IMPACT OF SYSTEM EXPANSION ON SPECIFICATION OF PERSONAL PROTECTIVE EQUIPMENT: ARC FLASH ANALYSIS

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Abstract: Electricity network expansion require the installation of new substations and switchgear equipment. This, in many cases, is intended to cater for electrical energy demand much needed for industrial operations. Such an increase in power available for use by consumers translates in high short circuit capacity or fault level of the network, which in turn causes the arc flash incident energy to be high in case of a fault. In this paper, the impact of network expansion on the arc flash incident energy is assessed using the digsilent software version 15.1. The influence of protective relays time setting on the reduction of arc flash energy, available during three-phase fault conditions, is also analysed for the purpose of PPE specification. The results obtained show that an increase in the short circuit capacity or fault level as well as in the fault clearing time, causes the arc flash incident energy to increase to higher level than the corresponding PPE prescribed.

Key words: Arc Flash Incident Energy, System Expansion, Short Circuit Capacity, Fault Clearing Time, Personal Protective Equipment.

1. INTRODUCTION

The South African industrial and mining sectors require greater demand for electricity as a result of economic growth and expansion [1]. This ultimately imposes the need for the development or upgrading of electricity infrastructure and network capable of conveying high energy demand from supply companies to consumers. However, this increases the risk of exposure to high dissipated arc energy during fault conditions, particularly for consumers with indoor switchgear which places operators in a close proximity to arc flash that may be created during switching.

In this article, an attempt to determine minimum personal protective equipment (PPE), as required for operators in close proximity to MV or LV switchgear, is undertaken on the basis of arc flash hasard analysis. Therefore, the arc incident energy and clearing time obtained by simulating a power network on the digSilent software version 15.1 are used to determine the optimum minimum required PPE. The results obtained indicate that an increase in the short circuit capacity or fault level as well as in the fault clearing time, causes the arc flash incident energy to increase to higher level than the corresponding PPE prescribed.

2. ARC FLASH ANALYSIS

Several contributing factors are usually regarded during arc flash analysis for the purpose required PPE determination:

2.1 Arc Flash Incident Energy

This is the amount of thermal energy which the operator's face and chest could be exposed to, at working distance in case of an electrical arc event [2]. Three-phase fault level analysis is usually relied upon in a bid to estimate the fault current likely to be responsible for arc triggering [3]. The arc flash incident energy in a cubicle box could therefore be calculated on the basis of the following empirical equation:

$$E_i = 1038.7 \times d^{-1.4738} \times t_a \left(aI_F^2 - bI_F + c\right) \qquad (1)$$

Where:

E_i = arc flash incident energy in J/m^2
a = 0.0093
b = 0.3453
c = 5.9675
d = distance between arc electrodes in metres
t_a = arc duration time in second
I_F = fault current in kA

It is worth noting from equation 1 that the distance between the arc electrodes d is a constant parameter, and therefore the arc duration t_a as well as the fault current I_F are the key influencing factors of the arc flash incident energy.

Since system expansion or upgrading is meant to increase the amount of power, this will have no other effect than to increase the short circuit capacity (MVA_F) of the network, and hence the short circuit current (I_F). This could be observed in equation 2 and 3 expressed as follows:

$$MVA_F = \frac{MVA_b}{Z_{pu}} \qquad (2)$$

Where:

MVA_b = base value of system capacity in MVA
Z_{pu} = system impedance in per unit value

The resulting fault current is therefore:

$$I_F = \frac{MVA_F}{\sqrt{3} \cdot V_b} = \frac{I_b}{Z_{pu}} \tag{3}$$

Where:

V_b = base value of system voltage in kV
I_b = base value of system current in kA

2.2 Arc Flash duration Time

The duration of an arc flash could be retrieved from a fault clearing process, as applicable to the conjunctive operation of protective relays and circuit breakers. This process commences with relay tripping command to the instant at which the arc extinction of the short circuit current is completed. The total fault clearing time is therefore the sum of the relay tripping time, the breaker opening time and the arcing time [4]. Figure 1 depicts the total fault clearing time.

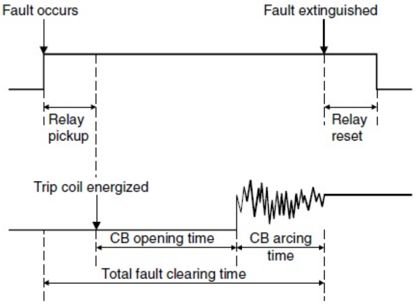

Figure 1: Total clearing time

The two tripping modes of protective relays namely: the isntantaneous and time delay operation, as well as the speed of operation of circuit breakers could either increase or reduce the total fault clearing time. Instantaneous tripping of relays is usually recommended for differential protection of highly critical components such as: transformers, bus bars, feeders...

Protection settings are determined on the basis of the fault level as well as the prospective short circuit current of the network. Therefore, since network expansion increases the system fault level and the prospective short circuit current, the fault clearing time of the protection involved should be adequately selected.

2.3 Arc Flash Boundary and Working Distance

This is the maximum distance at which an operator will be exposed to an arc incident energy. To access the switchgear cubicle, the operator has no other choice than to encroach the arc flash boundary. Therefore, the distance between the arc flash and the body of the operator is normally referred to as the working distance.

Table 1: Classes of equipment and typical working distances (IEEE-1584-2002)

Classes of Equipment	**working distance in mm**
15 kV Switchgear	910
5 kV Switchgear	910
Low voltage switchgear	610
Low voltage MCC and panel boards	455
Cables	455

The relationship between the incident energy and the arc flash boundary D is expressed as follows:

$$E_i = 2.142 \times 10^6 \times V \times I_F \left(\frac{t_a}{D^2} \right) \tag{4}$$

Where:

V = system working voltage in kV
D = distance of the arc flash boundaries in metres

From equation 4, it could be observed that if network expansion could possibly have some influence on the arc flash boundary, but cannot be related to the working distance. Typical working distances based on classes of equipment are given on table 1.

3. PPE CATEGORIES

The five categories of required PPE are specified by the National Fire Protection Association (NFPA) standard 70. Each category corresponds to a determined value of an arc flash incident energy. This is shown in figure 2.

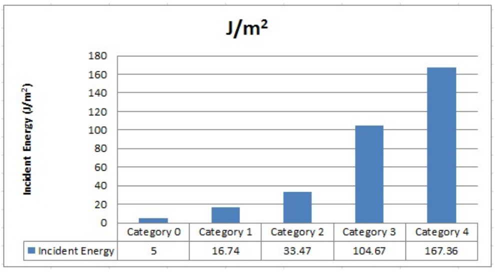

Figure 2: Arc flash incident energy versus PPE Category

As indicated above, expansion on the network will cause the prospective short circuit current to increase, and will therefore yield quite a significant amount of arc flash incident energy which should be cleared as quick as possible. The determination of the required PPE could be expected to vary as the network expands.

4. VARIATIONS OF ARC FLASH ENERGY RATINGS

Arc flash studies have been conducted on a power network built up on version 15.1 of the digsilent software. The applied network consisted of a 100 MVA/11 kV, star-connected and solidly earthed synchronous generator, supplying a 10 MVA, 11/88 kV power transformer with 0.1 pu impedance. The 11kV bus of the network is fed from a 88/11 kV transformer of similar power and p.u impedance ratings. Figure 3 shows the power network under study.

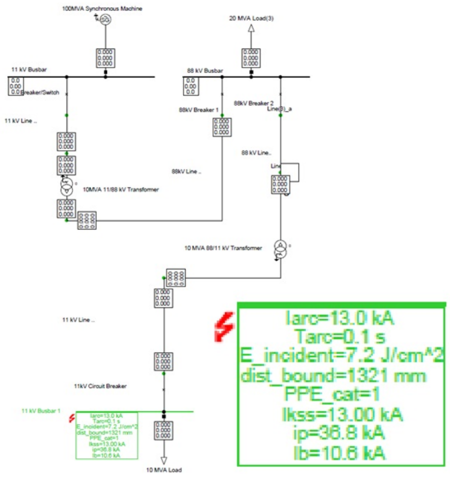

Figure 3: Power network under study

For the purpose of arc flash analysis on the power network depicted on figure 3, a steady state three-phase fault current of 13.00 kA is simulated on the 11 kV downstream bus bar. The fault clearing duration, obtained from the protection setting is taken to be 100 ms. The digsilent fault simulation run of the network points to the incident energy being 7.2 J/cm^2, with an arc flash boundary of 1.321 m. Based on figure 2, the minimum manadatory PPE required will be categoty 1 protection, which is also suggested by the simulation results.

The power network thus far described is now expanded in such a way that a steady state simulated three-phase fault current of 17.70 kA will be measured on the same bus bar under fault conditions. A resulting incident energy of of 10.0 J/cm^2 is obtained with an arc flash boundary of 1.858 m. The required PPE corresponding to this incident energy is still category 1, although the results show 35 % increase in the energy dissipated during the fault. Figure 4 depicts the comparison between the two incident energies, and the expanded power network is depicted in figure 5.

Figure 5 implies that the expansion of the network has lead to the increase of the incident energy, which did not necessarily required a change in the PPE category, since the maximum energy required for category 1 of protection has not been exceeded.

However, if the expansion consists of downstream feeders to the 11 kV bus, with graded protection being used. The fault clearing time is taken to be 400 ms with the grading margin of 300 ms. For a simulated three-phase fault of 13.00 kA on the same bus, the incident energy is risen to 28.7 J/cm^2, and the arc flash boundary distance increases to 5.474 m. In this case, the required PPE at the downstream 11 kV bus bar is category 2 of protection.

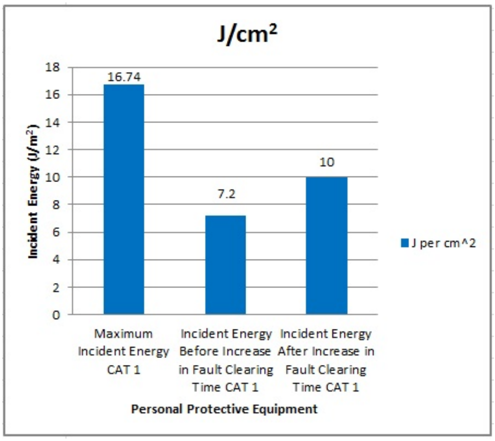

Figure 4: Comparison of Resulting incident energies

The grading margin selected implies that for a 3.4 kA three-phase fault on the downstream substation, the clearing time should be 100 ms. The simulation results point to an incident energy of 1.7 J/cm^2, with the arc flash boundary distance of 0.2 m. The required PPE specification will therefore be of category 0 of protection.

Figure 6 depicts the downstream feeders that form the expansion of the network.

Figure 7 shows the variations of the arc flash incident energy with the protection time grading.

Figure 7 implies that an increase in the fault clearing time causes the arc flash incident energy to increase, and this may lead to changes in the specification of the required PPE.

It could also be noticed that relay grading is significant contributory to the increase of arc flash incident energy since the upstream relays will experience longer fault clearing times, hence larger incident energy, arc flash boundary distance and probably higher category of required PPE as compared to the downstream protective relays.

5. CONCLUSION

The growth in economy imposes the need for industrial development which remains increasingly dependent on the availability of reliable electrical energy. Electricity network expansion is therefore unavoidable for industrial consumers. In such environments, employers are required by law to specify PPE requirements to employees or operators in a bid to adequately reinforce potential risk

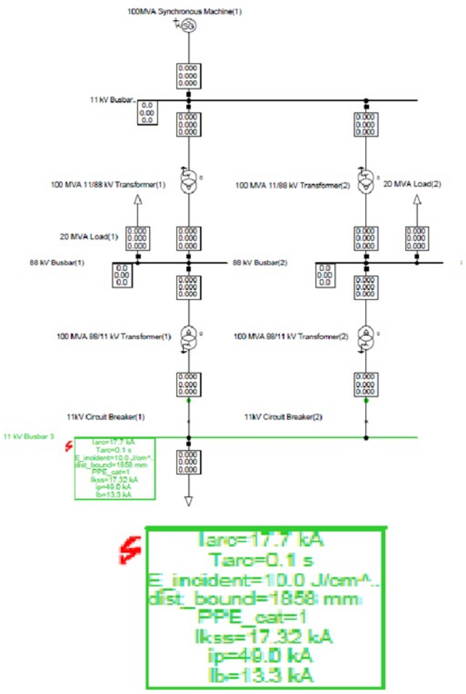

Figure 5: Expanded power network

prevention of arcing. Arc flash analysis on a network enable employers to quantify such potential risk of an arc flash. An increase of the network fault level, results in an increase of the incident energy likely to be produced by the arc during fault conditions. Similarly, an increase or delay in the fault clearing time of a relay will also prompt the arc flash incident energy to rise. Since power system expansion usually brings about an increase in the short circuit capacity or fault level, and the resetting of the protective relays. Arc flash analysis should also be conducted to determine whether or not the previously prescribed PPE is still valid with system expansion.

Bus zone and arc protection should be highly recommended over graded protection. This significantly reduces the incident energy level because of instantaneous tripping of protective relays. It is therefore of utmost importance that employers be cleary in tune with the implications of arc flash incident energy related to system expansion for correct prescriptions of required PPE.

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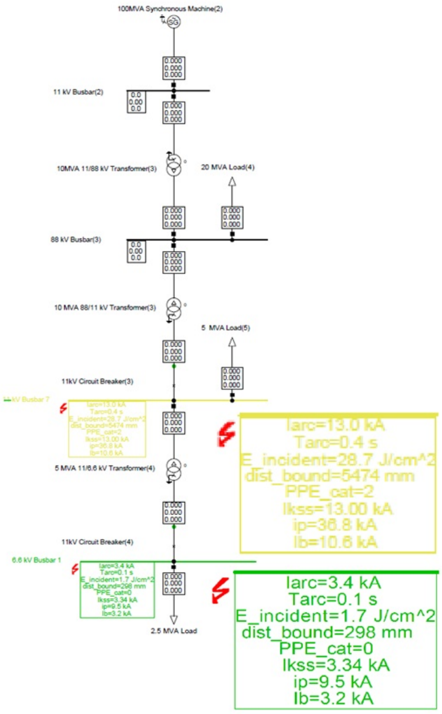

Figure 6: Feeder expansion of the network

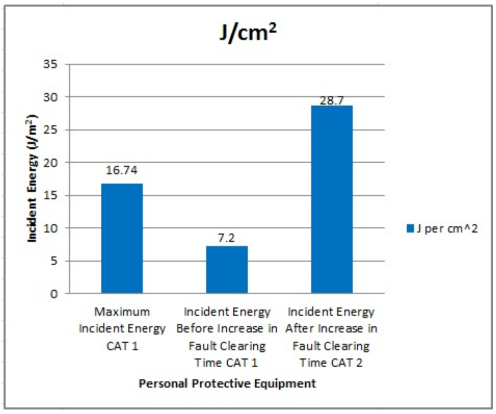

Figure 7: Arc flash incident variations with fault clearing time

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