An Empirically Derived Arc Flash Discharge Energy Model and Comparison to Established Safety Codes

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ABSTRACT. Arc flash is a constant hazard when discussing industrial safety, however, little is known about the arc flash. Current safety standards require the use of the NFPA 70E equation to establish safety limits for arc flash hazards. However, when compared to an empirically derived model, these safety limits are much too low to account for all working conditions. A comparison of these two methods will lead to the conclusion that arc flash safety distances must be increased.

1. Introduction. In industrial electrical safety, arc flash hazards can be some of the most disastrous and deadly accidents in the work place. An arc flash can reach temperatures of over 35000 deg*C* and cause an explosion with a blast force of 2000 psi and an audible report of over 140 decibels. At a current of just 0.5 Amps, an electrical shock, such as the shock generated from an arc flash, will stop the heart of an adult. [1]. Current arc flash safety codes require that the worker be at a distance that, if an arc flash were to occur, would only result in 2nd degree burns. The current accepted standard for arc flash energy calculations is given by the NFPA 70E equation, which was derived experimentally. However, an empirical approach to determining arc energy will be derived in this paper and the results compared and examined.

2. Methods. In analyzing the safety limits for arc flashes, two methods will be used. The first is the well-known NFPA 70E equation for calculating arc flash energy. The second method is an expression derived from Paschen's law.

2.1. The NFPA 70E Equation. Current safety limits require that a worker be at a distance that is at least far enough away from the arc flash hazard to produce only 2nd degree burns if an arc flash is initiated. To calculate this the NFPA 70E equation for a cubic box must be considered. This equation gives the arc energy, E_{MB} as

$$E_{MB} = 1038.7 D_B^{-1.4738} t_A [0.0093F^2 + 0.3453F + 5.9673], \tag{1}$$

where E_{MB} – is the arc flash energy in *cal/cm*^{2};

D_B – is the working distance in inches and F is the short circuit, in amps.

Fig. (1) below shows the arc energy as a function of distance from the hazard [2].

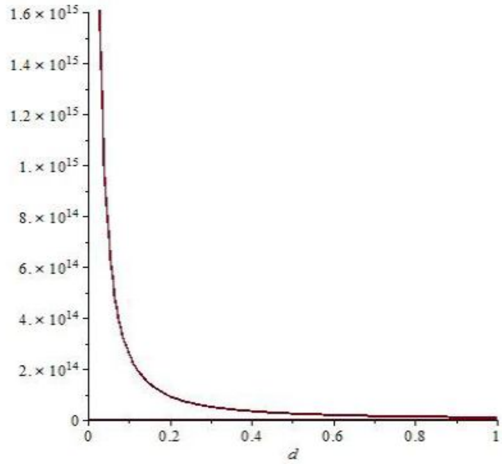

Fig. 1. Arc Energy with respect to distance

In accordance with Eq. (1) a worker would have to be 0.52 meters away from the potential hazard to only receive a 2nd degree burn.

2.2. Paschen's Law. While NFPA 70E provides a convenient experimentally derived equation for calculating arc energy, a more empirical approach by applying the well-known Paschen's law can be developed. The breakdown voltage, VB or the minimum voltage required to discharge an electric arc between two electrodes, is described by Paschen's Law, named after the Friedrich Paschen in the 19-th Century. This relationship is a function only of the pressure, p and the gap distance, d. and the gap distance. In this system, a human and an electrical breaker box are modeled as two cathodes. Paschen's law is given as [3]

$$V_B = \frac{BpD_B}{ln(APD_B) - ln[ln(1+\frac{1}{\gamma_{se}})]} , \tag{2}$$

where the experimental constants *A* and *B* are determined experimentally.

For air at atmospheric pressure, the breakdown voltage as a function of gap distance is shown below in Fig. (2).

It can be shown that the electrical power *P* could be written as follows:

$$P = VI , \tag{3}$$

where V – is voltage;

i – is the electrical current.

Combing Eqs. (2 - 3) yields the following expression for the electrical power generated in an electric arc at the breakdown voltage, P_{EA}, such that

$$P_{EA} = \frac{BpD_B}{ln(APD_B) - ln[ln(1+\frac{1}{\gamma_{se}})]} I \qquad (4)$$

Finally, to calculate the total energy from the electric arc over a sustained time period, E_{EA} the product of the electric power and the total time that the arc is sustained, t_A must be taken such that

$$E_{EA} = \frac{BpD_B}{ln(APD_B) - ln[ln(1+\frac{1}{\gamma_{se}})]} It_A \qquad (5)$$

This expression, when the theoretical constants for A, B and γ_{se} are substituted in depends solely on the distance from the arc flash hazard. Because in the segment of the Paschen curve, the breakdown voltage increases with distance, at the same current and same discharge time – the arc will require a greater potential difference to initiate. Thus increasing the total output energy as distance increases as shown below in Fig. 2. Solving Eq. (5) for the distance from the arc hazard, d, yields the following expression

$$D_B = -0.2300e^{-5}\, E_{EA}\, W(-\frac{0.3813e^{-1}}{E_{EA}}), \qquad (6)$$

where W – is the Lambert W function described as the function, which satisfies:

$$W(z)e^{W(z)} = z \qquad (7)$$

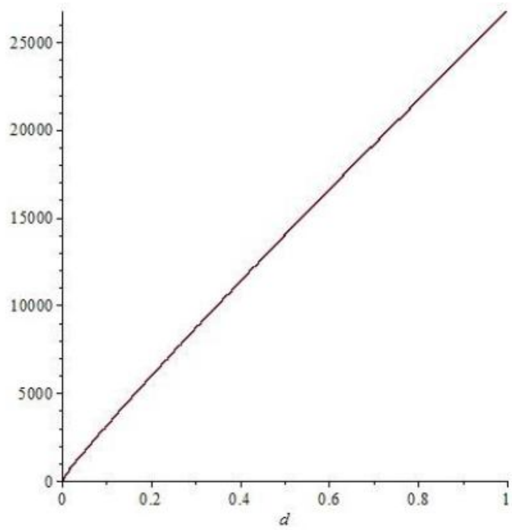

Fig. 2. Output energy based on distance from arc flash hazard

3. Results. In both cases, the current used in the system was 20 Amps. In the case of a short circuit, this would deliver 20 Amps of current to the worker. It is also important to note that the specified ”safe distance” from an arc flash hazard is the distance where a worker would only receive second degree burns as a direct of being hit with an arc. This is calculated to be 2 cal/cm2 of discharge energy. For the NFPA 70 E equation, it was calculated that the "safe distance" from the hazard for a worker was 0.52 meters. This is a very reasonable distance. However, when that same distance of 0.52 meters was used to calculate the arc energy in the Paschen's law derivation, a resulting discharge of 3.46 cal/cm2 was obtained using the following parameters:

Table 1. Arc Discharge Parameters

Parameter	Value
A	112.5
B	2737.5
p	101325 Pa
γSE	1.5
i	20 A

Summary. It is obvious, that this value is much higher and capable of inflicting more than a second-degree burn. There are several reasons for this discrepancy. First, the NFPA 70E standard requires the use of certain protective equipment to reduce the Creative Inquiry risk of the arc flash. Secondly the 70E equation also assumes that the hazard is placed within and electrical box, while this is not always the case. To improve worker health and safety, it is necessary to increase the distance of the worker from the hazard to account for a more general case. Such considerations indicate that the 70E equation indicates and inadequate safe distance for the worker and this distance must be increased to conform the limits set in Eq. (5).

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