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# Arc Flash Hazard in Distribution System with Distributed Generation

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**Abstract**

This work presents the arc flash hazard assessment in distribution system including Distributed Generations (DGs). The results demonstrate the impacts of DGs on the incident energy released from arc due to short circuits. The fault current contribution from DGs decreases the arcing time consequently decreases the incident energy. This situation causes the underestimated arc flash hazard. Finally, the circumstances and the parameters should be aware for arc flash assessments are discussed.



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*Keywords:* Arc Flash; Distributed Generation; Overcurrent; Plasma; Protection

## 1. Introduction

Arc occurs when a current passes through air between conductors. The high temperature from arcing can reach 20,000-50,000 K [1]. It causes serious burn of skin and fire. Arc do not only emits heat, but also high pressure particularly for arc in an enclosure. This can cause explosion of switch gear enclosure if the pressure cannot be vented out appropriately. The standards to deal with arc flash assessment are NFPA 70E and IEEE 1584. In the standards, the severity is described in term of incident energy released form arc source. Three phase faults occurred in system are considered to be the source of the highest arc flash hazard [2], [3]. However, the present of DGs changes short circuit

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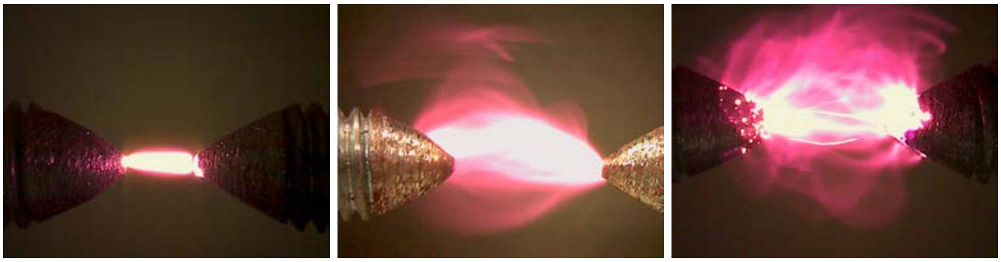
condition of system due to their contribution of fault current. They do not only cause the protective device malfunction, but also the arc flash [4].

This paper presents how DGs impact on arc flash assessment. The studies were carried out on IEEE 34 nodes test system [5]. The protective devices and DGs are deliberately modeled using power system simulation software, DIgSILENT. The arc flash incident energy are calculated and compared with one from the system including DGs. The circumstances and parameters should be concerned are presented and discussed.

## 2. Arc Flash Phenomena

Fig. 1 demonstrates atmospheric air arc flash phenomena observed from the reduced-scale laboratory test. In this work, the direct current voltage of 10 kVdc was supplied to metal electrode tips. The gap between tips was ~ 4 mm, causing the average field strength around ~25 kV/cm that is close to typical breakdown voltage of air (~3x104 V /cm). However, the edge of electrodes concentrate localized electric field up to ~105 V/cm, altering the air-insulator into the conductive path, causing arc flash (Fig 1a). Therefore, gas around electrode is reaching the very high temperature up to several thousand degrees Kelvin known as thermal plasma (Fig 1b: with pink glow color). If the protection system such as circuit breaker does not operate properly, the intense heat from the arc will extend damaged and heated area, resulting in arc flash explosion in a blast (Fig 1c). Therefore, the arc flash hazard assessment has been one of a crucial subject to increase the level of safety for the electrical worker and environment.



(a) (b) (c)

Fig. 1. Arc flash processes. Development of (a) arc flash and (b) thermal plasma between terminals. (c) An intense arc flash explosion.

## 3. Arc Flash Hazard Assessment

In this section, the brief procedures of assessments based on IEEE 1584-2002 are demonstrated. The arcing current ($I_a$) for system voltage under 1 kV can be determined using three phase bolted fault current ($I_{bf}$) as Eq. 1.

$$\log I_a = K + 0.662\log I_{bf} + 0.0966V + 0.000526G + 0.5588V\log I_{bf} - 0.00304\log I_{bf} \quad (1)$$

where $K$ = -0.153 for arc in open air and -0.097 for arc in an enclosure, $G$ is the gap between conductors and $V$ is system voltage. The incident energy ($E$) for a specific working distance ($D$) is as follow.

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

where $C_f$ =1 for system voltage above 1 kV and 1.5 for voltage below 1 kV, $t$ is arcing time, $x$ is the distance exponent and $E_n$ is normalized incident energy which is as a function of $I_a$ as express in Eq. 3.

$$\log E_n = K_1 + K_2 + 1.081\log I_a + 0.0011G \quad (3)$$

For the system voltage above 15 kV, the incident energy can be calculated using Lee's formula as in Eq. 4.

$$E = 2.142 V I_{bf} \left( \frac{t}{D^2} \right) \times 10^6 \tag{4}$$

## 4. System Model and Study Procedures

IEEE 34 nodes test system in Fig. 2 including protective devices and DGs was modeled using DIgSILENT [5], [6]. Main feeder are protect by OC relay and circuit breaker (CB) at substation (node 800). For protection of laterals i.e. 834-842, the fuses are used. MCCB is used for protecting low voltage section 888-890. The DGs are modelled as wind turbine induction generators. For arc flash assessment, the working distances are set as 910 mm. and 455 mm. for medium and low voltage node respectively. The three phase faults are applied on the considered nodes to assess arc flash hazard. The incident energy is then calculated using $I_{bf}$ with the equations in the previous section. The simulation results from the system with and without DG are compared.

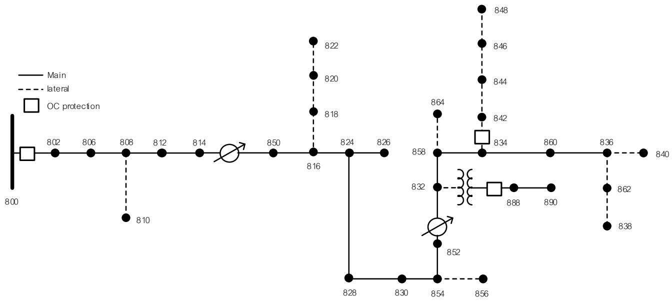



Fig. 2. IEEE 34 Node Test Feeder.

## 5. Results

Case 1: A three phase fault is applied to node 800 to analyze arc flash in MV switchgear. The simulation result is illustrated in Fig. 3 (a) as time-current diagram. Without DG, the fault current is 0.667 kA and fault clearing time is about 2.32 s. The calculated incident energy is 99.67 J/cm$^2$. When a DG is connected at node 828, fault current becomes 0.84 kA and fault clearing time is reduced to 1.49 s. Consequently, the incident energy is decrease to 80.61 J/cm$^2$. The results obviously demonstrate the instinct of inverse time characteristic of OC protection. Increasing the fault current due to present of DG result in decreasing clearing time of OC protective device. Especially for very inverse and extremely inverse characteristic, a small deviation in current could result in a large change in fault clearing time. Under this circumstance, the operators may underestimate the arc flash hazard.

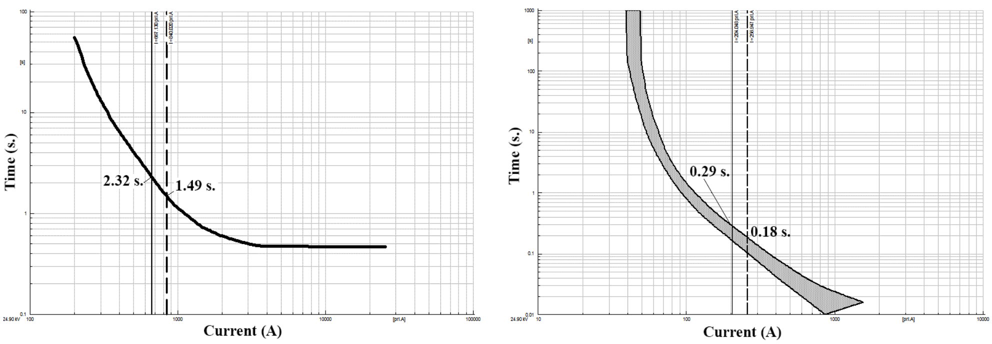



Fig. 3. Time-current diagram a) OC relay at substation b) MV fuse (Dash and solid line mean system with and without DG respectively)

Case 2: Fig. 3 (b) illustrated time-current diagram for the case of fault at node 834 and DG connect at node 828. $I_{bf}$ observed by MV fuse is increased due to fault current contribution from DGs. The incident energy decrease from 4.48 to 3.04 J/cm$^2$. For this case, the present of DG tend to reduce severity of arc flash.

Case 3: Feeder 888-890 is assumed to be protected by a MCCB. The characteristic of MCCB show in Fig. 4. The short circuit current at node 888 is increased from 798.71 A to 1.12 kA when DG is connected at node 828. In contrast to current, the fault clearing time is decreased from 3.49 s. to 0.011 s. Without DG, the calculated incident energy is raised from 0.12 J/cm$^2$ to 29.98 J/cm$^2$. It is because the characteristic of MCCB change to long time inverse when fault current below 1 kA.

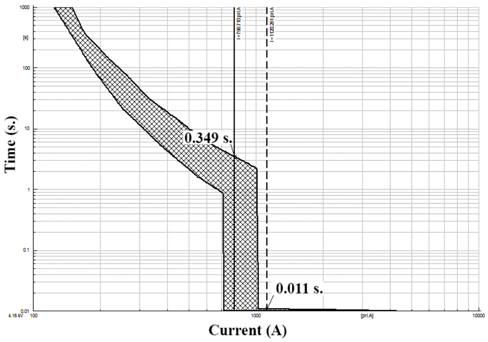



Fig. 4. Time-current diagram of MCCB: Dash line is the fault current with DG and solid line is the fault current without DG.

## 6. Conclusions

This paper demonstrates that the present of DGs not only affects the system performance, but also safety issues. The fault current is higher due to contribution of fault current from DGs, but the arcing time reduces. Due to inverse-time characteristics of overcurrent protective devices, a small change in fault current can cause a much higher incident energy. This situation may mislead the operators in making decision. If an arc flash hazard is underestimated, the tragedy may be occurred.

## Acknowledgement

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