R | #DIV/0! | | | |
| 6 | Ia | 0 | #DIV/0! | | |
| 7 | Calc Ra | #DIV/0! | | | |
| 8 | va | 0 | | | |
| 9 | Ia(calc) | #DIV/0! | | | |
| 10 | err(ia) | #DIV/0! | | | |
| 11 | Formula Ra | #DIV/0! | | | |
| 12 | | | | | |
| 13 | Ia (% of Ib) | #DIV/0! | | | |
| 14 | | | | | |
| 15 | | IEEE 1584 | | IEEE 1584 | |
| 16 | Energy | 0 | J/cm2 | 0 | cal/cm2 |
| 17 | Power | 0 | | | |
| 18 | Arcing Time | | seconds | | |
| 19 | Working Dist | 18 | in | 457.92 | mm |

**Figure 63: Excel Setup for Lee Equations**

However, the main difference is the energy equations. Using the equation from IEEE 1584 will calculate the incident energy in terms of J/cm$^2$ in cell B16.

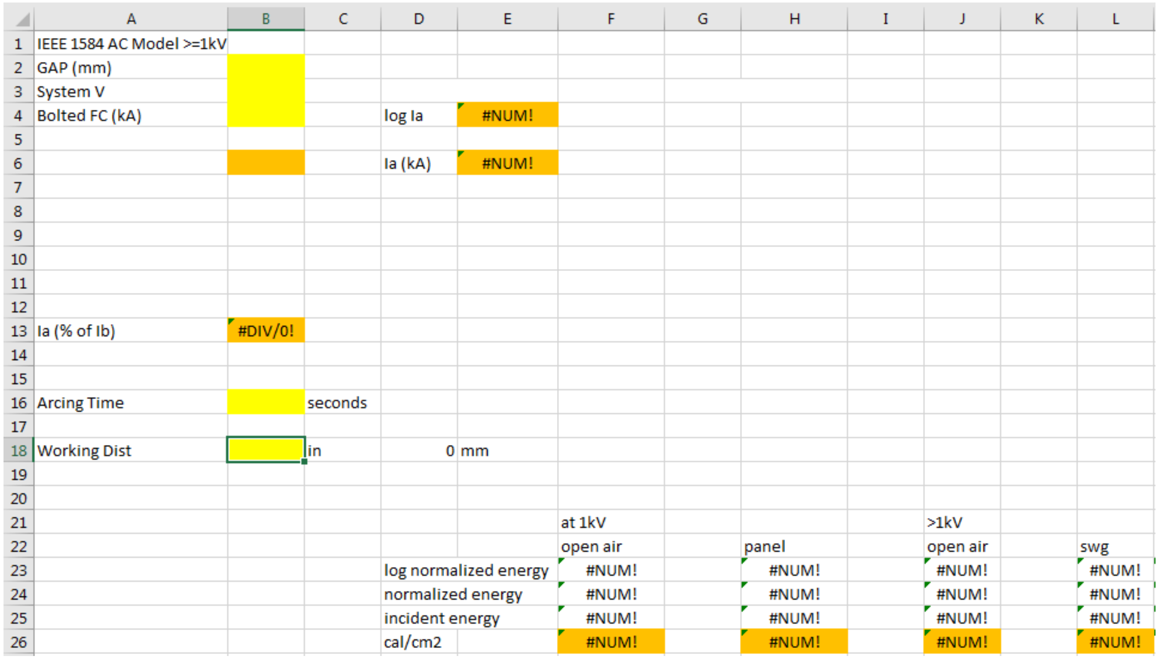
$$\mathbf{B16 = 2.142 * 10\text{^}6 * (B3/1000) * (B4/1000) * (B18/(D19)\text{^}2)} \quad \text{(0-27)}$$

Cell D16 simply converts the result of cell B16 into cal/cm$^2$ by multiplying by a factor of 0.239.

To calculate the IEEE 1584 results, two sets of formulas were needed, one for voltages less than 1kV and another for voltages greater than or equal to 1kV. The setups are shown below:

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | IEEE 1584 AC Model <1kV | | | | | | | |
| 2 | GAP (mm) | | | | | | | |
| 3 | System V | | | Open Air | | | Box | |
| 4 | Bolted FC (kA) | | | log Ia | #NUM! | | log Ia | #NUM! |
| 5 | | | | | | | | |
| 6 | Ia | #NUM! | | Ia (kA) | #NUM! | #NUM! | Ia (kA) | #NUM! |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 10 | | | | | | | | |
| 11 | | | | | | | | |
| 12 | | | | | | | | |
| 13 | Ia (% of Ib) | #NUM! | | | | | | |
| 14 | | | | | | | | |
| 15 | | | | | | | | |
| 16 | Arcing Time | | seconds | | | | | |
| 17 | | | | | | | | |
| 18 | Working Dist | | in | 0 | mm | | | |
| 19 | | | | | | | | |
| 20 | | | | | | | | |
| 21 | | | | | | | | |
| 22 | | | | | | open air | | panel |
| 23 | | | | log normalized energy | | #NUM! | | #NUM! |
| 24 | | | | normalized energy | | #NUM! | | #NUM! |
| 25 | | | | incident energy | | #NUM! | | #NUM! |
| 26 | | | | cal/cm2 | | #NUM! | | #NUM! |

**Figure 64:Excel Setup for IEEE 1584 Equations Less than 1kV**



| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | IEEE 1584 AC Model >=1kV | | | | | | | | | | | |
| 2 | GAP (mm) | | | | | | | | | | | |
| 3 | System V | | | | | | | | | | | |
| 4 | Bolted FC (kA) | | | log Ia | #NUM! | | | | | | | |
| 5 | | | | | | | | | | | | |
| 6 | | | | Ia (kA) | #NUM! | | | | | | | |
| 7 | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | |
| 13 | Ia (% of Ib) | #DIV/0! | | | | | | | | | | |
| 14 | | | | | | | | | | | | |
| 15 | | | | | | | | | | | | |
| 16 | Arcing Time | | seconds | | | | | | | | | |
| 17 | | | | | | | | | | | | |
| 18 | Working Dist | | in | 0 | mm | | | | | | | |
| 19 | | | | | | | | | | | | |
| 20 | | | | | | | | | | | | |
| 21 | | | | | | at 1kV | | | | >1kV | | |
| 22 | | | | | | open air | | panel | | open air | | swg |
| 23 | | | | log normalized energy | | #NUM! | | #NUM! | | #NUM! | | #NUM! |
| 24 | | | | normalized energy | | #NUM! | | #NUM! | | #NUM! | | #NUM! |
| 25 | | | | incident energy | | #NUM! | | #NUM! | | #NUM! | | #NUM! |
| 26 | | | | cal/cm2 | | #NUM! | | #NUM! | | #NUM! | | #NUM! |

**Figure 65: Excel Setup for IEEE 1584 Equations 1kV and Greater**

For voltages less than 1kV, the logarithmic arc current equations in Figure 64 for open-air and enclosure situations, respectively:

$$\mathbf{E4 = -0.153 + 0.662 * LOG(\$B\$4) + 0.0966 * (\$B\$3/1000) + 0.000526 * \$B\$2 + 0.5588 * (\$B\$3/1000) * (LOG(\$B\$4)) - 0.00304 * \$B\$2 * (LOG(\$B\$4))} \qquad (0\text{-}28)$$

$$\mathbf{H4 = -0.097 + 0.662 * LOG(\$B\$4) + 0.0966 * (\$B\$3/1000) + 0.000526 * \$B\$2 + 0.5588 * (\$B\$3/1000) * (LOG(\$B\$4)) - 0.00304 * \$B\$2 * (LOG(\$B\$4))} \qquad (0\text{-}29)$$

The arcing current is then found by using a base ten exponent of the results in cells E4 and H4. To find the log of the normalized energy, the following Excel formulas are used for open-air and enclosures, respectively:

$$\mathbf{F23 = -0.792 - 0.113 + 1.081 * LOG(B6) + 0.0011 * B2} \quad (0\text{-}30)$$

$$\mathbf{H23 = -0.555 - 0.113 + 1.081 * LOG(H6) + 0.0011 * B2} \quad (0\text{-}31)$$

To convert to the actual incident energy once the normalized energy has been found using a base ten exponent of F23 and H23, the following equations are used from IEEE 1584 for open-air and enclosures, respectively:

$$\mathbf{F25 = 4.184 * 1.5 * F24 * (B16/0.2) * ((610\text{^}2)/(D18\text{^}2))} \quad (0\text{-}32)$$

$$\mathbf{H25 = 4.184 * 1.5 * H24 * (B16/0.2) * ((610\text{^}1.641)/(D18\text{^}1.641))} \quad (0\text{-}33)$$

These are then calculated to cal/cm$^2$ using a factor of 0.239 which results in cells F26 and H26.

For voltages 1kV and greater, the arcing current was the same regardless of whether it was in open-air or an enclosure. So only one equation is needed as seen in Figure 65:

$$\mathbf{E4 = 0.00402 + 0.983 * (LOG(B4))} \quad (0\text{-}34)$$

Finding the incident energy however, differs depending on whether the voltage is at 1kV or greater than 1kV and whether it was in open-air or an enclosure. In order to

find the log of the normalized energy at 1kV, the following equations are used for open-air and panel enclosures, respectively:

$$\mathbf{F23 = -0.792 - 0.113 + 1.081 * LOG(\$E\$6) + 0.0011 * \$B\$2} \quad \text{(0-35)}$$

$$\mathbf{H23 = -0.555 - 0.113 + 1.081 * LOG(\$E\$6) + 0.0011 * \$B\$2} \quad \text{(0-36)}$$

The normalized energy is then found using a base ten exponent. Calculating the actual incident energy for open-air and panel situations, respectively:

$$\mathbf{F25 = 4.184 * 1.5 * F24 * (\$B\$16/0.2) * ((610\text{^}2)/(\$D\$18\text{^}2))} \quad \text{(0-37)}$$

$$\mathbf{H25 = 4.184 * 1.5 * \$H\$24 * (\$B\$16/0.2) * ((610\text{^}1.641)/(\$D\$18\text{^}1.641))} \quad \text{(0-38)}$$

The results in F25 and H25 are then multiplied by a factor of 0.239 to produce the results in F26 and H26 in terms of cal instead of J.

A similar process is used for voltages greater than 1kV. The log of the normalized energy is found using the equations below for open-air and switchgear, respectively:

$$\mathbf{J23 = -0.792 - 0.113 + 1.081 * LOG(\$E\$6) + 0.0011 * B2} \quad \text{(0-39)}$$

$$\mathbf{L23 = -0.555 - 0.113 + 1.081 * E4 + 0.0011 * \$B\$2} \quad \text{(0-40)}$$

The normalized energy is then found using a base ten exponent. Calculating the actual incident energy for open-air and panel situations, respectively:

$$\mathbf{J25} = \mathbf{4.184} * \mathbf{1} * \mathbf{J24} * (\$\mathbf{B}\$\mathbf{16}/\mathbf{0.2}) * ((\mathbf{610\hat{}2})/(\$\mathbf{D}\$\mathbf{18\hat{}2})) \qquad (0\text{-}41)$$

$$\mathbf{L25} = \mathbf{4.184} * \mathbf{1} * \mathbf{L24} * (\$\mathbf{B}\$\mathbf{16}/\mathbf{0.2}) * ((\mathbf{610\hat{}0.973})/(\$\mathbf{D}\$\mathbf{18\hat{}0.973}))$$

(0-42)

The results in J25 and L25 are then multiplied by a factor of 0.239 to produce the results in J26 and L26 in terms of cal instead of J.

## A.2 Excel Results

**Table 9: Stokes/Oppenlander 125V Arcing Current and Relative Power Results**

| Gap Value | Stokes 125V | | | | | |
|---|---|---|---|---|---|---|
| | If | Ia | Va | Pa (Watts) | Ia % | Relative Power |
| 6 | 1000 | 600.0245 | 50.00 | 29999.36694 | 60.00% | 96.00% |
| | 10000 | 4859.096 | 64.26 | 312251.8255 | 48.59% | 99.92% |
| | 20000 | 8938.043 | 69.14 | 617951.525 | 44.69% | 98.87% |
| | 50000 | 19610.62 | 75.97 | 1489886.428 | 39.22% | 95.35% |
| | 75000 | 27523.51 | 79.13 | 2177866.068 | 36.70% | 92.92% |
| | 100000 | 34874.16 | 81.41 | 2839011.108 | 34.87% | 90.85% |
| 13 | 1000 | 541.2964 | 57.34 | 31036.82061 | 54.13% | 99.32% |
| | 10000 | 4143.895 | 73.20 | 303338.5462 | 41.44% | 97.07% |
| | 20000 | 7436.418 | 78.52 | 583925.3012 | 37.18% | 93.43% |
| | 50000 | 15655.96 | 85.86 | 1344222.265 | 31.31% | 86.03% |
| | 75000 | 21488.62 | 89.19 | 1916476.404 | 28.65% | 81.77% |
| | 100000 | 26751.14 | 91.56 | 2449362.958 | 26.75% | 78.38% |
| 25 | 1000 | 445.3378 | 69.33 | 30876.50501 | 44.53% | 98.80% |
| | 10000 | 3020.865 | 87.24 | 263537.7609 | 30.21% | 84.33% |
| | 20000 | 5126.978 | 92.96 | 476585.3733 | 25.63% | 76.25% |
| | 50000 | 9807.636 | 100.48 | 985480.142 | 19.62% | 63.07% |
| | 75000 | 12770.89 | 103.72 | 1324534.892 | 17.03% | 56.51% |
| | 100000 | 15245.49 | 105.94 | 1615155.303 | 15.25% | 51.68% |
| 50 | 1000 | 268.9241 | 91.38 | 24575.49117 | 26.89% | 78.64% |
| | 10000 | 1227.869 | 109.65 | 134637.8316 | 12.28% | 43.08% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 20000 | 1725.108 | 114.22 | 197038.5119 | 8.63% | 31.53% |
| | 50000 | 2419.665 | 118.95 | 287821.1578 | 4.84% | 18.42% |
| | 75000 | 2696.308 | 120.51 | 324921.7105 | 3.60% | 13.86% |
| | 100000 | 2870.03 | 121.41 | 348457.4081 | 2.87% | 11.15% |
| 100 | 1000 | 53.45264 | 118.32 | 6324.431838 | 5.35% | 20.24% |
| | 10000 | 79.07701 | 124.01 | 9806.462035 | 0.79% | 3.14% |
| | 20000 | 81.65389 | 124.49 | 10165.06579 | 0.41% | 1.63% |
| | 50000 | 83.31957 | 124.79 | 10397.59126 | 0.17% | 0.67% |
| | 75000 | 83.70311 | 124.86 | 10451.2118 | 0.11% | 0.45% |
| | 100000 | 83.89679 | 124.90 | 10478.30007 | 0.08% | 0.34% |
| 150 | 1000 | 6.053296 | 124.24 | 752.0817225 | 0.61% | 2.41% |
| | 10000 | 6.333927 | 124.92 | 791.2394176 | 0.06% | 0.25% |
| | 20000 | 6.350629 | 124.96 | 793.5765923 | 0.03% | 0.13% |
| | 50000 | 6.36071 | 124.98 | 794.9875935 | 0.01% | 0.05% |
| | 75000 | 6.362958 | 124.99 | 795.3022922 | 0.01% | 0.03% |
| | 100000 | 6.364082 | 124.99 | 795.4596774 | 0.01% | 0.03% |

**Table 10: Paukert 125V Arcing Current and Relative Power Results**

| | Paukert 125V | | | | | |
|---|---|---|---|---|---|---|
| Gap Value | If | Ia | Va | Pa (Watts) | Ia % | Relative Power |
| 6 | 1000 | 568.9285 | 53.88394 | 30656.11 | 56.89% | 98.10% |
| | 10000 | 3627.506 | 79.65618 | 288953.2 | 36.28% | 92.47% |
| | 20000 | 5885.048 | 88.21845 | 519169.8 | 29.43% | 83.07% |
| | 50000 | 10293.93 | 99.26515 | 1021829 | 20.59% | 65.40% |
| | 75000 | 12720.59 | 103.799 | 1320385 | 16.96% | 56.34% |
| | 100000 | 14560.18 | 106.7998 | 1555024 | 14.56% | 49.76% |
| 13 | 1000 | 619.4726 | 47.56589 | 29465.77 | 61.95% | 94.29% |
| | 10000 | 4704.511 | 66.19359 | 311408.5 | 47.05% | 99.65% |
| | 20000 | 8366.931 | 72.70668 | 608331.8 | 41.83% | 97.33% |
| | 50000 | 17270.65 | 81.82337 | 1413143 | 34.54% | 90.44% |
| | 75000 | 23410.51 | 85.98249 | 2012894 | 31.21% | 85.88% |
| | 100000 | 28836.57 | 88.95428 | 2565136 | 28.84% | 82.08% |
| 25 | 1000 | 480.065 | 64.99188 | 31200.32 | 48.01% | 99.84% |
| | 10000 | 2754.035 | 90.57457 | 249445.5 | 27.54% | 79.82% |
| | 20000 | 4257.548 | 98.39032 | 418901.5 | 21.29% | 67.02% |
| | 50000 | 6882.941 | 107.7926 | 741930.4 | 13.77% | 47.48% |
| | 75000 | 8175.179 | 111.3747 | 910508.1 | 10.90% | 38.85% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 100000 | 9088.734 | 113.6391 | 1032835 | 9.09% | 33.05% |
| 50 | 1000 | 309.8689 | 86.26638 | 26731.27 | 30.99% | 85.54% |
| | 10000 | 1129.865 | 110.8767 | 125275.7 | 11.30% | 40.09% |
| | 20000 | 1430.045 | 116.0622 | 165974.1 | 7.15% | 26.56% |
| | 50000 | 1745.365 | 120.6366 | 210554.9 | 3.49% | 13.48% |
| | 75000 | 1843.768 | 121.9271 | 224805.2 | 2.46% | 9.59% |
| | 100000 | 1898.928 | 122.6263 | 232858.6 | 1.90% | 7.45% |
| 100 | 1000 | 65.06144 | 93.49385 | 6082.844 | 6.51% | 19.47% |
| | 10000 | 83.08464 | 99.16914 | 8239.433 | 0.83% | 2.64% |
| | 20000 | 84.51324 | 99.57743 | 8415.612 | 0.42% | 1.35% |
| | 50000 | 85.40339 | 99.82919 | 8525.751 | 0.17% | 0.55% |
| | 75000 | 85.60469 | 99.88585 | 8550.697 | 0.11% | 0.36% |
| | 100000 | 85.70589 | 99.91429 | 8563.243 | 0.09% | 0.27% |
| 150 | 1000 | 55.37341 | 118.08 | 6538.399 | 5.54% | 20.92% |
| | 10000 | 47.70341 | 124.40 | 5934.481 | 0.48% | 1.90% |
| | 20000 | 47.37605 | 124.70 | 5907.978 | 0.24% | 0.95% |
| | 50000 | 47.1832 | 124.88 | 5892.335 | 0.09% | 0.38% |
| | 75000 | 47.14072 | 124.92 | 5888.886 | 0.06% | 0.25% |
| | 100000 | 47.11951 | 124.94 | 5887.164 | 0.05% | 0.19% |

**Table 11: Max Power 125V Arcing Current and Power Results**

| Gap Value | Max Power 125V | | | | |
|---|---|---|---|---|---|
| | If | Ia | Va | Pa (Watts) | Ia % |
| 6 | 1000 | 500 | 62.5 | 31250 | 50.00% |
| | 10000 | 5000 | 62.5 | 312500 | 50.00% |
| | 20000 | 10000 | 62.5 | 625000 | 50.00% |
| | 50000 | 25000 | 62.5 | 1562500 | 50.00% |
| | 75000 | 37500 | 62.5 | 2343750 | 50.00% |
| | 100000 | 50000 | 62.5 | 3125000 | 50.00% |
| 13 | 1000 | 500 | 62.5 | 31250 | 50.00% |
| | 10000 | 5000 | 62.5 | 312500 | 50.00% |
| | 20000 | 10000 | 62.5 | 625000 | 50.00% |
| | 50000 | 25000 | 62.5 | 1562500 | 50.00% |
| | 75000 | 37500 | 62.5 | 2343750 | 50.00% |
| | 100000 | 50000 | 62.5 | 3125000 | 50.00% |
| 25 | 1000 | 500 | 62.5 | 31250 | 50.00% |
| | 10000 | 5000 | 62.5 | 312500 | 50.00% |

| | | | | | |
|---|---|---|---|---|---|
| | 20000 | 10000 | 62.5 | 625000 | 50.00% |
| | 50000 | 25000 | 62.5 | 1562500 | 50.00% |
| | 75000 | 37500 | 62.5 | 2343750 | 50.00% |
| | 100000 | 50000 | 62.5 | 3125000 | 50.00% |
| 50 | 1000 | 500 | 62.5 | 31250 | 50.00% |
| | 10000 | 5000 | 62.5 | 312500 | 50.00% |
| | 20000 | 10000 | 62.5 | 625000 | 50.00% |
| | 50000 | 25000 | 62.5 | 1562500 | 50.00% |
| | 75000 | 37500 | 62.5 | 2343750 | 50.00% |
| | 100000 | 50000 | 62.5 | 3125000 | 50.00% |
| 100 | 1000 | 500 | 62.5 | 31250 | 50.00% |
| | 10000 | 5000 | 62.5 | 312500 | 50.00% |
| | 20000 | 10000 | 62.5 | 625000 | 50.00% |
| | 50000 | 25000 | 62.5 | 1562500 | 50.00% |
| | 75000 | 37500 | 62.5 | 2343750 | 50.00% |
| | 100000 | 50000 | 62.5 | 3125000 | 50.00% |
| 150 | 1000 | 500 | 62.5 | 31250 | 50.00% |
| | 10000 | 5000 | 62.5 | 312500 | 50.00% |
| | 20000 | 10000 | 62.5 | 625000 | 50.00% |
| | 50000 | 25000 | 62.5 | 1562500 | 50.00% |
| | 75000 | 37500 | 62.5 | 2343750 | 50.00% |
| | 100000 | 50000 | 62.5 | 3125000 | 50.00% |

**Table 12: IEEE 1584 AC Arcing Results Open and Boxed 125V**

| Gap Value | IEEE 1584 AC (open) 125V | | | IEEE 1584 AC (box) 125V | | |
|---|---|---|---|---|---|---|
| | If | Ia (kA) | Ia % of Ib | If | Ia (kA) | Ia % of Ib |
| 6 | 1000 | | 0.00% | 1000 | | 0.00% |
| | 10000 | | 0.00% | 10000 | | 0.00% |
| | 20000 | | 0.00% | 20000 | | 0.00% |
| | 50000 | | 0.00% | 50000 | | 0.00% |
| | 75000 | | 0.00% | 75000 | | 0.00% |
| | 100000 | | 0.00% | 100000 | | 0.00% |
| 13 | 1000 | 0.734367 | 73.44% | 1000 | 0.835436 | 83.54% |
| | 10000 | 3.616121 | 36.16% | 10000 | 4.113798 | 41.14% |
| | 20000 | 5.843258 | 29.22% | 20000 | 6.64745 | 33.24% |
| | 50000 | 11.01947 | 22.04% | 50000 | 12.53606 | 25.07% |
| | 75000 | 14.59063 | 19.45% | 75000 | 16.5987 | 22.13% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 100000 | 17.80627 | 17.81% | 100000 | 20.2569 | 20.26% |
| 25 | 1000 | 0.745118 | 74.51% | 1000 | 0.847666 | 84.77% |
| | 10000 | 3.373456 | 33.73% | 10000 | 3.837735 | 38.38% |
| | 20000 | 5.315028 | 26.58% | 20000 | 6.04652 | 30.23% |
| | 50000 | 9.693809 | 19.39% | 50000 | 11.02794 | 22.06% |
| | 75000 | 12.6469 | 16.86% | 75000 | 14.38745 | 19.18% |
| | 100000 | 15.27302 | 15.27% | 100000 | 17.37501 | 17.38% |
| 50 | 1000 | 0.768024 | 76.80% | 1000 | 0.873725 | 87.37% |
| | 10000 | 2.918939 | 29.19% | 10000 | 3.320665 | 33.21% |
| | 20000 | 4.36292 | 21.81% | 20000 | 4.963377 | 24.82% |
| | 50000 | 7.422031 | 14.84% | 50000 | 8.443505 | 16.89% |
| | 75000 | 9.389215 | 12.52% | 75000 | 10.68143 | 14.24% |
| | 100000 | 11.09366 | 11.09% | 100000 | 12.62045 | 12.62% |
| 100 | 1000 | 0.815972 | 81.60% | 1000 | 0.928271 | 92.83% |
| | 10000 | 2.18537 | 21.85% | 10000 | 2.486137 | 24.86% |
| | 20000 | 2.93982 | 14.70% | 20000 | 3.344419 | 16.72% |
| | 50000 | 4.350902 | 8.70% | 50000 | 4.949705 | 9.90% |
| | 75000 | 5.175114 | 6.90% | 75000 | 5.887351 | 7.85% |
| | 100000 | 5.852953 | 5.85% | 100000 | 6.658478 | 6.66% |
| 150 | 1000 | 0.866912 | 86.69% | 1000 | 0.986223 | 98.62% |
| | 10000 | 1.636157 | 16.36% | 10000 | 1.861337 | 18.61% |
| | 20000 | 1.980907 | 9.90% | 20000 | 2.253534 | 11.27% |
| | 50000 | 2.550562 | 5.10% | 50000 | 2.901589 | 5.80% |
| | 75000 | 2.852401 | 3.80% | 75000 | 3.24497 | 4.33% |
| | 100000 | 3.087984 | 3.09% | 100000 | 3.512975 | 3.51% |

**Table 13: Stokes/Oppenlander 208V Arcing Current and Relative Power Results**

| Gap Value | Stokes 208V | | | | | |
|---|---|---|---|---|---|---|
| | If | Ia (A) | Va | Pa (Watts) | Ia % of Ib | Relative Power |
| 6 | 1000 | 752.9902 | 51.37804 | 38687.16181 | 75.30% | 74.40% |
| | 10000 | 6784.267 | 66.88723 | 453780.7944 | 67.84% | 87.27% |
| | 20000 | 13043.71 | 72.34541 | 943652.5984 | 65.22% | 90.74% |
| | 50000 | 30726.06 | 80.17956 | 2463601.877 | 61.45% | 94.75% |
| | 75000 | 44754.47 | 83.88093 | 3754046.688 | 59.67% | 96.26% |
| | 100000 | 58366.83 | 86.59699 | 5054391.913 | 58.37% | 97.20% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 13 | 1000 | 714.9759 | 59.285 | 42387.34682 | 71.50% | 81.51% |
| | 5000 | 3288.502 | 71.1983 | 234135.7435 | 65.77% | 90.05% |
| | 10000 | 6299.318 | 76.97418 | 484884.8168 | 62.99% | 93.25% |
| | 20000 | 12003.27 | 83.16599 | 998263.8561 | 60.02% | 95.99% |
| | 50000 | 27880.63 | 92.01659 | 2565480.26 | 55.76% | 98.67% |
| | 75000 | 40319.19 | 96.18143 | 3877957.059 | 53.76% | 99.43% |
| | 100000 | 52293.24 | 99.23007 | 5189061.371 | 52.29% | 99.79% |
| 25 | 1000 | 651.1232 | 72.57 | 47249.64618 | 65.11% | 90.86% |
| | 5000 | 2912.111 | 86.86 | 252934.839 | 58.24% | 97.28% |
| | 10000 | 5493.734 | 93.73029 | 514929.3153 | 54.94% | 99.02% |
| | 20000 | 10283.31 | 101.0536 | 1039165.182 | 51.42% | 99.92% |
| | 50000 | 23214.83 | 111.4263 | 2586742.277 | 46.43% | 99.49% |
| | 75000 | 33078.29 | 116.2629 | 3845776.91 | 44.10% | 98.61% |
| | 100000 | 42412.09 | 119.7828 | 5080240.428 | 42.41% | 97.70% |
| 50 | 1000 | 524.0333 | 99.00108 | 51879.85939 | 52.40% | 99.77% |
| | 5000 | 2176.687 | 117.4498 | 255651.4816 | 43.53% | 98.33% |
| | 10000 | 3937.167 | 126.1069 | 496504.0159 | 39.37% | 95.48% |
| | 20000 | 7006.071 | 135.1369 | 946778.4251 | 35.03% | 91.04% |
| | 50000 | 14540.47 | 147.5116 | 2144888.699 | 29.08% | 82.50% |
| | 75000 | 19802.33 | 153.0815 | 3031370.961 | 26.40% | 77.73% |
| | 100000 | 24499.17 | 157.0417 | 3847391.032 | 24.50% | 73.99% |
| 100 | 1000 | 300.2654 | 145.5448 | 43702.06543 | 30.03% | 84.04% |
| | 5000 | 971.7942 | 167.5734 | 162846.8228 | 19.44% | 62.63% |
| | 10000 | 1507.639 | 176.6411 | 266311.0828 | 15.08% | 51.21% |
| | 20000 | 2213.88 | 184.9756 | 409513.8984 | 11.07% | 39.38% |
| | 50000 | 3319.662 | 194.1902 | 644645.8363 | 6.64% | 24.79% |
| | 75000 | 3810.708 | 197.4316 | 752354.3618 | 5.08% | 19.29% |
| | 100000 | 4137.936 | 199.3931 | 825075.836 | 4.14% | 15.87% |
| 150 | 1000 | 133.8816 | 180.1526 | 24119.12089 | 13.39% | 46.38% |
| | 5000 | 276.2139 | 196.5095 | 54278.6598 | 5.52% | 20.88% |
| | 10000 | 334.1317 | 201.0501 | 67177.20699 | 3.34% | 12.92% |
| | 20000 | 378.272 | 204.066 | 77192.4358 | 1.89% | 7.42% |
| | 50000 | 413.8388 | 206.2784 | 85366.01262 | 0.83% | 3.28% |
| | 75000 | 423.0935 | 206.8266 | 87506.99286 | 0.56% | 2.24% |
| | 100000 | 427.9462 | 207.1099 | 88631.88468 | 0.43% | 1.70% |

**Table 14: Paukert 208V Arcing Current and Relative Power Results**

| Gap Value | Paukert 208V | | | | | |
|---|---|---|---|---|---|---|
| | If | Ia (kA) | Va | Pa (Watts) | Ia % of Ib | Relative Power |
| 6 | 1000 | 727.1747 | 56.75 | 41265.46 | 72.72% | 79.36% |
| | 10000 | 5775.509 | 87.87 | 507490.6 | 57.76% | 97.59% |
| | 20000 | 10428.98 | 99.54 | 1038086 | 52.14% | 99.82% |
| | 50000 | 21992.78 | 116.51 | 2562380 | 43.99% | 98.55% |
| | 75000 | 30110.12 | 124.49 | 3748547 | 40.15% | 96.12% |
| | 100000 | 37359.46 | 130.29 | 4867649 | 37.36% | 93.61% |
| 13 | 1000 | 763.3966 | 49.21 | 37569.42 | 76.34% | 72.25% |
| | 10000 | 6634.229 | 70.01 | 464449.3 | 66.34% | 89.32% |
| | 20000 | 12533.01 | 77.66 | 973272.3 | 62.67% | 93.58% |
| | 50000 | 28640.52 | 88.86 | 2544865 | 57.28% | 97.88% |
| | 75000 | 41027.66 | 94.22 | 3865488 | 54.70% | 99.12% |
| | 100000 | 52801.89 | 98.17 | 5183671 | 52.80% | 99.69% |
| 25 | 1000 | 667.3581 | 69.19 | 46174.18 | 66.74% | 88.80% |
| | 10000 | 5103.901 | 101.84 | 519775.5 | 51.04% | 99.96% |
| | 20000 | 9076.061 | 113.61 | 1031122 | 45.38% | 99.15% |
| | 50000 | 18676.8 | 130.30 | 2433671 | 37.35% | 93.60% |
| | 75000 | 25246.11 | 137.98 | 3483562 | 33.66% | 89.32% |
| | 100000 | 31015.8 | 143.49 | 4450368 | 31.02% | 85.58% |
| 50 | 1000 | 538.3468 | 96.02 | 51694.14 | 53.83% | 99.41% |
| | 10000 | 3399.417 | 137.29 | 466713 | 33.99% | 89.75% |
| | 20000 | 5504.814 | 150.75 | 829850.3 | 27.52% | 79.79% |
| | 50000 | 9618.494 | 167.99 | 1615783 | 19.24% | 62.15% |
| | 75000 | 11887.27 | 175.03 | 2080661 | 15.85% | 53.35% |
| | 100000 | 13610.47 | 179.69 | 2445668 | 13.61% | 47.03% |
| 100 | 1000 | 333.5262 | 138.63 | 46235.58 | 33.35% | 88.91% |
| | 10000 | 1104.909 | 185.02 | 204427.9 | 11.05% | 39.31% |
| | 20000 | 1345.341 | 194.01 | 261007.5 | 6.73% | 25.10% |
| | 50000 | 1572.963 | 201.46 | 316883.5 | 3.15% | 12.19% |
| | 75000 | 1638.738 | 203.46 | 333409.8 | 2.18% | 8.55% |
| | 100000 | 1674.517 | 204.52 | 342467.1 | 1.67% | 6.59% |

**Table 15: Max Power 208V Arcing Current and Power Results**

| Gap Value | Max Power 208V | | | | |
|---|---|---|---|---|---|
| | If | Ia | Va | Pa (Watts) | Ia % |
| 6 | 1000 | 500 | 104 | 52000 | 50.00% |
| | 10000 | 5000 | 104 | 520000 | 50.00% |
| | 20000 | 10000 | 104 | 1040000 | 50.00% |
| | 50000 | 25000 | 104 | 2600000 | 50.00% |
| | 75000 | 37500 | 104 | 3900000 | 50.00% |
| | 100000 | 50000 | 104 | 5200000 | 50.00% |
| 13 | 1000 | 500 | 104 | 52000 | 50.00% |
| | 10000 | 5000 | 104 | 520000 | 50.00% |
| | 20000 | 10000 | 104 | 1040000 | 50.00% |
| | 50000 | 25000 | 104 | 2600000 | 50.00% |
| | 75000 | 37500 | 104 | 3900000 | 50.00% |
| | 100000 | 50000 | 104 | 5200000 | 50.00% |
| 25 | 1000 | 500 | 104 | 52000 | 50.00% |
| | 10000 | 5000 | 104 | 520000 | 50.00% |
| | 20000 | 10000 | 104 | 1040000 | 50.00% |
| | 50000 | 25000 | 104 | 2600000 | 50.00% |
| | 75000 | 37500 | 104 | 3900000 | 50.00% |
| | 100000 | 50000 | 104 | 5200000 | 50.00% |
| 50 | 1000 | 500 | 104 | 52000 | 50.00% |
| | 10000 | 5000 | 104 | 520000 | 50.00% |
| | 20000 | 10000 | 104 | 1040000 | 50.00% |
| | 50000 | 25000 | 104 | 2600000 | 50.00% |
| | 75000 | 37500 | 104 | 3900000 | 50.00% |
| | 100000 | 50000 | 104 | 5200000 | 50.00% |
| 100 | 1000 | 500 | 104 | 52000 | 50.00% |
| | 10000 | 5000 | 104 | 520000 | 50.00% |
| | 20000 | 10000 | 104 | 1040000 | 50.00% |
| | 50000 | 25000 | 104 | 2600000 | 50.00% |
| | 75000 | 37500 | 104 | 3900000 | 50.00% |
| | 100000 | 50000 | 104 | 5200000 | 50.00% |
| 150 | 1000 | 500 | 104 | 52000 | 50.00% |
| | 10000 | 5000 | 104 | 520000 | 50.00% |
| | 20000 | 10000 | 104 | 1040000 | 50.00% |
| | 50000 | 25000 | 104 | 2600000 | 50.00% |
| | 75000 | 37500 | 104 | 3900000 | 50.00% |

| | | | | |
|---|---|---|---|---|
| | 100000 | 50000 104 | 5200000 | 50.00% |

**Table 16: IEEE 1584 AC Arcing Results Open and Boxed 208V**

| Gap Value | IEEE 1584 AC (open) 208V If | Ia (kA) | Ia % of Ib | IEEE 1584 AC (box) 208V If | Ia (kA) | Ia % of Ib |
|---|---|---|---|---|---|---|
| 6 | 1000 | | 0.00% | 1000 | | 0.00% |
| | 10000 | | 0.00% | 10000 | | 0.00% |
| | 20000 | | 0.00% | 20000 | | 0.00% |
| | 50000 | | 0.00% | 50000 | | 0.00% |
| | 75000 | | 0.00% | 75000 | | 0.00% |
| | 100000 | | 0.00% | 100000 | | 0.00% |
| 13 | 1000 | 0.74805 | 74.81% | 1000 | 0.851002 | 85.10% |
| | 10000 | 4.098653 | 40.99% | 10000 | 4.66274 | 46.63% |
| | 20000 | 6.839356 | 34.20% | 20000 | 7.780638 | 38.90% |
| | 50000 | 13.45791 | 26.92% | 50000 | 15.31009 | 30.62% |
| | 75000 | 18.15758 | 24.21% | 75000 | 20.65656 | 27.54% |
| | 100000 | 22.45699 | 22.46% | 100000 | 25.54769 | 25.55% |
| 25 | 1000 | 0.759002 | 75.90% | 1000 | 0.863461 | 86.35% |
| | 10000 | 3.823607 | 38.24% | 10000 | 4.349839 | 43.50% |
| | 20000 | 6.221078 | 31.11% | 20000 | 7.077268 | 35.39% |
| | 50000 | 11.8389 | 23.68% | 50000 | 13.46825 | 26.94% |
| | 75000 | 15.73866 | 20.98% | 75000 | 17.90473 | 23.87% |
| | 100000 | 19.2621 | 19.26% | 100000 | 21.91309 | 21.91% |
| 50 | 1000 | 0.782335 | 78.23% | 1000 | 0.890006 | 89.00% |
| | 10000 | 3.30844 | 33.08% | 10000 | 3.763771 | 37.64% |
| | 20000 | 5.106665 | 25.53% | 20000 | 5.809481 | 29.05% |
| | 50000 | 9.064408 | 18.13% | 50000 | 10.31192 | 20.62% |
| | 75000 | 11.68458 | 15.58% | 75000 | 13.2927 | 17.72% |
| | 100000 | 13.99116 | 13.99% | 100000 | 15.91672 | 15.92% |
| 100 | 1000 | 0.831176 | 83.12% | 1000 | 0.945568 | 94.56% |
| | 10000 | 2.476984 | 24.77% | 10000 | 2.817885 | 28.18% |
| | 20000 | 3.440969 | 17.20% | 20000 | 3.91454 | 19.57% |
| | 50000 | 5.313688 | 10.63% | 50000 | 6.044996 | 12.09% |
| | 75000 | 6.440267 | 8.59% | 75000 | 7.326623 | 9.77% |
| | 100000 | 7.381653 | 7.38% | 100000 | 8.397569 | 8.40% |
| 150 | 1000 | 0.883065 | 88.31% | 1000 | 1.004599 | 100.46% |
| | 10000 | 1.854484 | 18.54% | 10000 | 2.109712 | 21.10% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 20000 | 2.318591 | 11.59% | 20000 | 2.637693 | 13.19% |
| | 50000 | 3.114961 | 6.23% | 50000 | 3.543664 | 7.09% |
| | 75000 | 3.549724 | 4.73% | 75000 | 4.038262 | 5.38% |
| | 100000 | 3.894517 | 3.89% | 100000 | 4.430509 | 4.43% |

**Table 17: Stokes/Oppenlander 250V Arcing Current and Relative Power Results**

| | Stokes 250V | | | | | |
|---|---|---|---|---|---|---|
| Gap Value | If | Ia | Va | Pa (Watts) | Ia % | Relative Power |
| 6 | 1000 | 793.2007 | 51.70 | 41008.31177 | 79.32% | 65.61% |
| | 10000 | 7300.846 | 67.48 | 492652.6505 | 73.01% | 78.82% |
| | 20000 | 14155.28 | 73.06 | 1034169.185 | 70.78% | 82.73% |
| | 50000 | 33780.66 | 81.10 | 2739499.55 | 67.56% | 87.66% |
| | 75000 | 49527.83 | 84.91 | 4205271.385 | 66.04% | 89.71% |
| | 100000 | 64916.31 | 87.71 | 5693759.345 | 64.92% | 91.10% |
| 13 | 1000 | 761.075 | 59.73 | 45459.91361 | 76.11% | 72.74% |
| | 10000 | 6887.853 | 77.80 | 535900.0006 | 68.88% | 85.74% |
| | 20000 | 13266.36 | 84.17 | 1116636.31 | 66.33% | 89.33% |
| | 50000 | 31336.79 | 93.32 | 2924225.527 | 62.67% | 93.58% |
| | 75000 | 45707.92 | 97.64 | 4462931.977 | 60.94% | 95.21% |
| | 100000 | 59674.06 | 100.81 | 6016026.049 | 59.67% | 96.26% |
| 25 | 1000 | 706.8595 | 73.29 | 51802.28476 | 70.69% | 82.88% |
| | 10000 | 6196.255 | 95.09 | 589224.3075 | 61.96% | 94.28% |
| | 20000 | 11782.59 | 102.72 | 1210279.474 | 58.91% | 96.82% |
| | 50000 | 27279.1 | 113.60 | 3099028.394 | 54.56% | 99.17% |
| | 75000 | 39383.24 | 118.72 | 4675678.021 | 52.51% | 99.75% |
| | 100000 | 51013.33 | 122.47 | 6247432.823 | 51.01% | 99.96% |
| 50 | 1000 | 597.6958 | 100.58 | 60113.87709 | 59.77% | 96.18% |
| | 10000 | 4830.422 | 129.24 | 624281.0232 | 48.30% | 99.88% |
| | 20000 | 8877.513 | 139.03 | 1234250.046 | 44.39% | 98.74% |
| | 50000 | 19449.64 | 152.75 | 2970967.067 | 38.90% | 95.07% |
| | 75000 | 27276.46 | 159.08 | 4339097.128 | 36.37% | 92.57% |
| | 100000 | 34540.05 | 163.65 | 5652474.138 | 34.54% | 90.44% |
| 100 | 1000 | 397.8292 | 150.54 | 59890.2841 | 39.78% | 95.82% |
| | 10000 | 2494.316 | 187.64 | 468038.7302 | 24.94% | 74.89% |
| | 20000 | 4076.947 | 199.04 | 811467.9298 | 20.38% | 64.92% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 50000 | 7305.955 | 213.47 | 1559603.745 | 14.61% | 49.91% |
| | 75000 | 9179.954 | 219.40 | 2014083.332 | 12.24% | 42.97% |
| | 100000 | 10655.8 | 223.36 | 2380084.517 | 10.66% | 38.08% |
| 150 | 1000 | 230.7455 | 192.31 | 44375.50125 | 23.07% | 71.00% |
| | 10000 | 919.3994 | 227.02 | 208717.4663 | 9.19% | 33.39% |
| | 20000 | 1217.091 | 234.79 | 285756.4056 | 6.09% | 22.86% |
| | 50000 | 1573.381 | 242.13 | 380967.6536 | 3.15% | 12.19% |
| | 75000 | 1697.125 | 244.34 | 414680.5614 | 2.26% | 8.85% |
| | 100000 | 1769.801 | 245.58 | 434619.7887 | 1.77% | 6.95% |
| 200 | 1000 | 109.2148 | 222.70 | 24321.72169 | 10.92% | 38.91% |
| | 10000 | 234.868 | 244.13 | 57337.93146 | 2.35% | 9.17% |
| | 20000 | 257.0531 | 246.79 | 63437.31606 | 1.29% | 5.07% |
| | 50000 | 273.5188 | 248.63 | 68005.64831 | 0.55% | 2.18% |
| | 75000 | 277.5997 | 249.07 | 69143.04902 | 0.37% | 1.48% |
| | 100000 | 279.7064 | 249.30 | 69731.00907 | 0.28% | 1.12% |

**Table 18: Paukert 250V Arcing Current and Relative Power Results**

| | Paukert 250V | | | | | |
|---|---|---|---|---|---|---|
| Gap Value | If | Ia | Va | Pa (Watts) | Ia % | Relative Power |
| 6 | 1000 | 770.2371 | 57.44073 | 44242.98 | 77.02% | 70.79% |
| | 10000 | 6407.377 | 89.81558 | 575482.3 | 64.07% | 92.08% |
| | 20000 | 11823.27 | 102.2092 | 1208446 | 59.12% | 96.68% |
| | 50000 | 25883.23 | 120.5838 | 3121099 | 51.77% | 99.88% |
| | 75000 | 36176.74 | 129.4109 | 4681663 | 48.24% | 99.88% |
| | 100000 | 45635.53 | 135.9112 | 6202378 | 45.64% | 99.24% |
| 13 | 1000 | 801.5738 | 49.60653 | 39763.29 | 80.16% | 63.62% |
| | 10000 | 7164.366 | 70.89082 | 507887.8 | 71.64% | 81.26% |
| | 20000 | 13696.88 | 78.78896 | 1079163 | 68.48% | 86.33% |
| | 50000 | 31912.76 | 90.43619 | 2886069 | 63.83% | 92.35% |
| | 75000 | 46184.26 | 96.05248 | 4436112 | 61.58% | 94.64% |
| | 100000 | 59913.96 | 100.2151 | 6004283 | 59.91% | 96.07% |
| 25 | 1000 | 719.2744 | 70.1814 | 50479.69 | 71.93% | 80.77% |
| | 10000 | 5823.123 | 104.4219 | 608061.7 | 58.23% | 97.29% |
| | 20000 | 10633.62 | 117.0797 | 1244981 | 53.17% | 99.60% |
| | 50000 | 22908.07 | 135.4596 | 3103119 | 45.82% | 99.30% |
| | 75000 | 31759.6 | 144.1346 | 4577658 | 42.35% | 97.66% |
| | 100000 | 39815.79 | 150.4605 | 5990705 | 39.82% | 95.85% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 50 | 1000 | 606.8721 | 98.28198 | 59644.59 | 60.69% | 95.43% |
| | 10000 | 4262.026 | 143.4494 | 611384.9 | 42.62% | 97.82% |
| | 20000 | 7271.043 | 159.112 | 1156910 | 36.36% | 92.55% |
| | 50000 | 13909.91 | 180.4504 | 2510049 | 27.82% | 80.32% |
| | 75000 | 18055.11 | 189.8163 | 3427154 | 24.07% | 73.11% |
| | 100000 | 21474.98 | 196.3125 | 4215809 | 21.47% | 67.45% |
| 100 | 1000 | 415.3761 | 146.1559 | 60709.69 | 41.54% | 97.14% |
| | 10000 | 1741.558 | 206.461 | 359563.8 | 17.42% | 57.53% |
| | 20000 | 2313.37 | 221.0829 | 511446.4 | 11.57% | 40.92% |
| | 50000 | 2984.385 | 235.0781 | 701563.5 | 5.97% | 22.45% |
| | 75000 | 3212.664 | 239.2911 | 768761.9 | 4.28% | 16.40% |
| | 100000 | 3345.357 | 241.6366 | 808360.6 | 3.35% | 12.93% |
| 150 | 1000 | | | 0 | 0.00% | 0.00% |
| | 10000 | | | 0 | 0.00% | 0.00% |
| | 20000 | | | 0 | 0.00% | 0.00% |
| | 50000 | | | 0 | 0.00% | 0.00% |
| | 75000 | | | 0 | 0.00% | 0.00% |
| | 100000 | | | 0 | 0.00% | 0.00% |
| 200 | 1000 | 175.846 | 206.0385 | 36231.05 | 17.58% | 57.97% |
| | 10000 | 323.0448 | 241.9239 | 78152.25 | 3.23% | 12.50% |
| | 20000 | 342.6528 | 245.7168 | 84195.56 | 1.71% | 6.74% |
| | 50000 | 356.0623 | 248.2197 | 88381.67 | 0.71% | 2.83% |
| | 75000 | 359.2395 | 248.8025 | 89379.7 | 0.48% | 1.91% |
| | 100000 | 360.8575 | 249.0979 | 89888.82 | 0.36% | 1.44% |

**Table 19: Max Power 250V Arcing Current and Power Results**

| | Max Power 250V | | | | |
|---|---|---|---|---|---|
| Gap Value | If | Ia | Va | Pa (Watts) | Ia % |
| 6 | 1000 | 500 | 125 | 62500 | 50.00% |
| | 10000 | 5000 | 125 | 625000 | 50.00% |
| | 20000 | 10000 | 125 | 1250000 | 50.00% |
| | 50000 | 25000 | 125 | 3125000 | 50.00% |
| | 75000 | 37500 | 125 | 4687500 | 50.00% |
| | 100000 | 50000 | 125 | 6250000 | 50.00% |
| 13 | 1000 | 500 | 125 | 62500 | 50.00% |
| | 10000 | 5000 | 125 | 625000 | 50.00% |
| | 20000 | 10000 | 125 | 1250000 | 50.00% |

| | | | | | |
|---|---|---|---|---|---|
| | 50000 | 25000 | 125 | 3125000 | 50.00% |
| | 75000 | 37500 | 125 | 4687500 | 50.00% |
| | 100000 | 50000 | 125 | 6250000 | 50.00% |
| 25 | 1000 | 500 | 125 | 62500 | 50.00% |
| | 10000 | 5000 | 125 | 625000 | 50.00% |
| | 20000 | 10000 | 125 | 1250000 | 50.00% |
| | 50000 | 25000 | 125 | 3125000 | 50.00% |
| | 75000 | 37500 | 125 | 4687500 | 50.00% |
| | 100000 | 50000 | 125 | 6250000 | 50.00% |
| 50 | 1000 | 500 | 125 | 62500 | 50.00% |
| | 10000 | 5000 | 125 | 625000 | 50.00% |
| | 20000 | 10000 | 125 | 1250000 | 50.00% |
| | 50000 | 25000 | 125 | 3125000 | 50.00% |
| | 75000 | 37500 | 125 | 4687500 | 50.00% |
| | 100000 | 50000 | 125 | 6250000 | 50.00% |
| 100 | 1000 | 500 | 125 | 62500 | 50.00% |
| | 10000 | 5000 | 125 | 625000 | 50.00% |
| | 20000 | 10000 | 125 | 1250000 | 50.00% |
| | 50000 | 25000 | 125 | 3125000 | 50.00% |
| | 75000 | 37500 | 125 | 4687500 | 50.00% |
| | 100000 | 50000 | 125 | 6250000 | 50.00% |
| 150 | 1000 | 500 | 125 | 62500 | 50.00% |
| | 10000 | 5000 | 125 | 625000 | 50.00% |
| | 20000 | 10000 | 125 | 1250000 | 50.00% |
| | 50000 | 25000 | 125 | 3125000 | 50.00% |
| | 75000 | 37500 | 125 | 4687500 | 50.00% |
| | 100000 | 50000 | 125 | 6250000 | 50.00% |
| 200 | 1000 | 500 | 125 | 62500 | 50.00% |
| | 10000 | 5000 | 125 | 625000 | 50.00% |
| | 20000 | 10000 | 125 | 1250000 | 50.00% |
| | 50000 | 25000 | 125 | 3125000 | 50.00% |
| | 75000 | 37500 | 125 | 4687500 | 50.00% |
| | 100000 | 50000 | 125 | 6250000 | 50.00% |

**Table 20: IEEE 1584 AC Arcing Results Open and Boxed 250V**

| Gap Value | IEEE 1584 AC (open) 250V | | | IEEE 1584 AC (box) 250V | | |
|---|---|---|---|---|---|---|
| | If | Ia (kA) | Ia % of Ib | If | Ia (kA) | Ia % of Ib |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6 | 1000 | | | 1000 | | 0.00% |
| | 10000 | | | 10000 | | 0.00% |
| | 20000 | | | 20000 | | 0.00% |
| | 50000 | | | 50000 | | 0.00% |
| | 75000 | | | 75000 | | 0.00% |
| | 100000 | | | 100000 | | 0.00% |
| 13 | 1000 | 0.755071 | 75.51% | 1000 | 0.85899 | 85.90% |
| | 10000 | 4.366847 | 43.67% | 10000 | 4.967845 | 49.68% |
| | 20000 | 7.406398 | 37.03% | 20000 | 8.42572 | 42.13% |
| | 50000 | 14.89049 | 29.78% | 50000 | 16.93983 | 33.88% |
| | 75000 | 20.28253 | 27.04% | 75000 | 23.07396 | 30.77% |
| | 100000 | 25.25504 | 25.26% | 100000 | 28.73082 | 28.73% |
| 25 | 1000 | 0.766126 | 76.61% | 1000 | 0.871565 | 87.16% |
| | 10000 | 4.073803 | 40.74% | 10000 | 4.634469 | 46.34% |
| | 20000 | 6.736859 | 33.68% | 20000 | 7.664035 | 38.32% |
| | 50000 | 13.09913 | 26.20% | 50000 | 14.90193 | 29.80% |
| | 75000 | 17.58053 | 23.44% | 75000 | 20.00009 | 26.67% |
| | 100000 | 21.66207 | 21.66% | 100000 | 24.64336 | 24.64% |
| 50 | 1000 | 0.789678 | 78.97% | 1000 | 0.898359 | 89.84% |
| | 10000 | 3.524926 | 35.25% | 10000 | 4.010052 | 40.10% |
| | 20000 | 5.530052 | 27.65% | 20000 | 6.291138 | 31.46% |
| | 50000 | 10.0293 | 20.06% | 50000 | 11.40961 | 22.82% |
| | 75000 | 13.05201 | 17.40% | 75000 | 14.84832 | 19.80% |
| | 100000 | 15.73439 | 15.73% | 100000 | 17.89988 | 17.90% |
| 100 | 1000 | 0.838977 | 83.90% | 1000 | 0.954443 | 95.44% |
| | 10000 | 2.639064 | 26.39% | 10000 | 3.002272 | 30.02% |
| | 20000 | 3.726255 | 18.63% | 20000 | 4.23909 | 21.20% |
| | 50000 | 5.879324 | 11.76% | 50000 | 6.688479 | 13.38% |
| | 75000 | 7.19396 | 9.59% | 75000 | 8.184045 | 10.91% |
| | 100000 | 8.301374 | 8.30% | 100000 | 9.44387 | 9.44% |
| 150 | 1000 | 0.891354 | 89.14% | 1000 | 1.014028 | 101.40% |
| | 10000 | 1.975832 | 19.76% | 10000 | 2.24776 | 22.48% |
| | 20000 | 2.510823 | 12.55% | 20000 | 2.856381 | 14.28% |
| | 50000 | 3.446545 | 6.89% | 50000 | 3.920883 | 7.84% |
| | 75000 | 3.965141 | 5.29% | 75000 | 4.510853 | 6.01% |
| | 100000 | 4.379757 | 4.38% | 100000 | 4.982531 | 4.98% |

**Table 21: Stokes/Oppenlander 480V Arcing Current and Relative Power Results**

| Gap Value | Stokes 480V | | | | | |
|---|---|---|---|---|---|---|
| | If | Ia (A) | Va | Pa (Watts) | Ia % of Ib | Relative Power |
| 13 | 1000 | 873.4858 | 60.72682 | 53044.01 | 87.35% | 44.20% |
| | 5000 | 4235.482 | 73.3936 | 310857.3 | 84.71% | 51.81% |
| | 10000 | 8341.416 | 79.61201 | 664076.9 | 83.41% | 55.34% |
| | 20000 | 16402.44 | 86.34135 | 1416209 | 82.01% | 59.01% |
| | 50000 | 39990.92 | 96.08713 | 3842613 | 79.98% | 64.04% |
| | 75000 | 59260.82 | 100.7307 | 5969385 | 79.01% | 66.33% |
| | 100000 | 78300.93 | 104.1554 | 8155466 | 78.30% | 67.96% |
| 25 | 1000 | 844.0381 | 74.86 | 63186.07 | 84.40% | 52.66% |
| | 5000 | 4058.483 | 90.39 | 366828.6 | 81.17% | 61.14% |
| | 10000 | 7958.477 | 97.99309 | 779875.7 | 79.58% | 64.99% |
| | 20000 | 15574.38 | 106.2148 | 1654230 | 77.87% | 68.93% |
| | 50000 | 37697.8 | 118.1011 | 4452150 | 75.40% | 74.20% |
| | 75000 | 55663.2 | 123.7554 | 6888619 | 74.22% | 76.54% |
| | 100000 | 73349.68 | 127.9215 | 9383003 | 73.35% | 78.19% |
| 50 | 1000 | 783.5469 | 103.8974 | 81408.49 | 78.35% | 67.84% |
| | 5000 | 3696.3 | 125.1552 | 462611.2 | 73.93% | 77.10% |
| | 10000 | 7176.516 | 135.5272 | 972613.3 | 71.77% | 81.05% |
| | 20000 | 13887.48 | 146.7005 | 2037300 | 69.44% | 84.89% |
| | 50000 | 33043.49 | 162.7823 | 5378896 | 66.09% | 89.65% |
| | 75000 | 48374.9 | 170.4007 | 8243114 | 64.50% | 91.59% |
| | 100000 | 63333.33 | 176 | 11146667 | 63.33% | 92.89% |
| 100 | 1000 | 666.3442 | 160.1548 | 106718.2 | 66.63% | 88.93% |
| | 5000 | 3001.494 | 191.8565 | 575856.3 | 60.03% | 95.98% |
| | 10000 | 5684.62 | 207.1382 | 1177502 | 56.85% | 98.13% |
| | 20000 | 10689.76 | 223.4458 | 2388582 | 53.45% | 99.52% |
| | 50000 | 24312.36 | 246.6013 | 5995459 | 48.62% | 99.92% |
| | 75000 | 34777.27 | 257.4255 | 8952555 | 46.37% | 99.47% |
| | 100000 | 44725.87 | 265.3158 | 11866481 | 44.73% | 98.89% |
| 150 | 1000 | 554.8616 | 213.6664 | 118555.3 | 55.49% | 98.80% |
| | 10000 | 4307.536 | 273.2383 | 1176984 | 43.08% | 98.08% |
| | 20000 | 7778.362 | 293.3193 | 2281544 | 38.89% | 95.06% |
| | 50000 | 16548.61 | 321.1334 | 5314310 | 33.10% | 88.57% |
| | 75000 | 22843.77 | 333.7999 | 7625247 | 30.46% | 84.72% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 100000 | 28567.28 | 342.877 | 9795063 | 28.57% | 81.63% |
| 200 | 1000 | 450.1095 | 263.9474 | 118805.2 | 45.01% | 99.00% |
| | 10000 | 3075.004 | 332.3998 | 1022131 | 30.75% | 85.18% |
| | 20000 | 5236.408 | 354.3262 | 1855397 | 26.18% | 77.31% |
| | 50000 | 10075.47 | 383.2755 | 3861680 | 20.15% | 64.36% |
| | 75000 | 13161.78 | 395.7646 | 5208965 | 17.55% | 57.88% |
| | 100000 | 15752.15 | 404.3896 | 6370005 | 15.75% | 53.08% |
| 250 | 1000 | 353.3714 | 310.3817 | 109680 | 35.34% | 91.40% |
| | 10000 | 2026.154 | 382.7446 | 775499.5 | 20.26% | 64.62% |
| | 20000 | 3171.416 | 403.886 | 1280890 | 15.86% | 53.37% |
| | 50000 | 5277.374 | 429.3372 | 2265773 | 10.55% | 37.76% |
| | 75000 | 6376.125 | 439.1928 | 2800348 | 8.50% | 31.11% |
| | 100000 | 7183.308 | 445.5201 | 3200308 | 7.18% | 26.67% |

**Table 22: Paukert 480V Arcing Current and Relative Power Results**

| Gap Value | Paukert 480V | | | | | |
|---|---|---|---|---|---|---|
| | If | Ia (kA) | Va | Pa (Watts) | Ia % of Ib | Relative Power |
| 13 | 1000 | 894.7832 | 50.50 | 45190.16 | 89.48% | 37.66% |
| | 10000 | 8481.904 | 72.87 | 618064.5 | 84.82% | 51.51% |
| | 20000 | 16612.22 | 81.31 | 1350683 | 83.06% | 56.28% |
| | 50000 | 40217.62 | 93.91 | 3776872 | 80.44% | 62.95% |
| | 75000 | 59364.87 | 100.06 | 5940335 | 79.15% | 66.00% |
| | 100000 | 78195.63 | 104.66 | 8184031 | 78.20% | 68.20% |
| 25 | 1000 | 849.1054 | 72.43 | 61500.18 | 84.91% | 51.25% |
| | 10000 | 7705.625 | 110.13 | 848620.3 | 77.06% | 70.72% |
| | 20000 | 14805.08 | 124.68 | 1845869 | 74.03% | 76.91% |
| | 50000 | 34728.84 | 146.60 | 5091356 | 69.46% | 84.86% |
| | 75000 | 50412.5 | 157.36 | 7932911 | 67.22% | 88.14% |
| | 100000 | 65540.59 | 165.41 | 10840751 | 65.54% | 90.34% |
| 50 | 1000 | 784.7752 | 103.31 | 81073.49 | 78.48% | 67.56% |
| | 10000 | 6734.133 | 156.76 | 1055653 | 67.34% | 87.97% |
| | 20000 | 12621.66 | 177.08 | 2235045 | 63.11% | 93.13% |
| | 50000 | 28409.89 | 207.27 | 5888378 | 56.82% | 98.14% |
| | 75000 | 40336.07 | 221.85 | 8948519 | 53.78% | 99.43% |
| | 100000 | 51532.03 | 232.65 | 11988734 | 51.53% | 99.91% |
| 100 | 1000 | 659.6084 | 163.39 | 107772.1 | 65.96% | 89.81% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 10000 | 4572.226 | 260.53 | 1191216 | 45.72% | 99.27% |
| | 20000 | 7693.865 | 295.35 | 2272362 | 38.47% | 94.68% |
| | 50000 | 14286.22 | 342.85 | 4898062 | 28.57% | 81.63% |
| | 75000 | 18205.9 | 363.48 | 6617521 | 24.27% | 73.53% |
| | 100000 | 21329.19 | 377.62 | 8054326 | 21.33% | 67.12% |
| 150 | 1000 | | | 0 | 0.00% | 0.00% |
| | 10000 | | | 0 | 0.00% | 0.00% |
| | 20000 | | | 0 | 0.00% | 0.00% |
| | 50000 | | | 0 | 0.00% | 0.00% |
| | 75000 | | | 0 | 0.00% | 0.00% |
| | 100000 | | | 0 | 0.00% | 0.00% |
| 200 | 1000 | 449.9257 | 264.0356 | 118796.4 | 44.99% | 99.00% |
| | 10000 | 1925.535 | 387.57 | 746288 | 19.26% | 62.19% |
| | 20000 | 2570.761 | 418.3017 | 1075354 | 12.85% | 44.81% |
| | 50000 | 3333.44 | 447.999 | 1493378 | 6.67% | 24.89% |
| | 75000 | 3594.229 | 456.9969 | 1642551 | 4.79% | 18.25% |
| | 100000 | 3746.135 | 462.0185 | 1730784 | 3.75% | 14.42% |
| 250 | 1000 | | | 0 | 0.00% | 0.00% |
| | 10000 | | | 0 | 0.00% | 0.00% |
| | 20000 | | | 0 | 0.00% | 0.00% |
| | 50000 | | | 0 | 0.00% | 0.00% |
| | 75000 | | | 0 | 0.00% | 0.00% |
| | 100000 | | | 0 | 0.00% | 0.00% |

**Table 23: Max Power 480V Arcing Current and Power Results**

| Gap Value | Max Power 480V | | | | |
|---|---|---|---|---|---|
| | If | Ia | Va | Pa (Watts) | Ia % |
| 13 | 1000 | 500 | 240 | 120000 | 50.00% |
| | 5000 | 2500 | 240 | 600000 | 50.00% |
| | 10000 | 5000 | 240 | 1200000 | 50.00% |
| | 20000 | 10000 | 240 | 2400000 | 50.00% |
| | 50000 | 25000 | 240 | 6000000 | 50.00% |
| | 75000 | 37500 | 240 | 9000000 | 50.00% |
| | 100000 | 50000 | 240 | 12000000 | 50.00% |
| 25 | 1000 | 500 | 240 | 120000 | 50.00% |
| | 5000 | 2500 | 240 | 600000 | 50.00% |

| | | | | | |
|---|---|---|---|---|---|
| | 10000 | 5000 | 240 | 1200000 | 50.00% |
| | 20000 | 10000 | 240 | 2400000 | 50.00% |
| | 50000 | 25000 | 240 | 6000000 | 50.00% |
| | 75000 | 37500 | 240 | 9000000 | 50.00% |
| | 100000 | 50000 | 240 | 12000000 | 50.00% |
| 50 | 1000 | 500 | 240 | 120000 | 50.00% |
| | 5000 | 2500 | 240 | 600000 | 50.00% |
| | 10000 | 5000 | 240 | 1200000 | 50.00% |
| | 20000 | 10000 | 240 | 2400000 | 50.00% |
| | 50000 | 25000 | 240 | 6000000 | 50.00% |
| | 75000 | 37500 | 240 | 9000000 | 50.00% |
| | 100000 | 50000 | 240 | 12000000 | 50.00% |
| 100 | 1000 | 500 | 240 | 120000 | 50.00% |
| | 5000 | 2500 | 240 | 600000 | 50.00% |
| | 10000 | 5000 | 240 | 1200000 | 50.00% |
| | 20000 | 10000 | 240 | 2400000 | 50.00% |
| | 50000 | 25000 | 240 | 6000000 | 50.00% |
| | 75000 | 37500 | 240 | 9000000 | 50.00% |
| | 100000 | 50000 | 240 | 12000000 | 50.00% |
| 150 | 1000 | 500 | 240 | 120000 | 50.00% |
| | 10000 | 5000 | 240 | 1200000 | 50.00% |
| | 20000 | 10000 | 240 | 2400000 | 50.00% |
| | 50000 | 25000 | 240 | 6000000 | 50.00% |
| | 75000 | 37500 | 240 | 9000000 | 50.00% |
| | 100000 | 50000 | 240 | 12000000 | 50.00% |
| 200 | 1000 | 500 | 240 | 120000 | 50.00% |
| | 10000 | 5000 | 240 | 1200000 | 50.00% |
| | 20000 | 10000 | 240 | 2400000 | 50.00% |
| | 50000 | 25000 | 240 | 6000000 | 50.00% |
| | 75000 | 37500 | 240 | 9000000 | 50.00% |
| | 100000 | 50000 | 240 | 12000000 | 50.00% |
| 250 | 1000 | 500 | 240 | 120000 | 50.00% |
| | 10000 | 5000 | 240 | 1200000 | 50.00% |
| | 20000 | 10000 | 240 | 2400000 | 50.00% |
| | 50000 | 25000 | 240 | 6000000 | 50.00% |
| | 75000 | 37500 | 240 | 9000000 | 50.00% |
| | 100000 | 50000 | 240 | 12000000 | 50.00% |

**Table 24: IEEE 1584 AC Arcing Results Open and Boxed 480V**

| Gap Value | IEEE 1584 AC (open) 480V | | | IEEE 1584 AC (box) 480V | | |
|---|---|---|---|---|---|---|
| | If | Ia (kA) | Ia % of Ib | If | Ia (kA) | Ia % of Ib |
| 13 | 1000 | 0.794705 | 79.47% | 1000 | 0.904078 | 90.41% |
| | 10000 | 6.178883 | 61.79% | 10000 | 7.029266 | 70.29% |
| | 20000 | 11.45615 | 57.28% | 20000 | 13.03283 | 65.16% |
| | 50000 | 25.91107 | 51.82% | 50000 | 29.47714 | 58.95% |
| | 75000 | 37.18181 | 49.58% | 75000 | 42.29905 | 56.40% |
| | 100000 | 48.04122 | 48.04% | 100000 | 54.653 | 54.65% |
| 25 | 1000 | 0.80634 | 80.63% | 1000 | 0.917314 | 91.73% |
| | 10000 | 5.764239 | 57.64% | 10000 | 6.557556 | 65.58% |
| | 20000 | 10.42051 | 52.10% | 20000 | 11.85466 | 59.27% |
| | 50000 | 22.79392 | 45.59% | 50000 | 25.93098 | 51.86% |
| | 75000 | 32.22852 | 42.97% | 75000 | 36.66404 | 48.89% |
| | 100000 | 41.20653 | 41.21% | 100000 | 46.87767 | 46.88% |
| 50 | 1000 | 0.831128 | 83.11% | 1000 | 0.945514 | 94.55% |
| | 10000 | 4.987604 | 49.88% | 10000 | 5.674035 | 56.74% |
| | 20000 | 8.553833 | 42.77% | 20000 | 9.731074 | 48.66% |
| | 50000 | 17.45208 | 34.90% | 50000 | 19.85396 | 39.71% |
| | 75000 | 23.92686 | 31.90% | 75000 | 27.21985 | 36.29% |
| | 100000 | 29.93064 | 29.93% | 100000 | 34.04991 | 34.05% |
| 100 | 1000 | 0.883015 | 88.30% | 1000 | 1.004542 | 100.45% |
| | 10000 | 3.734152 | 37.34% | 10000 | 4.248073 | 42.48% |
| | 20000 | 5.763738 | 28.82% | 20000 | 6.556985 | 32.78% |
| | 50000 | 10.23066 | 20.46% | 50000 | 11.63868 | 23.28% |
| | 75000 | 13.18792 | 17.58% | 75000 | 15.00294 | 20.00% |
| | 100000 | 15.79123 | 15.79% | 100000 | 17.96454 | 17.96% |

**Table 25: Stokes/Oppenlander 500V Arcing Current and Relative Power Results**

| Gap Value | Stokes 500V | | | | | |
|---|---|---|---|---|---|---|
| | If | Ia | Va | Pa (Watts) | Ia% | Relative Power |
| 6 | 1000 | 895.09 | 52.45 | 46951.94 | 89.51% | 37.56% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 10000 | 8623.193 | 68.84 | 593623.6 | 86.23% | 47.49% |
| | 20000 | 17012.45 | 74.69 | 1270638 | 85.06% | 50.83% |
| | 50000 | 41683.16 | 83.17 | 3466720 | 83.37% | 55.47% |
| | 75000 | 61918.05 | 87.21 | 5400055 | 82.56% | 57.60% |
| | 100000 | 81960.45 | 90.20 | 7392642 | 81.96% | 59.14% |
| 13 | 1000 | 878.4635 | 60.77 | 53382.68 | 87.85% | 42.71% |
| | 10000 | 8406.279 | 79.69 | 669863.1 | 84.06% | 53.59% |
| | 20000 | 16542.81 | 86.43 | 1429790 | 82.71% | 57.19% |
| | 50000 | 40380.11 | 96.20 | 3884520 | 80.76% | 62.15% |
| | 75000 | 59871.77 | 100.85 | 6038355 | 79.83% | 64.41% |
| | 100000 | 79142.19 | 104.29 | 8253665 | 79.14% | 66.03% |
| 25 | 1000 | 850.1468 | 74.93 | 63698.48 | 85.01% | 50.96% |
| | 10000 | 8037.803 | 98.11 | 788587.2 | 80.38% | 63.09% |
| | 20000 | 15745.82 | 106.35 | 1674638 | 78.73% | 66.99% |
| | 50000 | 38172.16 | 118.28 | 4514942 | 76.34% | 72.24% |
| | 75000 | 56407.09 | 123.95 | 6991809 | 75.21% | 74.58% |
| | 100000 | 74373.12 | 128.13 | 9529755 | 74.37% | 76.24% |
| 50 | 1000 | 791.9393 | 104.03 | 82385.69 | 79.19% | 65.91% |
| | 10000 | 7284.589 | 135.77 | 989032.5 | 72.85% | 79.12% |
| | 20000 | 14120.26 | 146.99 | 2075586 | 70.60% | 83.02% |
| | 50000 | 33684.2 | 163.16 | 5495842 | 67.37% | 87.93% |
| | 75000 | 49376.94 | 170.82 | 8434589 | 65.84% | 89.97% |
| | 100000 | 64709.1 | 176.45 | 11418212 | 64.71% | 91.35% |
| 100 | 1000 | 678.9682 | 160.52 | 108985.2 | 67.90% | 87.19% |
| | 10000 | 5843.508 | 207.82 | 1214425 | 58.44% | 97.15% |
| | 20000 | 11028.63 | 224.28 | 2473548 | 55.14% | 98.94% |
| | 50000 | 25229.99 | 247.70 | 6249471 | 50.46% | 99.99% |
| | 75000 | 36199.94 | 258.67 | 9363730 | 48.27% | 99.88% |
| | 100000 | 46665.79 | 266.67 | 12444415 | 46.67% | 99.56% |
| 150 | 1000 | 571.1784 | 214.41 | 122466.8 | 57.12% | 97.97% |
| | 10000 | 4505.665 | 274.72 | 1237782 | 45.06% | 99.02% |
| | 20000 | 8193.75 | 295.16 | 2418436 | 40.97% | 96.74% |
| | 50000 | 17639.67 | 323.60 | 5708256 | 35.28% | 91.33% |
| | 75000 | 24506.16 | 336.63 | 8249401 | 32.67% | 87.99% |
| | 100000 | 30802 | 345.99 | 10657182 | 30.80% | 85.26% |
| 200 | 1000 | 469.4353 | 265.28 | 124532.9 | 46.94% | 99.63% |
| | 10000 | 3296.326 | 335.18 | 1104875 | 32.96% | 88.39% |
| | 20000 | 5686.125 | 357.85 | 2034762 | 28.43% | 81.39% |
| | 50000 | 11187.78 | 388.12 | 4342225 | 22.38% | 69.48% |
| | 75000 | 14795.77 | 401.36 | 5938452 | 19.73% | 63.34% |
| | 100000 | 17881.9 | 410.59 | 7342138 | 17.88% | 58.74% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 250 | 1000 | 374.8294 | 312.59 | 117166.1 | 37.48% | 93.73% |
| | 10000 | 2248.755 | 387.56 | 871532.6 | 22.49% | 69.72% |
| | 20000 | 3598.027 | 410.05 | 1475368 | 17.99% | 59.01% |
| | 50000 | 6215.22 | 437.85 | 2721320 | 12.43% | 43.54% |
| | 75000 | 7657.436 | 448.95 | 3437809 | 10.21% | 36.67% |
| | 100000 | 8754.992 | 456.22 | 3994246 | 8.75% | 31.95% |
| 300 | 1000 | 288.7182 | 355.64 | 102680 | 28.87% | 82.14% |
| | 10000 | 1402.033 | 429.90 | 602731.7 | 14.02% | 48.22% |
| | 20000 | 2026.666 | 449.33 | 910648.6 | 10.13% | 36.43% |
| | 50000 | 2965.873 | 470.34 | 1394972 | 5.93% | 22.32% |
| | 75000 | 3366.903 | 477.55 | 1607878 | 4.49% | 17.15% |
| | 100000 | 3628.318 | 481.86 | 1748336 | 3.63% | 13.99% |
| 400 | 1000 | 148.5867 | 425.71 | 63254.35 | 14.86% | 50.60% |
| | 10000 | 402.9774 | 479.85 | 193369.2 | 4.03% | 15.47% |
| | 20000 | 466.3881 | 488.34 | 227756.1 | 2.33% | 9.11% |
| | 50000 | 520.3345 | 494.80 | 257459.8 | 1.04% | 4.12% |
| | 75000 | 534.8609 | 496.43 | 265523.3 | 0.71% | 2.83% |
| | 100000 | 542.567 | 497.29 | 269811.6 | 0.54% | 2.16% |

**Table 26: Paukert 500V Arcing Current and Relative Power Results**

| | Paukert | | | | | |
|---|---|---|---|---|---|---|
| Gap Value | If | Ia | Va | Pa (Watts) | Ia% | Relative Power |
| 6 | 1000 | 881.7926 | 59.10367 | 52117.18 | 88.18% | 41.69% |
| | 10000 | 8112.016 | 94.3992 | 765767.8 | 81.12% | 61.26% |
| | 20000 | 15661.76 | 108.456 | 1698612 | 78.31% | 67.94% |
| | 50000 | 36997.51 | 130.0249 | 4810597 | 74.00% | 76.97% |
| | 75000 | 53885.8 | 140.7613 | 7585036 | 71.85% | 80.91% |
| | 100000 | 70229.4 | 148.853 | 10453858 | 70.23% | 83.63% |
| 13 | 1000 | 898.9159 | 50.54198 | 45432.99 | 89.89% | 36.35% |
| | 10000 | 8540.978 | 72.95109 | 623073.7 | 85.41% | 49.85% |
| | 20000 | 16743.56 | 81.41103 | 1363110 | 83.72% | 54.52% |
| | 50000 | 40594.61 | 94.05381 | 3818078 | 81.19% | 61.09% |
| | 75000 | 59965.62 | 100.2292 | 6010304 | 79.95% | 64.11% |
| | 100000 | 79031.49 | 104.8425 | 8285861 | 79.03% | 66.29% |
| 25 | 1000 | 854.9522 | 72.52388 | 62004.45 | 85.50% | 49.60% |
| | 10000 | 7792.693 | 110.3653 | 860043.2 | 77.93% | 68.80% |
| | 20000 | 15000.44 | 124.989 | 1874890 | 75.00% | 75.00% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 50000 | 35294.6 | 147.0539 | 5190210 | 70.59% | 83.04% |
| | 75000 | 51316.19 | 157.8921 | 8102420 | 68.42% | 86.43% |
| | 100000 | 66799.17 | 166.004 | 11088930 | 66.80% | 88.71% |
| 50 | 1000 | 792.9675 | 103.5163 | 82085.03 | 79.30% | 65.67% |
| | 10000 | 6854.017 | 157.2992 | 1078131 | 68.54% | 86.25% |
| | 20000 | 12888.04 | 177.799 | 2291481 | 64.44% | 91.66% |
| | 50000 | 29167.41 | 208.3259 | 6076327 | 58.33% | 97.22% |
| | 75000 | 41533.27 | 223.1115 | 9266549 | 55.38% | 98.84% |
| | 100000 | 53184.88 | 234.0755 | 12449279 | 53.18% | 99.59% |
| 100 | 1000 | 671.7809 | 164.1096 | 110245.7 | 67.18% | 88.20% |
| | 10000 | 4743.068 | 262.8466 | 1246699 | 47.43% | 99.74% |
| | 20000 | 8054.844 | 298.6289 | 2405409 | 40.27% | 96.22% |
| | 50000 | 15199.12 | 348.0088 | 5289427 | 30.40% | 84.63% |
| | 75000 | 19540.28 | 369.7314 | 7224657 | 26.05% | 77.06% |
| | 100000 | 23050.28 | 384.7486 | 8868564 | 23.05% | 70.95% |
| 150 | 1000 | | | 0 | 0.00% | 0.00% |
| | 10000 | | | 0 | 0.00% | 0.00% |
| | 20000 | | | 0 | 0.00% | 0.00% |
| | 50000 | | | 0 | 0.00% | 0.00% |
| | 75000 | | | 0 | 0.00% | 0.00% |
| | 100000 | | | 0 | 0.00% | 0.00% |
| 200 | 1000 | 466.7774 | 266.6112 | 124448.1 | 46.68% | 99.56% |
| | 10000 | 2084.486 | 395.7757 | 824989 | 20.84% | 66.00% |
| | 20000 | 2833.121 | 429.172 | 1215896 | 14.17% | 48.64% |
| | 50000 | 3758.367 | 462.4163 | 1737930 | 7.52% | 27.81% |
| | 75000 | 4086.718 | 472.7552 | 1932017 | 5.45% | 20.61% |
| | 100000 | 4281.219 | 478.5939 | 2048965 | 4.28% | 16.39% |

**Table 27: Max Power 500V Arcing Current and Power Results**

| | Max Power 500V | | | | |
|---|---|---|---|---|---|
| Gap Value | If | Ia | Va | Pa (Watts) | Ia% |
| 6 | 1000 | 500 | 250 | 125000 | 50.00% |
| | 10000 | 5000 | 250 | 1250000 | 50.00% |
| | 20000 | 10000 | 250 | 2500000 | 50.00% |
| | 50000 | 25000 | 250 | 6250000 | 50.00% |
| | 75000 | 37500 | 250 | 9375000 | 50.00% |
| | 100000 | 50000 | 250 | 12500000 | 50.00% |

| | | | | | |
|---|---|---|---|---|---|
| 13 | 1000 | 500 | 250 | 125000 | 50.00% |
| | 10000 | 5000 | 250 | 1250000 | 50.00% |
| | 20000 | 10000 | 250 | 2500000 | 50.00% |
| | 50000 | 25000 | 250 | 6250000 | 50.00% |
| | 75000 | 37500 | 250 | 9375000 | 50.00% |
| | 100000 | 50000 | 250 | 12500000 | 50.00% |
| 25 | 1000 | 500 | 250 | 125000 | 50.00% |
| | 10000 | 5000 | 250 | 1250000 | 50.00% |
| | 20000 | 10000 | 250 | 2500000 | 50.00% |
| | 50000 | 25000 | 250 | 6250000 | 50.00% |
| | 75000 | 37500 | 250 | 9375000 | 50.00% |
| | 100000 | 50000 | 250 | 12500000 | 50.00% |
| 50 | 1000 | 500 | 250 | 125000 | 50.00% |
| | 10000 | 5000 | 250 | 1250000 | 50.00% |
| | 20000 | 10000 | 250 | 2500000 | 50.00% |
| | 50000 | 25000 | 250 | 6250000 | 50.00% |
| | 75000 | 37500 | 250 | 9375000 | 50.00% |
| | 100000 | 50000 | 250 | 12500000 | 50.00% |
| 100 | 1000 | 500 | 250 | 125000 | 50.00% |
| | 10000 | 5000 | 250 | 1250000 | 50.00% |
| | 20000 | 10000 | 250 | 2500000 | 50.00% |
| | 50000 | 25000 | 250 | 6250000 | 50.00% |
| | 75000 | 37500 | 250 | 9375000 | 50.00% |
| | 100000 | 50000 | 250 | 12500000 | 50.00% |
| 150 | 1000 | 500 | 250 | 125000 | 50.00% |
| | 10000 | 5000 | 250 | 1250000 | 50.00% |
| | 20000 | 10000 | 250 | 2500000 | 50.00% |
| | 50000 | 25000 | 250 | 6250000 | 50.00% |
| | 75000 | 37500 | 250 | 9375000 | 50.00% |
| | 100000 | 50000 | 250 | 12500000 | 50.00% |
| 200 | 1000 | 500 | 250 | 125000 | 50.00% |
| | 10000 | 5000 | 250 | 1250000 | 50.00% |
| | 20000 | 10000 | 250 | 2500000 | 50.00% |
| | 50000 | 25000 | 250 | 6250000 | 50.00% |
| | 75000 | 37500 | 250 | 9375000 | 50.00% |
| | 100000 | 50000 | 250 | 12500000 | 50.00% |
| 250 | 1000 | 500 | 250 | 125000 | 50.00% |
| | 10000 | 5000 | 250 | 1250000 | 50.00% |
| | 20000 | 10000 | 250 | 2500000 | 50.00% |
| | 50000 | 25000 | 250 | 6250000 | 50.00% |
| | 75000 | 37500 | 250 | 9375000 | 50.00% |

| | | | | | |
|---|---|---|---|---|---|
| | 100000 | 50000 | 250 | 12500000 | 50.00% |
| 300 | 1000 | 500 | 250 | 125000 | 50.00% |
| | 10000 | 5000 | 250 | 1250000 | 50.00% |
| | 20000 | 10000 | 250 | 2500000 | 50.00% |
| | 50000 | 25000 | 250 | 6250000 | 50.00% |
| | 75000 | 37500 | 250 | 9375000 | 50.00% |
| | 100000 | 50000 | 250 | 12500000 | 50.00% |
| 400 | 1000 | 500 | 250 | 125000 | 50.00% |
| | 10000 | 5000 | 250 | 1250000 | 50.00% |
| | 20000 | 10000 | 250 | 2500000 | 50.00% |
| | 50000 | 25000 | 250 | 6250000 | 50.00% |
| | 75000 | 37500 | 250 | 9375000 | 50.00% |
| | 100000 | 50000 | 250 | 12500000 | 50.00% |

**Table 28: IEEE 1584 AC Arcing Results Open and Boxed 500V**

| Gap Value | IEEE 1584 AC (open) 500V | | | IEEE 1584 AC (box) 500V | | |
|---|---|---|---|---|---|---|
| | If | Ia (kA) | Ia % of Ib | If | Ia (kA) | Ia % of Ib |
| 6 | 1000 | | 0.00% | 1000 | | 0.00% |
| | 10000 | | 0.00% | 10000 | | 0.00% |
| | 20000 | | 0.00% | 20000 | | 0.00% |
| | 50000 | | 0.00% | 50000 | | 0.00% |
| | 75000 | | 0.00% | 75000 | | 0.00% |
| | 100000 | | 0.00% | 100000 | | 0.00% |
| 13 | 1000 | 0.798248 | 79.82% | 1000 | 0.908109 | 90.81% |
| | 10000 | 6.368219 | 63.68% | 10000 | 7.24466 | 72.45% |
| | 20000 | 11.89901 | 59.50% | 20000 | 13.53664 | 67.68% |
| | 50000 | 27.18974 | 54.38% | 50000 | 30.93179 | 61.86% |
| | 75000 | 39.19388 | 52.26% | 75000 | 44.58803 | 59.45% |
| | 100000 | 50.80401 | 50.80% | 100000 | 57.79603 | 57.80% |
| 25 | 1000 | 0.809935 | 80.99% | 1000 | 0.921404 | 92.14% |
| | 10000 | 5.940869 | 59.41% | 10000 | 6.758495 | 67.58% |
| | 20000 | 10.82334 | 54.12% | 20000 | 12.31293 | 61.56% |
| | 50000 | 23.91876 | 47.84% | 50000 | 27.21063 | 54.42% |
| | 75000 | 33.97254 | 45.30% | 75000 | 38.64809 | 51.53% |
| | 100000 | 43.57626 | 43.58% | 100000 | 49.57355 | 49.57% |
| 50 | 1000 | 0.834834 | 83.48% | 1000 | 0.94973 | 94.97% |
| | 10000 | 5.140437 | 51.40% | 10000 | 5.847901 | 58.48% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 20000 | 8.884502 | 44.42% | 20000 | 10.10725 | 50.54% |
| | 50000 | 18.31331 | 36.63% | 50000 | 20.83372 | 41.67% |
| | 75000 | 25.22164 | 33.63% | 75000 | 28.69283 | 38.26% |
| | 100000 | 31.65192 | 31.65% | 100000 | 36.00808 | 36.01% |
| 100 | 1000 | 0.886952 | 88.70% | 1000 | 1.009021 | 100.90% |
| | 10000 | 3.848575 | 38.49% | 10000 | 4.378244 | 43.78% |
| | 20000 | 5.986549 | 29.93% | 20000 | 6.810461 | 34.05% |
| | 50000 | 10.73553 | 21.47% | 50000 | 12.21303 | 24.43% |
| | 75000 | 13.90158 | 18.54% | 75000 | 15.81481 | 21.09% |
| | 100000 | 16.69937 | 16.70% | 100000 | 18.99766 | 19.00% |
| 150 | 1000 | 0.942323 | 94.23% | 1000 | 1.072013 | 107.20% |
| | 10000 | 2.881376 | 28.81% | 10000 | 3.277932 | 32.78% |
| | 20000 | 4.033852 | 20.17% | 20000 | 4.58902 | 22.95% |
| | 50000 | 6.293323 | 12.59% | 50000 | 7.159456 | 14.32% |
| | 75000 | 7.662222 | 10.22% | 75000 | 8.716753 | 11.62% |
| | 100000 | 8.810489 | 8.81% | 100000 | 10.02305 | 10.02% |

**Table 29: Stokes/Oppenlander 1000V Arcing Current and Relative Power Results**

| | Stokes 1000V | | | | | |
|---|---|---|---|---|---|---|
| Gap Value | If | Ia | Va | Pa (Watts) | Ia% | Relative Power |
| 6 | 1000 | 947.1874 | 52.81 | 50023.15628 | 94.72% | 20.01% |
| | 10000 | 9305.279 | 69.47 | 646457.185 | 93.05% | 25.86% |
| | 20000 | 18491.21 | 75.44 | 1394967.322 | 92.46% | 27.90% |
| | 50000 | 45794.38 | 84.11 | 3851877.511 | 91.59% | 30.82% |
| | 75000 | 68380.64 | 88.26 | 6035148.857 | 91.17% | 32.19% |
| | 100000 | 90867.87 | 91.32 | 8298172.073 | 90.87% | 33.19% |
| 13 | 1000 | 938.7458 | 61.25 | 57502.08864 | 93.87% | 23.00% |
| | 10000 | 9194.522 | 80.55 | 740597.9498 | 91.95% | 29.62% |
| | 20000 | 18250.9 | 87.45 | 1596130.135 | 91.25% | 31.92% |
| | 50000 | 45125.5 | 97.49 | 4399288.573 | 90.25% | 35.19% |
| | 75000 | 67328.58 | 102.29 | 6886733.135 | 89.77% | 36.73% |
| | 100000 | 89417.2 | 105.83 | 9462838.99 | 89.42% | 37.85% |
| 25 | 1000 | 924.3177 | 75.68 | 69954.4995 | 92.43% | 27.98% |
| | 10000 | 9005.428 | 99.46 | 895654.8933 | 90.05% | 35.83% |
| | 20000 | 17840.79 | 107.96 | 1926102.851 | 89.20% | 38.52% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 50000 | 43984.63 | 120.31 | 5291672.397 | 87.97% | 42.33% |
| | 75000 | 65534.71 | 126.20 | 8270729.606 | 87.38% | 44.11% |
| | 100000 | 86944.16 | 130.56 | 11351287.56 | 86.94% | 45.41% |
| 50 | 1000 | 894.4391 | 105.56 | 94417.77543 | 89.44% | 37.77% |
| | 10000 | 8614.694 | 138.53 | 1193398.609 | 86.15% | 47.74% |
| | 20000 | 16994.04 | 150.30 | 2554165.89 | 84.97% | 51.08% |
| | 50000 | 41632.06 | 167.36 | 6967486.977 | 83.26% | 55.74% |
| | 75000 | 61837.79 | 175.50 | 10852288.95 | 82.45% | 57.88% |
| | 100000 | 81849.89 | 181.50 | 14855838.53 | 81.85% | 59.42% |
| 100 | 1000 | 835.4394 | 164.56 | 137480.4017 | 83.54% | 54.99% |
| | 10000 | 7846.918 | 215.31 | 1689503.368 | 78.47% | 67.58% |
| | 20000 | 15333.38 | 233.33 | 3577753.622 | 76.67% | 71.56% |
| | 50000 | 37031.36 | 259.37 | 9604926.818 | 74.06% | 76.84% |
| | 75000 | 54618.39 | 271.75 | 14842791.49 | 72.82% | 79.16% |
| | 100000 | 71912.53 | 280.87 | 20198409.47 | 71.91% | 80.79% |
| 150 | 1000 | 777.5059 | 222.49 | 172990.4813 | 77.75% | 69.20% |
| | 10000 | 7098.808 | 290.12 | 2059499.741 | 70.99% | 82.38% |
| | 20000 | 13720.18 | 313.99 | 4308013.095 | 68.60% | 86.16% |
| | 50000 | 32583.39 | 348.33 | 11349842.54 | 65.17% | 90.80% |
| | 75000 | 47655.56 | 364.59 | 17374859.61 | 63.54% | 92.67% |
| | 100000 | 62346 | 376.54 | 23475762.63 | 62.35% | 93.90% |
| 200 | 1000 | 720.7129 | 279.29 | 201285.7437 | 72.07% | 80.51% |
| | 10000 | 6372.273 | 362.77 | 2311686.629 | 63.72% | 92.47% |
| | 20000 | 12159.58 | 392.02 | 4766811.027 | 60.80% | 95.34% |
| | 50000 | 28307.14 | 433.86 | 12281256.05 | 56.61% | 98.25% |
| | 75000 | 40983.21 | 453.56 | 18588227.57 | 54.64% | 99.14% |
| | 100000 | 53201.68 | 467.98 | 24897492.17 | 53.20% | 99.59% |
| 250 | 1000 | 665.1439 | 334.86 | 222727.4988 | 66.51% | 89.09% |
| | 10000 | 5669.539 | 433.05 | 2455171.663 | 56.70% | 98.21% |
| | 20000 | 10657.62 | 467.12 | 4978376.893 | 53.29% | 99.57% |
| | 50000 | 24225.45 | 515.49 | 12488000.54 | 48.45% | 99.90% |
| | 75000 | 34642.62 | 538.10 | 18641137.79 | 46.19% | 99.42% |
| | 100000 | 44542.38 | 554.58 | 24702139.44 | 44.54% | 98.81% |
| 300 | 1000 | 610.8917 | 389.11 | 237703.0272 | 61.09% | 95.08% |
| | 10000 | 4993.2 | 500.68 | 2499995.358 | 49.93% | 100.00% |
| | 20000 | 9221.442 | 538.93 | 4969691.849 | 46.11% | 99.39% |
| | 50000 | 20365.81 | 592.68 | 12070486.38 | 40.73% | 96.56% |
| | 75000 | 28683.84 | 617.55 | 17713667.22 | 38.25% | 94.47% |
| | 100000 | 36444.8 | 635.55 | 23162563.16 | 36.44% | 92.65% |
| 400 | 1000 | 506.7693 | 493.23 | 249954.1761 | 50.68% | 99.98% |
| | 10000 | 3732.276 | 626.77 | 2339286.861 | 37.32% | 93.57% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 20000 | 6581.553 | 670.92 | 4415710.602 | 32.91% | 88.31% |
| | 50000 | 13449.86 | 731.00 | 9831887.258 | 26.90% | 78.66% |
| | 75000 | 18162.48 | 757.83 | 13764137.14 | 24.22% | 73.41% |
| | 100000 | 22319.13 | 776.81 | 17337692.2 | 22.32% | 69.35% |

**Table 30: Paukert 1000V Arcing Current and Relative Power Results**

| Gap Value | Paukert 1000V | | | | | |
|---|---|---|---|---|---|---|
| | If | Ia | Va | Pa (Watts) | Ia% | Relative Power |
| 6 | 1000 | 940.0925 | 59.90749 | 56318.59 | 94.01% | 22.53% |
| | 10000 | 9034.314 | 96.56862 | 872431.2 | 90.34% | 34.90% |
| | 20000 | 17772.24 | 111.3878 | 1979612 | 88.86% | 39.59% |
| | 50000 | 43280.01 | 134.3999 | 5816826 | 86.56% | 46.53% |
| | 75000 | 64050.85 | 145.9886 | 9350694 | 85.40% | 49.87% |
| | 100000 | 84521.38 | 154.7862 | 13082739 | 84.52% | 52.33% |
| 13 | 1000 | 949.0092 | 50.99072 | 48390.66 | 94.90% | 19.36% |
| | 10000 | 9260.803 | 73.91963 | 684555.1 | 92.61% | 27.38% |
| | 20000 | 18347.32 | 82.63393 | 1516111 | 91.74% | 30.32% |
| | 50000 | 45213.96 | 95.72061 | 4327908 | 90.43% | 34.62% |
| | 75000 | 67339.36 | 102.1419 | 6878169 | 89.79% | 36.68% |
| | 100000 | 89304.76 | 106.9519 | 9551316 | 89.30% | 38.21% |
| 25 | 1000 | 926.3622 | 73.63774 | 68215.21 | 92.64% | 27.29% |
| | 10000 | 8868.883 | 113.1116 | 1003174 | 88.69% | 40.13% |
| | 20000 | 17427.95 | 128.6023 | 2241275 | 87.14% | 44.83% |
| | 50000 | 42386.98 | 152.2601 | 6453849 | 84.77% | 51.63% |
| | 75000 | 62698.66 | 164.0179 | 10283700 | 83.60% | 54.85% |
| | 100000 | 82711.8 | 172.882 | 14299384 | 82.71% | 57.20% |
| 50 | 1000 | 894.0457 | 105.9539 | 94727.61 | 89.40% | 37.89% |
| | 10000 | 8365.023 | 163.4977 | 1367662 | 83.65% | 54.71% |
| | 20000 | 16279.17 | 186.0415 | 3028601 | 81.40% | 60.57% |
| | 50000 | 38980.85 | 220.3831 | 8590718 | 77.96% | 68.73% |
| | 75000 | 57195.01 | 237.3999 | 13578089 | 76.26% | 72.42% |
| | 100000 | 74979.72 | 250.2028 | 18760136 | 74.98% | 75.04% |
| 100 | 1000 | 827.4376 | 172.5624 | 142784.6 | 82.74% | 57.11% |
| | 10000 | 7102.872 | 289.7128 | 2057793 | 71.03% | 82.31% |
| | 20000 | 13264.49 | 336.7755 | 4467155 | 66.32% | 89.34% |
| | 50000 | 29572.06 | 408.5587 | 12081924 | 59.14% | 96.66% |
| | 75000 | 41710.15 | 443.8644 | 18513650 | 55.61% | 98.74% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 100000 | 52979.96 | 470.2004 | 24911198 | 52.98% | 99.64% |
| 150 | 1000 | | | 0 | 0.00% | 0.00% |
| | 10000 | | | 0 | 0.00% | 0.00% |
| | 20000 | | | 0 | 0.00% | 0.00% |
| | 50000 | | | 0 | 0.00% | 0.00% |
| | 75000 | | | 0 | 0.00% | 0.00% |
| | 100000 | | | 0 | 0.00% | 0.00% |
| 200 | 1000 | 702.9547 | 297.045 | 208809.2 | 70.30% | 83.52% |
| | 10000 | 5011.001 | 498.8999 | 2499988 | 50.11% | 100.00% |
| | 20000 | 8520.828 | 573.9586 | 4890603 | 42.60% | 97.81% |
| | 50000 | 16069.61 | 678.6077 | 10904961 | 32.14% | 87.24% |
| | 75000 | 20632.72 | 724.897 | 14956600 | 27.51% | 79.77% |
| | 100000 | 24305.97 | 756.9403 | 18398169 | 24.31% | 73.59% |

**Table 31: Max Power 1000V Arcing Current and Power Results**

| Gap Value | Max Power 1000V | | | | |
|---|---|---|---|---|---|
| | If | Ia (kA) | Va | Pa (Watts) | Ia% |
| 6 | 1000 | 500 | 500 | 250000 | 50.00% |
| | 10000 | 5000 | 500 | 2500000 | 50.00% |
| | 20000 | 10000 | 500 | 5000000 | 50.00% |
| | 50000 | 25000 | 500 | 12500000 | 50.00% |
| | 75000 | 37500 | 500 | 18750000 | 50.00% |
| | 100000 | 50000 | 500 | 25000000 | 50.00% |
| 13 | 1000 | 500 | 500 | 250000 | 50.00% |
| | 10000 | 5000 | 500 | 2500000 | 50.00% |
| | 20000 | 10000 | 500 | 5000000 | 50.00% |
| | 50000 | 25000 | 500 | 12500000 | 50.00% |
| | 75000 | 37500 | 500 | 18750000 | 50.00% |
| | 100000 | 50000 | 500 | 25000000 | 50.00% |
| 25 | 1000 | 500 | 500 | 250000 | 50.00% |
| | 10000 | 5000 | 500 | 2500000 | 50.00% |
| | 20000 | 10000 | 500 | 5000000 | 50.00% |
| | 50000 | 25000 | 500 | 12500000 | 50.00% |
| | 75000 | 37500 | 500 | 18750000 | 50.00% |
| | 100000 | 50000 | 500 | 25000000 | 50.00% |
| 50 | 1000 | 500 | 500 | 250000 | 50.00% |
| | 10000 | 5000 | 500 | 2500000 | 50.00% |

| | | | | | |
|---|---|---|---|---|---|
| | 20000 | 10000 | 500 | 5000000 | 50.00% |
| | 50000 | 25000 | 500 | 12500000 | 50.00% |
| | 75000 | 37500 | 500 | 18750000 | 50.00% |
| | 100000 | 50000 | 500 | 25000000 | 50.00% |
| 100 | 1000 | 500 | 500 | 250000 | 50.00% |
| | 10000 | 5000 | 500 | 2500000 | 50.00% |
| | 20000 | 10000 | 500 | 5000000 | 50.00% |
| | 50000 | 25000 | 500 | 12500000 | 50.00% |
| | 75000 | 37500 | 500 | 18750000 | 50.00% |
| | 100000 | 50000 | 500 | 25000000 | 50.00% |
| 150 | 1000 | 500 | 500 | 250000 | 50.00% |
| | 10000 | 5000 | 500 | 2500000 | 50.00% |
| | 20000 | 10000 | 500 | 5000000 | 50.00% |
| | 50000 | 25000 | 500 | 12500000 | 50.00% |
| | 75000 | 37500 | 500 | 18750000 | 50.00% |
| | 100000 | 50000 | 500 | 25000000 | 50.00% |
| 200 | 1000 | 500 | 500 | 250000 | 50.00% |
| | 10000 | 5000 | 500 | 2500000 | 50.00% |
| | 20000 | 10000 | 500 | 5000000 | 50.00% |
| | 50000 | 25000 | 500 | 12500000 | 50.00% |
| | 75000 | 37500 | 500 | 18750000 | 50.00% |
| | 100000 | 50000 | 500 | 25000000 | 50.00% |
| 250 | 1000 | 500 | 500 | 250000 | 50.00% |
| | 10000 | 5000 | 500 | 2500000 | 50.00% |
| | 20000 | 10000 | 500 | 5000000 | 50.00% |
| | 50000 | 25000 | 500 | 12500000 | 50.00% |
| | 75000 | 37500 | 500 | 18750000 | 50.00% |
| | 100000 | 50000 | 500 | 25000000 | 50.00% |
| 300 | 1000 | 500 | 500 | 250000 | 50.00% |
| | 10000 | 5000 | 500 | 2500000 | 50.00% |
| | 20000 | 10000 | 500 | 5000000 | 50.00% |
| | 50000 | 25000 | 500 | 12500000 | 50.00% |
| | 75000 | 37500 | 500 | 18750000 | 50.00% |
| | 100000 | 50000 | 500 | 25000000 | 50.00% |
| 400 | 1000 | 500 | 500 | 250000 | 50.00% |
| | 10000 | 5000 | 500 | 2500000 | 50.00% |
| | 20000 | 10000 | 500 | 5000000 | 50.00% |
| | 50000 | 25000 | 500 | 12500000 | 50.00% |
| | 75000 | 37500 | 500 | 18750000 | 50.00% |
| | 100000 | 50000 | 500 | 25000000 | 50.00% |

**Table 32: IEEE 1584 AC Arcing Results Open and Boxed 500V**

| Gap Value | IEEE 1584 AC (open) 1000V If | Ia (kA) | Ia % of Ib | IEEE 1584 AC (box) 1000V If | Ia (kA) | Ia % of Ib |
|---|---|---|---|---|---|---|
| 6 | | | | | | |
| 13 | 1000 | | 0.00% | 1000 | | 0.00% |
| | 10000 | 9.705547 | 97.06% | 10000 | 9.705547 | 97.06% |
| | 20000 | 19.1837 | 95.92% | 20000 | 19.1837 | 95.92% |
| | 50000 | 47.21799 | 94.44% | 50000 | 47.21799 | 94.44% |
| | 75000 | 70.34046 | 93.79% | 75000 | 70.34046 | 93.79% |
| | 100000 | 93.32973 | 93.33% | 100000 | 93.32973 | 93.33% |
| 25 | 1000 | | 0.00% | 1000 | | 0.00% |
| | 10000 | 9.705547 | 97.06% | 10000 | 9.705547 | 97.06% |
| | 20000 | 19.1837 | 95.92% | 20000 | 19.1837 | 95.92% |
| | 50000 | 47.21799 | 94.44% | 50000 | 47.21799 | 94.44% |
| | 75000 | 70.34046 | 93.79% | 75000 | 70.34046 | 93.79% |
| | 100000 | 93.32973 | 93.33% | 100000 | 93.32973 | 93.33% |
| 50 | 1000 | | 0.00% | 1000 | | 0.00% |
| | 10000 | 9.705547 | 97.06% | 10000 | 9.705547 | 97.06% |
| | 20000 | 19.1837 | 95.92% | 20000 | 19.1837 | 95.92% |
| | 50000 | 47.21799 | 94.44% | 50000 | 47.21799 | 94.44% |
| | 75000 | 70.34046 | 93.79% | 75000 | 70.34046 | 93.79% |
| | 100000 | 93.32973 | 93.33% | 100000 | 93.32973 | 93.33% |
| 100 | 1000 | | 0.00% | 1000 | | 0.00% |
| | 10000 | 9.705547 | 97.06% | 10000 | 9.705547 | 97.06% |
| | 20000 | 19.1837 | 95.92% | 20000 | 19.1837 | 95.92% |
| | 50000 | 47.21799 | 94.44% | 50000 | 47.21799 | 94.44% |
| | 75000 | 70.34046 | 93.79% | 75000 | 70.34046 | 93.79% |
| | 100000 | 93.32973 | 93.33% | 100000 | 93.32973 | 93.33% |
| 150 | 1000 | | 0.00% | 1000 | | 0.00% |
| | 10000 | 9.705547 | 97.06% | 10000 | 9.705547 | 97.06% |
| | 20000 | 19.1837 | 95.92% | 20000 | 19.1837 | 95.92% |
| | 50000 | 47.21799 | 94.44% | 50000 | 47.21799 | 94.44% |
| | 75000 | 70.34046 | 93.79% | 75000 | 70.34046 | 93.79% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 100000 | 93.32973 | 93.33% | 100000 | 93.32973 | 93.33% |

**Table 33: Stokes/Oppenlander 1500V Arcing Current and Relative Power Results**

| | Stokes 1500V | | | | | |
|---|---|---|---|---|---|---|
| Gap Value | If | Ia | Va | Pa (Watts) | Ia% | Relative Power |
| 6 | 1000 | 964.714 | 52.93 | 51060.99 | 96.47% | 13.62% |
| | 10000 | 9535.492 | 69.68 | 664396.2 | 95.35% | 17.72% |
| | 20000 | 18990.91 | 75.68 | 1437256 | 94.95% | 19.16% |
| | 50000 | 47186.16 | 84.42 | 3983229 | 94.37% | 21.24% |
| | 75000 | 70570.37 | 88.59 | 6252014 | 94.09% | 22.23% |
| | 100000 | 93887.97 | 91.68 | 8607678 | 93.89% | 22.95% |
| 13 | 1000 | 959.0588 | 61.41 | 58897.45 | 95.91% | 15.71% |
| | 10000 | 9461.168 | 80.82 | 764694.5 | 94.61% | 20.39% |
| | 20000 | 18829.56 | 87.78 | 1652916 | 94.15% | 22.04% |
| | 50000 | 46736.62 | 97.90 | 4575579 | 93.47% | 24.40% |
| | 75000 | 69863 | 102.74 | 7177724 | 93.15% | 25.52% |
| | 100000 | 92912.26 | 106.32 | 9878060 | 92.91% | 26.34% |
| 25 | 1000 | 949.3828 | 75.93 | 72082.55 | 94.94% | 19.22% |
| | 10000 | 9334.092 | 99.89 | 932344.8 | 93.34% | 24.86% |
| | 20000 | 18553.74 | 108.47 | 2012514 | 92.77% | 26.83% |
| | 50000 | 45968.47 | 120.95 | 5559696 | 91.94% | 29.65% |
| | 75000 | 68654.48 | 126.91 | 8712946 | 91.54% | 30.98% |
| | 100000 | 91245.53 | 131.32 | 11982097 | 91.25% | 31.95% |
| 50 | 1000 | 929.3023 | 106.05 | 98549.11 | 92.93% | 26.28% |
| | 10000 | 9070.728 | 139.39 | 1264376 | 90.71% | 33.72% |
| | 20000 | 17982.39 | 151.32 | 2721109 | 89.91% | 36.28% |
| | 50000 | 44378.45 | 168.65 | 7484273 | 88.76% | 39.92% |
| | 75000 | 66153.87 | 176.92 | 11704119 | 88.21% | 41.61% |
| | 100000 | 87797.61 | 183.04 | 16070061 | 87.80% | 42.85% |
| 100 | 1000 | 889.4646 | 165.80 | 147475.6 | 88.95% | 39.33% |
| | 10000 | 8549.758 | 217.54 | 1859877 | 85.50% | 49.60% |
| | 20000 | 16853.43 | 235.99 | 3977287 | 84.27% | 53.03% |
| | 50000 | 41241.79 | 262.75 | 10836127 | 82.48% | 57.79% |
| | 75000 | 61224.81 | 275.50 | 16867660 | 81.63% | 59.97% |
| | 100000 | 81005.52 | 284.92 | 23079821 | 81.01% | 61.55% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 150 | 1000 | 850.0738 | 224.89 | 191172.5 | 85.01% | 50.98% |
| | 10000 | 8036.851 | 294.47 | 2366630 | 80.37% | 63.11% |
| | 20000 | 15743.76 | 319.22 | 5025688 | 78.72% | 67.01% |
| | 50000 | 38166.46 | 355.01 | 13549329 | 76.33% | 72.26% |
| | 75000 | 56398.15 | 372.04 | 20982186 | 75.20% | 74.60% |
| | 100000 | 74360.82 | 384.59 | 28598256 | 74.36% | 76.26% |
| 200 | 1000 | 811.1486 | 283.28 | 229779.7 | 81.11% | 61.27% |
| | 10000 | 7532.48 | 370.13 | 2787981 | 75.32% | 74.35% |
| | 20000 | 14654.66 | 400.90 | 5875058 | 73.27% | 78.33% |
| | 50000 | 35157.07 | 445.29 | 15655015 | 70.31% | 83.49% |
| | 75000 | 51682.07 | 466.36 | 24102379 | 68.91% | 85.70% |
| | 100000 | 67875.7 | 481.86 | 32706892 | 67.88% | 87.22% |
| 250 | 1000 | 772.7106 | 340.93 | 263443.4 | 77.27% | 70.25% |
| | 10000 | 7037.182 | 444.42 | 3127483 | 70.37% | 83.40% |
| | 20000 | 13587.55 | 480.93 | 6534710 | 67.94% | 87.13% |
| | 50000 | 32218.83 | 533.44 | 17186651 | 64.44% | 91.66% |
| | 75000 | 47085.8 | 558.28 | 26287248 | 62.78% | 93.47% |
| | 100000 | 61564.14 | 576.54 | 35494048 | 61.56% | 94.65% |
| 300 | 1000 | 734.7822 | 397.83 | 292315.9 | 73.48% | 77.95% |
| | 10000 | 6551.543 | 517.27 | 3388907 | 65.52% | 90.37% |
| | 20000 | 12544 | 559.20 | 7014604 | 62.72% | 93.53% |
| | 50000 | 29357.61 | 619.27 | 18180337 | 58.72% | 96.96% |
| | 75000 | 42619.89 | 647.60 | 27600733 | 56.83% | 98.14% |
| | 100000 | 55442.14 | 668.37 | 37055747 | 55.44% | 98.82% |
| 400 | 1000 | 660.5541 | 509.17 | 336333.6 | 66.06% | 89.69% |
| | 10000 | 5611.916 | 658.21 | 3693834 | 56.12% | 98.50% |
| | 20000 | 10534.86 | 709.89 | 7478544 | 52.67% | 99.71% |
| | 50000 | 23893.68 | 783.19 | 18713281 | 47.79% | 99.80% |
| | 75000 | 34128.8 | 817.42 | 27897700 | 45.51% | 99.19% |
| | 100000 | 43842.36 | 842.36 | 36931252 | 43.84% | 98.48% |

**Table 34: Paukert 1500V Arcing Current and Relative Power Results**

| | Paukert 1500V | | | | | |
|---|---|---|---|---|---|---|
| Gap Value | If | Ia | Va | Pa (Watts) | Ia% | Relative Power |
| 6 | 1000 | 959.8852 | 60.17144 | 57757.68 | 95.99% | 15.40% |
| | 10000 | 9351.504 | 97.27431 | 909661.1 | 93.52% | 24.26% |
| | 20000 | 18502.16 | 112.3378 | 2078493 | 92.51% | 27.71% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 50000 | 45473.04 | 135.8089 | 6175643 | 90.95% | 32.94% |
| | 75000 | 67616.65 | 147.667 | 9984748 | 90.16% | 35.50% |
| | 100000 | 89554.22 | 156.6868 | 14031960 | 89.55% | 37.42% |
| 13 | 1000 | 965.9078 | 51.13763 | 49394.23 | 96.59% | 13.17% |
| | 10000 | 9505.106 | 74.23403 | 705602.3 | 95.05% | 18.82% |
| | 20000 | 18892.93 | 83.02958 | 1568672 | 94.46% | 20.92% |
| | 50000 | 46791.42 | 96.25718 | 4504010 | 93.58% | 24.02% |
| | 75000 | 69862.19 | 102.7561 | 7178765 | 93.15% | 25.52% |
| | 100000 | 92824.8 | 107.628 | 9990548 | 92.82% | 26.64% |
| 25 | 1000 | 950.666 | 74.00096 | 70350.2 | 95.07% | 18.76% |
| | 10000 | 9240.024 | 113.9961 | 1053327 | 92.40% | 28.09% |
| | 20000 | 18269.86 | 129.7603 | 2370703 | 91.35% | 31.61% |
| | 50000 | 44869.47 | 153.9156 | 6906114 | 89.74% | 36.83% |
| | 75000 | 66702.08 | 165.9581 | 11069752 | 88.94% | 39.36% |
| | 100000 | 88329.71 | 175.0541 | 15462480 | 88.33% | 41.23% |
| 50 | 1000 | 928.8388 | 106.7415 | 99145.69 | 92.88% | 26.44% |
| | 10000 | 8896.902 | 165.4647 | 1472123 | 88.97% | 39.26% |
| | 20000 | 17484.82 | 188.6381 | 3298304 | 87.42% | 43.98% |
| | 50000 | 42528.7 | 224.139 | 9532340 | 85.06% | 50.84% |
| | 75000 | 62908.7 | 241.826 | 15212957 | 83.88% | 54.09% |
| | 100000 | 82988.17 | 255.1774 | 21176706 | 82.99% | 56.47% |
| 100 | 1000 | 883.1379 | 175.2931 | 154808 | 88.31% | 41.28% |
| | 10000 | 8011.715 | 298.2428 | 2389436 | 80.12% | 63.72% |
| | 20000 | 15348.9 | 348.8323 | 5354190 | 76.74% | 71.39% |
| | 50000 | 35744.75 | 427.6576 | 15286512 | 71.49% | 81.53% |
| | 75000 | 51635.2 | 467.2959 | 24128921 | 68.85% | 85.79% |
| | 100000 | 66846.81 | 497.2978 | 33242772 | 66.85% | 88.65% |
| 150 | 1000 | | | 0 | 0.00% | 0.00% |
| | 10000 | | | 0 | 0.00% | 0.00% |
| | 20000 | | | 0 | 0.00% | 0.00% |
| | 50000 | | | 0 | 0.00% | 0.00% |
| | 75000 | | | 0 | 0.00% | 0.00% |
| | 100000 | | | 0 | 0.00% | 0.00% |
| 200 | 1000 | 795.4039 | 306.8941 | 244104.7 | 79.54% | 65.09% |
| | 10000 | 6445.447 | 533.1829 | 3436602 | 64.45% | 91.64% |
| | 20000 | 11682.36 | 623.8231 | 7287725 | 58.41% | 97.17% |
| | 50000 | 24669.55 | 759.9131 | 18746718 | 49.34% | 99.98% |
| | 75000 | 33732.49 | 825.35 | 27841110 | 44.98% | 98.99% |
| | 100000 | 41779.44 | 873.3081 | 36486328 | 41.78% | 97.30% |

**Table 35: Max Power 1500V Arcing Current and Power Results**

| | Max Power 1500V | | | | |
|---|---|---|---|---|---|
| Gap Value | If | Ia | Va | Pa (Watts) | Ia% |
| 6 | 1000 | 500 | 750 | 375000 | 50.00% |
| | 10000 | 5000 | 750 | 3750000 | 50.00% |
| | 20000 | 10000 | 750 | 7500000 | 50.00% |
| | 50000 | 25000 | 750 | 18750000 | 50.00% |
| | 75000 | 37500 | 750 | 28125000 | 50.00% |
| | 100000 | 50000 | 750 | 37500000 | 50.00% |
| 13 | 1000 | 500 | 750 | 375000 | 50.00% |
| | 10000 | 5000 | 750 | 3750000 | 50.00% |
| | 20000 | 10000 | 750 | 7500000 | 50.00% |
| | 50000 | 25000 | 750 | 18750000 | 50.00% |
| | 75000 | 37500 | 750 | 28125000 | 50.00% |
| | 100000 | 50000 | 750 | 37500000 | 50.00% |
| 25 | 1000 | 500 | 750 | 375000 | 50.00% |
| | 10000 | 5000 | 750 | 3750000 | 50.00% |
| | 20000 | 10000 | 750 | 7500000 | 50.00% |
| | 50000 | 25000 | 750 | 18750000 | 50.00% |
| | 75000 | 37500 | 750 | 28125000 | 50.00% |
| | 100000 | 50000 | 750 | 37500000 | 50.00% |
| 50 | 1000 | 500 | 750 | 375000 | 50.00% |
| | 10000 | 5000 | 750 | 3750000 | 50.00% |
| | 20000 | 10000 | 750 | 7500000 | 50.00% |
| | 50000 | 25000 | 750 | 18750000 | 50.00% |
| | 75000 | 37500 | 750 | 28125000 | 50.00% |
| | 100000 | 50000 | 750 | 37500000 | 50.00% |
| 100 | 1000 | 500 | 750 | 375000 | 50.00% |
| | 10000 | 5000 | 750 | 3750000 | 50.00% |
| | 20000 | 10000 | 750 | 7500000 | 50.00% |
| | 50000 | 25000 | 750 | 18750000 | 50.00% |
| | 75000 | 37500 | 750 | 28125000 | 50.00% |
| | 100000 | 50000 | 750 | 37500000 | 50.00% |
| 150 | 1000 | 500 | 750 | 375000 | 50.00% |
| | 10000 | 5000 | 750 | 3750000 | 50.00% |
| | 20000 | 10000 | 750 | 7500000 | 50.00% |
| | 50000 | 25000 | 750 | 18750000 | 50.00% |
| | 75000 | 37500 | 750 | 28125000 | 50.00% |

| | | | | | |
|---|---|---|---|---|---|
| | 100000 | 50000 | 750 | 37500000 | 50.00% |
| 200 | 1000 | 500 | 750 | 375000 | 50.00% |
| | 10000 | 5000 | 750 | 3750000 | 50.00% |
| | 20000 | 10000 | 750 | 7500000 | 50.00% |
| | 50000 | 25000 | 750 | 18750000 | 50.00% |
| | 75000 | 37500 | 750 | 28125000 | 50.00% |
| | 100000 | 50000 | 750 | 37500000 | 50.00% |
| 250 | 1000 | 500 | 750 | 375000 | 50.00% |
| | 10000 | 5000 | 750 | 3750000 | 50.00% |
| | 20000 | 10000 | 750 | 7500000 | 50.00% |
| | 50000 | 25000 | 750 | 18750000 | 50.00% |
| | 75000 | 37500 | 750 | 28125000 | 50.00% |
| | 100000 | 50000 | 750 | 37500000 | 50.00% |
| 300 | 1000 | 500 | 750 | 375000 | 50.00% |
| | 10000 | 5000 | 750 | 3750000 | 50.00% |
| | 20000 | 10000 | 750 | 7500000 | 50.00% |
| | 50000 | 25000 | 750 | 18750000 | 50.00% |
| | 75000 | 37500 | 750 | 28125000 | 50.00% |
| | 100000 | 50000 | 750 | 37500000 | 50.00% |
| 400 | 1000 | 500 | 750 | 375000 | 50.00% |
| | 10000 | 5000 | 750 | 3750000 | 50.00% |
| | 20000 | 10000 | 750 | 7500000 | 50.00% |
| | 50000 | 25000 | 750 | 18750000 | 50.00% |
| | 75000 | 37500 | 750 | 28125000 | 50.00% |
| | 100000 | 50000 | 750 | 37500000 | 50.00% |

**Table 36: IEEE 1584 AC Arcing Results Open and Boxed 1500V**

| | IEEE 1584 AC (open) 1500V | | | IEEE 1584 AC (box) 1500V | | |
|---|---|---|---|---|---|---|
| Gap Value | If | Ia (kA) | Ia % of Ib | If | Ia (kA) | Ia % of Ib |
| 6 | | | | | | |
| 13 | 1000 | 1.009299 | 100.93% | 1000 | | 0.00% |
| | 10000 | 9.705547 | 97.06% | 10000 | 9.705547 | 97.06% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 20000 | 19.1837 | 95.92% | 20000 | 19.1837 | 95.92% |
| | 50000 | 47.21799 | 94.44% | 50000 | 47.21799 | 94.44% |
| | 75000 | 70.34046 | 93.79% | 75000 | 70.34046 | 93.79% |
| | 100000 | 93.32973 | 93.33% | 100000 | 93.32973 | 93.33% |
| 25 | 1000 | | 0.00% | 1000 | | 0.00% |
| | 10000 | 9.705547 | 97.06% | 10000 | 9.705547 | 97.06% |
| | 20000 | 19.1837 | 95.92% | 20000 | 19.1837 | 95.92% |
| | 50000 | 47.21799 | 94.44% | 50000 | 47.21799 | 94.44% |
| | 75000 | 70.34046 | 93.79% | 75000 | 70.34046 | 93.79% |
| | 100000 | 93.32973 | 93.33% | 100000 | 93.32973 | 93.33% |
| 50 | 1000 | | 0.00% | 1000 | | 0.00% |
| | 10000 | 9.705547 | 97.06% | 10000 | 9.705547 | 97.06% |
| | 20000 | 19.1837 | 95.92% | 20000 | 19.1837 | 95.92% |
| | 50000 | 47.21799 | 94.44% | 50000 | 47.21799 | 94.44% |
| | 75000 | 70.34046 | 93.79% | 75000 | 70.34046 | 93.79% |
| | 100000 | 93.32973 | 93.33% | 100000 | 93.32973 | 93.33% |
| 100 | 1000 | | 0.00% | 1000 | | 0.00% |
| | 10000 | 9.705547 | 97.06% | 10000 | 9.705547 | 97.06% |
| | 20000 | 19.1837 | 95.92% | 20000 | 19.1837 | 95.92% |
| | 50000 | 47.21799 | 94.44% | 50000 | 47.21799 | 94.44% |
| | 75000 | 70.34046 | 93.79% | 75000 | 70.34046 | 93.79% |
| | 100000 | 93.32973 | 93.33% | 100000 | 93.32973 | 93.33% |
| 150 | 1000 | | 0.00% | 1000 | | 0.00% |
| | 10000 | 9.705547 | 97.06% | 10000 | 9.705547 | 97.06% |
| | 20000 | 19.1837 | 95.92% | 20000 | 19.1837 | 95.92% |
| | 50000 | 47.21799 | 94.44% | 50000 | 47.21799 | 94.44% |
| | 75000 | 70.34046 | 93.79% | 75000 | 70.34046 | 93.79% |
| | 100000 | 93.32973 | 93.33% | 100000 | 93.32973 | 93.33% |

**Table 37: Incident Energy at 2s for All Methods at 125V**

| | | 125V | | | | |
|---|---|---|---|---|---|---|
| | | Stokes | Paukert | MP | Lee | IEEE 1584 |
| Gap Value | If | IE (2s) | IE (2s) | IE (2s) | IE (2s) | IE (2s) Open |
| 6 | 1000 | 0.55 | 0.56 | 0.57 | 0.61 | |
| | 10000 | 5.68 | 5.26 | 5.69 | 6.12 | |
| | 20000 | 11.25 | 9.45 | 11.37 | 12.25 | |
| | 50000 | 27.11 | 18.59 | 28.43 | 30.61 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 75000 | 39.63 | 24.03 | 42.65 | 45.92 | |
| | 100000 | 51.66 | 28.30 | 56.87 | 61.23 | |
| 13 | 1000 | 0.56 | 0.54 | 0.57 | 0.61 | 2.45 |
| | 10000 | 5.52 | 5.67 | 5.69 | 6.12 | 13.74 |
| | 20000 | 10.63 | 11.07 | 11.37 | 12.25 | 23.08 |
| | 50000 | 24.46 | 25.72 | 28.43 | 30.61 | 45.82 |
| | 75000 | 34.87 | 36.63 | 42.65 | 45.92 | 62.06 |
| | 100000 | 44.57 | 46.68 | 56.87 | 61.23 | 76.97 |
| 25 | 1000 | 0.56 | 0.57 | 0.57 | 0.61 | 2.57 |
| | 10000 | 4.80 | 4.54 | 5.69 | 6.12 | 13.14 |
| | 20000 | 8.67 | 7.62 | 11.37 | 12.25 | 21.47 |
| | 50000 | 17.93 | 13.50 | 28.43 | 30.61 | 41.12 |
| | 75000 | 24.10 | 16.57 | 42.65 | 45.92 | 54.82 |
| | 100000 | 29.39 | 18.79 | 56.87 | 61.23 | 67.22 |
| 50 | 1000 | 0.45 | 0.49 | 0.57 | 0.61 | 2.83 |
| | 10000 | 2.45 | 2.28 | 5.69 | 6.12 | 11.97 |
| | 20000 | 3.59 | 3.02 | 11.37 | 12.25 | 18.48 |
| | 50000 | 5.24 | 3.83 | 28.43 | 30.61 | 32.82 |
| | 75000 | 5.91 | 4.09 | 42.65 | 45.92 | 42.32 |
| | 100000 | 6.34 | 4.24 | 56.87 | 61.23 | 50.69 |
| 100 | 1000 | 0.12 | 0.25 | 0.57 | 0.61 | 3.43 |
| | 10000 | 0.18 | 0.45 | 5.69 | 6.12 | 9.94 |
| | 20000 | 0.18 | 0.47 | 11.37 | 12.25 | 13.69 |
| | 50000 | 0.19 | 0.48 | 28.43 | 30.61 | 20.92 |
| | 75000 | 0.19 | 0.49 | 42.65 | 45.92 | 25.23 |
| | 100000 | 0.19 | 0.49 | 56.87 | 61.23 | 28.82 |
| 150 | 1000 | | | 0.57 | 0.61 | 4.15 |
| | 10000 | | | 5.69 | 6.12 | 8.25 |
| | 20000 | | | 11.37 | 12.25 | 10.14 |
| | 50000 | | | 28.43 | 30.61 | 13.33 |
| | 75000 | | | 42.65 | 45.92 | 15.04 |
| | 100000 | | | 56.87 | 61.23 | 16.39 |

**Table 38: Incident Energy at 2s for All Methods at 250V**

| | | 250V | | | | |
|---|---|---|---|---|---|---|
| | | Stokes | Paukert | MP | Lee | IEEE 1584 |
| Gap Value | If | IE (2s) | IE (2s) | IE (2s) | IE (2s) | IE (2s) Open |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6 | 1000 | 0.75 | 0.81 | 1.14 | 1.22 | |
| | 10000 | 8.96 | 10.47 | 11.37 | 12.25 | |
| | 20000 | 18.82 | 21.99 | 22.75 | 24.49 | |
| | 50000 | 49.85 | 56.80 | 56.87 | 61.23 | |
| | 75000 | 76.52 | 85.19 | 85.30 | 91.84 | |
| | 100000 | 103.61 | 112.87 | 113.73 | 122.45 | |
| 13 | 1000 | 0.83 | 0.72 | 1.14 | 1.22 | 2.53 |
| | 10000 | 9.75 | 9.24 | 11.37 | 12.25 | 16.85 |
| | 20000 | 20.32 | 19.64 | 22.75 | 24.49 | 29.82 |
| | 50000 | 53.21 | 52.52 | 56.87 | 61.23 | 63.44 |
| | 75000 | 81.21 | 80.73 | 85.30 | 91.84 | 88.61 |
| | 100000 | 109.48 | 109.26 | 113.73 | 122.45 | 112.31 |
| 25 | 1000 | 0.94 | 0.92 | 1.14 | 1.22 | 2.65 |
| | 10000 | 10.72 | 11.07 | 11.37 | 12.25 | 16.11 |
| | 20000 | 22.02 | 22.66 | 22.75 | 24.49 | 27.75 |
| | 50000 | 56.39 | 56.47 | 56.87 | 61.23 | 56.94 |
| | 75000 | 85.08 | 83.30 | 85.30 | 91.84 | 78.26 |
| | 100000 | 113.69 | 109.01 | 113.73 | 122.45 | 98.07 |
| 50 | 1000 | 1.09 | 1.09 | 1.14 | 1.22 | 2.91 |
| | 10000 | 11.36 | 11.13 | 11.37 | 12.25 | 14.68 |
| | 20000 | 22.46 | 21.05 | 22.75 | 24.49 | 23.88 |
| | 50000 | 54.06 | 45.68 | 56.87 | 61.23 | 45.45 |
| | 75000 | 78.96 | 62.36 | 85.30 | 91.84 | 60.42 |
| | 100000 | 102.86 | 76.72 | 113.73 | 122.45 | 73.95 |
| 100 | 1000 | 1.09 | 1.10 | 1.14 | 1.22 | 3.53 |
| | 10000 | 8.52 | 6.54 | 11.37 | 12.25 | 12.18 |
| | 20000 | 14.77 | 9.31 | 22.75 | 24.49 | 17.69 |
| | 50000 | 28.38 | 12.77 | 56.87 | 61.23 | 28.96 |
| | 75000 | 36.65 | 13.99 | 85.30 | 91.84 | 36.02 |
| | 100000 | 43.31 | 14.71 | 113.73 | 122.45 | 42.05 |
| 150 | 1000 | 0.81 | | 1.14 | 1.22 | 4.28 |
| | 10000 | 3.80 | | 11.37 | 12.25 | 10.11 |
| | 20000 | 5.20 | | 22.75 | 24.49 | 13.10 |
| | 50000 | 6.93 | | 56.87 | 61.23 | 18.45 |
| | 75000 | 7.55 | | 85.30 | 91.84 | 21.47 |
| | 100000 | 7.91 | | 113.73 | 122.45 | 23.91 |
| 200 | 1000 | 0.44 | 0.66 | 1.14 | 1.22 | |
| | 10000 | 1.04 | 1.42 | 11.37 | 12.25 | |
| | 20000 | 1.15 | 1.53 | 22.75 | 24.49 | |
| | 50000 | 1.24 | 1.61 | 56.87 | 61.23 | |
| | 75000 | 1.26 | 1.63 | 85.30 | 91.84 | |

| 100000 | 1.27 | 1.64 | 113.73 | 122.45 | |
|---|---|---|---|---|---|

**Table 39: Incident Energy at 2s for All Methods at 500V**

| 500V | | | | |
|---|---|---|---|---|
| Stokes | Paukert | MP | Lee | IEEE 1584 |
| IE (2s) | IE (2s) | IE (2s) | IE (2s) Open | IE (2s) |
| 0.85 | 0.95 | 2.27 | 2.45 | |
| 10.80 | 13.93 | 22.75 | 24.49 | |
| 23.12 | 30.91 | 45.49 | 48.98 | |
| 63.08 | 87.54 | 113.73 | 122.45 | |
| 98.27 | 138.03 | 170.60 | 183.68 | |
| 134.53 | 190.23 | 227.47 | 244.91 | |
| 0.97 | 0.83 | 2.27 | 2.45 | 2.68 |
| 12.19 | 11.34 | 22.75 | 24.49 | 25.33 |
| 26.02 | 24.80 | 45.49 | 48.98 | 49.78 |
| 70.69 | 69.48 | 113.73 | 122.45 | 121.63 |
| 109.88 | 109.37 | 170.60 | 183.68 | 180.61 |
| 150.19 | 150.78 | 227.47 | 244.91 | 239.08 |
| 1.16 | 1.13 | 2.27 | 2.45 | 2.81 |
| 14.35 | 15.65 | 22.75 | 24.49 | 24.22 |
| 30.47 | 34.12 | 45.49 | 48.98 | 46.32 |
| 82.16 | 94.45 | 113.73 | 122.45 | 109.16 |
| 127.23 | 147.44 | 170.60 | 183.68 | 159.52 |
| 173.42 | 201.79 | 227.47 | 244.91 | 208.78 |
| 1.50 | 1.49 | 2.27 | 2.45 | 3.09 |
| 18.00 | 19.62 | 22.75 | 24.49 | 22.07 |
| 37.77 | 41.70 | 45.49 | 48.98 | 39.87 |
| 100.01 | 110.57 | 113.73 | 122.45 | 87.14 |
| 153.49 | 168.63 | 170.60 | 183.68 | 123.16 |
| 207.78 | 226.54 | 227.47 | 244.91 | 157.43 |
| 1.98 | 2.01 | 2.27 | 2.45 | 3.75 |
| 22.10 | 22.69 | 22.75 | 24.49 | 18.32 |
| 45.01 | 43.77 | 45.49 | 48.98 | 29.53 |
| 113.72 | 96.25 | 113.73 | 122.45 | 55.52 |
| 170.39 | 131.47 | 170.60 | 183.68 | 73.42 |
| 226.45 | 161.38 | 227.47 | 244.91 | 89.52 |
| 2.23 | 2.01 | 2.27 | 2.45 | 4.54 |
| 22.52 | 22.69 | 22.75 | 24.49 | 15.21 |

| | | | | |
|---|---|---|---|---|
| 44.01 | 43.77 | 45.49 | 48.98 | 21.87 |
| 103.87 | 96.25 | 113.73 | 122.45 | 35.38 |
| 150.12 | 131.47 | 170.60 | 183.68 | 43.77 |
| 193.93 | 161.38 | 227.47 | 244.91 | 50.90 |
| 2.27 | 2.26 | 2.27 | 2.45 | |
| 20.11 | 15.01 | 22.75 | 24.49 | |
| 37.03 | 22.13 | 45.49 | 48.98 | |
| 79.02 | 31.63 | 113.73 | 122.45 | |
| 108.06 | 35.16 | 170.60 | 183.68 | |
| 133.61 | 37.29 | 227.47 | 244.91 | |
| 2.13 | | 2.27 | 2.45 | |
| 15.86 | | 22.75 | 24.49 | |
| 26.85 | | 45.49 | 48.98 | |
| 49.52 | | 113.73 | 122.45 | |
| 62.56 | | 170.60 | 183.68 | |
| 72.68 | | 227.47 | 244.91 | |
| 1.87 | | 2.27 | 2.45 | |
| 10.97 | | 22.75 | 24.49 | |
| 16.57 | | 45.49 | 48.98 | |
| 25.38 | | 113.73 | 122.45 | |
| 29.26 | | 170.60 | 183.68 | |
| 31.81 | | 227.47 | 244.91 | |
| 1.15 | | 2.27 | 2.45 | |
| 3.52 | | 22.75 | 24.49 | |
| 4.14 | | 45.49 | 48.98 | |
| 4.69 | | 113.73 | 122.45 | |
| 4.83 | | 170.60 | 183.68 | |
| 4.91 | | 227.47 | 244.91 | |

**Table 40: Incident Energy at 2s for All Methods at 1000V**

| 1000V | | | | |
|---|---|---|---|---|
| Stokes | Paukert | MP | Lee | IEEE 1584 |
| IE (2s) | IE (2s) | IE (2s) | IE (2s) Open | IE (2s) |
| 0.91 | 1.02 | 4.55 | 4.90 | |
| 11.76 | 15.88 | 45.49 | 48.98 | |
| 25.38 | 36.02 | 90.99 | 97.96 | |
| 70.09 | 105.85 | 227.47 | 244.75 | |
| 109.82 | 170.16 | 341.20 | 366.21 | |

| | | | | |
|---|---|---|---|---|
| 151.00 | 238.07 | 454.93 | 489.51 | |
| 1.05 | 0.88 | 4.55 | 4.90 | |
| 13.48 | 12.46 | 45.49 | 48.98 | 40.07 |
| 29.05 | 27.59 | 90.99 | 97.96 | 83.69 |
| 80.05 | 78.76 | 227.47 | 244.75 | 221.58 |
| 125.32 | 125.16 | 341.20 | 366.21 | 340.92 |
| 172.20 | 173.81 | 454.93 | 489.51 | 462.83 |
| 1.27 | 1.24 | 4.55 | 4.90 | |
| 16.30 | 18.25 | 45.49 | 48.98 | 41.30 |
| 35.05 | 40.79 | 90.99 | 97.96 | 86.27 |
| 96.29 | 117.44 | 227.47 | 244.75 | 228.42 |
| 150.50 | 187.13 | 341.20 | 366.21 | 351.44 |
| 206.56 | 260.21 | 454.93 | 489.51 | 477.11 |
| 1.72 | 1.72 | 4.55 | 4.90 | |
| 21.72 | 24.89 | 45.49 | 48.98 | 44.00 |
| 46.48 | 55.11 | 90.99 | 97.96 | 91.91 |
| 126.79 | 156.33 | 227.47 | 244.75 | 243.35 |
| 197.48 | 247.08 | 341.20 | 366.21 | 374.42 |
| 270.34 | 341.38 | 454.93 | 489.51 | 508.30 |
| 2.50 | 2.60 | 4.55 | 4.90 | |
| 30.74 | 37.45 | 45.49 | 48.98 | |
| 65.11 | 81.29 | 90.99 | 97.96 | |
| 174.78 | 219.86 | 227.47 | 244.75 | |
| 270.10 | 336.90 | 341.20 | 366.21 | |
| 367.56 | 453.32 | 454.93 | 489.51 | |
| 3.15 | 2.60 | 4.55 | 4.90 | |
| 37.48 | 37.45 | 45.49 | 48.98 | |
| 78.39 | 81.29 | 90.99 | 97.96 | |
| 206.54 | 219.86 | 227.47 | 244.75 | |
| 316.17 | 336.90 | 341.20 | 366.21 | |
| 427.19 | 453.32 | 454.93 | 489.51 | |
| 3.66 | 3.80 | 4.55 | 4.90 | |
| 42.07 | 45.49 | 45.49 | 48.98 | |
| 86.74 | 89.00 | 90.99 | 97.96 | |
| 223.48 | 198.44 | 227.47 | 244.75 | |
| 338.25 | 272.17 | 341.20 | 366.21 | |
| 453.07 | 334.80 | 454.93 | 489.51 | |
| 4.05 | | 4.55 | 4.90 | |
| 44.68 | | 45.49 | 48.98 | |
| 90.59 | | 90.99 | 97.96 | |
| 227.25 | | 227.47 | 244.75 | |

| | | | | |
|---|---|---|---|---|
| 339.22 | | 341.20 | 366.21 | |
| 449.51 | | 454.93 | 489.51 | |
| 4.33 | | 4.55 | 4.90 | |
| 45.49 | | 45.49 | 48.98 | |
| 90.43 | | 90.99 | 97.96 | |
| 219.65 | | 227.47 | 244.75 | |
| 322.34 | | 341.20 | 366.21 | |
| 421.49 | | 454.93 | 489.51 | |
| 4.55 | | 4.55 | 4.90 | |
| 42.57 | | 45.49 | 48.98 | |
| 80.35 | | 90.99 | 97.96 | |
| 178.91 | | 227.47 | 244.75 | |
| 250.47 | | 341.20 | 366.21 | |
| 315.50 | | 454.93 | 489.51 | |

**Table 41: Incident Energy at 2s for All Methods at 1500V**

| 1500V | | | | |
|---|---|---|---|---|
| Stokes | Paukert | MP | Lee | IEEE 1584 |
| IE (2s) | IE (2s) | IE (2s) | IE (2s) Open | IE (2s) |
| 0.93 | 1.05 | 6.82 | 7.35 | |
| 12.09 | 16.55 | 68.24 | 73.47 | |
| 26.15 | 37.82 | 136.48 | 146.95 | |
| 72.48 | 112.38 | 341.20 | 367.36 | |
| 113.77 | 181.69 | 511.80 | 551.05 | |
| 156.64 | 255.34 | 682.40 | 734.73 | |
| 1.07 | 0.90 | 6.82 | 7.35 | |
| 13.92 | 12.84 | 68.24 | 73.47 | |
| 30.08 | 28.55 | 136.48 | 146.95 | |
| 83.26 | 81.96 | 341.20 | 367.36 | |
| 130.61 | 130.63 | 511.80 | 551.05 | |
| 179.75 | 181.80 | 682.40 | 734.73 | |
| 1.31 | 1.28 | 6.82 | 7.35 | |
| 16.97 | 19.17 | 68.24 | 73.47 | |
| 36.62 | 43.14 | 136.48 | 146.95 | |
| 101.17 | 125.67 | 341.20 | 367.36 | |
| 158.55 | 201.44 | 511.80 | 551.05 | |
| 218.04 | 281.37 | 682.40 | 734.73 | |

| | | | | |
|---|---|---|---|---|
| 1.79 | 1.80 | 6.82 | 7.35 | |
| 23.01 | 26.79 | 68.24 | 73.47 | |
| 49.52 | 60.02 | 136.48 | 146.95 | |
| 136.19 | 173.46 | 341.20 | 367.36 | |
| 212.98 | 276.83 | 511.80 | 551.05 | |
| 292.43 | 385.36 | 682.40 | 734.73 | |
| 2.68 | 2.82 | 6.82 | 7.35 | 2.88 |
| 33.84 | 43.48 | 68.24 | 73.47 | 33.30 |
| 72.38 | 97.43 | 136.48 | 146.95 | 69.55 |
| 197.19 | 278.17 | 341.20 | 367.36 | 184.14 |
| 306.94 | 439.08 | 511.80 | 551.05 | 283.31 |
| 419.99 | 604.93 | 682.40 | 734.73 | 384.62 |
| 3.48 | 2.82 | 6.82 | 7.35 | |
| 43.07 | 43.48 | 68.24 | 73.47 | |
| 91.45 | 97.43 | 136.48 | 146.95 | |
| 246.56 | 278.17 | 341.20 | 367.36 | |
| 381.82 | 439.08 | 511.80 | 551.05 | |
| 520.41 | 604.93 | 682.40 | 734.73 | |
| 4.18 | 4.44 | 6.82 | 7.35 | |
| 50.73 | 62.54 | 68.24 | 73.47 | |
| 106.91 | 132.62 | 136.48 | 146.95 | |
| 284.88 | 341.14 | 341.20 | 367.36 | |
| 438.60 | 506.63 | 511.80 | 551.05 | |
| 595.18 | 663.95 | 682.40 | 734.73 | |
| 4.79 | | 6.82 | 7.35 | |
| 56.91 | | 68.24 | 73.47 | |
| 118.91 | | 136.48 | 146.95 | |
| 312.75 | | 341.20 | 367.36 | |
| 478.36 | | 511.80 | 551.05 | |
| 645.89 | | 682.40 | 734.73 | |
| 5.32 | | 6.82 | 7.35 | |
| 61.67 | | 68.24 | 73.47 | |
| 127.65 | | 136.48 | 146.95 | |
| 330.83 | | 341.20 | 367.36 | |
| 502.26 | | 511.80 | 551.05 | |
| 674.31 | | 682.40 | 734.73 | |
| 6.12 | | 6.82 | 7.35 | |
| 67.22 | | 68.24 | 73.47 | |
| 136.09 | | 136.48 | 146.95 | |
| 340.53 | | 341.20 | 367.36 | |
| 507.66 | | 511.80 | 551.05 | |

| | | | | |
|---|---|---|---|---|
| 672.05 | | 682.40 | 734.73 | |

**Table 42: Stokes/Oppenlander Incident Energy Results in Open Air at Various Times**

| | | Stokes 250V | | | |
|---|---|---|---|---|---|
| Gap Value | | IE (0.5s) | IE (1s) | IE (1.5s) | IE (2s) |
| 13 | 1000 | 0.31 | 0.63 | 0.94 | 1.26 |
| | 10000 | 3.71 | 7.43 | 11.14 | 14.85 |
| | 20000 | 7.74 | 15.47 | 23.21 | 30.95 |
| | 50000 | 20.26 | 40.52 | 60.79 | 81.05 |
| | 75000 | 30.92 | 61.85 | 92.77 | 123.69 |
| | 100000 | 41.68 | 83.37 | 125.05 | 166.74 |