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Risk of electrocution during fire suppression activities involving photovoltaic systems

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ABSTRACT

Firefighting activities regarding buildings normally require electric power to be disconnected before a water jet is used, in order to minimize the risk of electrocution. As for as concerns Photovoltaic Systems, during a fire event it is not possible to turn off the whole power system in order to guarantee that all the components are de-energized. The object of this paper is to estimate the safe distances to respect during firefighting involving PV Systems. To this end a series of experimental tests have been performed, in order to measure the current flowing through the water stream, under different conditions of nozzle design, jet shape, water pressure and stream length. Experimental results have been compared with data in literature. Moreover, the electrical conductivity of the water streams, which actually consists of water mixed with air, has been evaluated.

1. Introduction

Photovoltaic (PV) Systems permit electrical power to be generated by converting solar radiation into electricity. As the use of PV systems proliferates, new electrical hazards to firefighters when they are involved in the mitigation of a fire concerning photovoltaic modules, have arisen [11]. Safe firefighting activities normally require the building's electrical power to be disconnected before water is applied, to prevent risk of electrocution due to water conductivity. During a fire event, turning off the PV System in order to guarantee that all the components are de-energized is difficult. In fact, these systems are live as long as there is light. Therefore, also at night, when illuminated by artificial light sources, such as fire department light trucks or the fire itself, PV systems continue to generate electricity.

At the moment limited data about the hazards associated with the application of water to a PV array during firefighting suppression efforts are available.

The NFPA Fire Protection Handbook [1], as for as concerns firefighting regarding live electrical equipment, recommends the use of water spray streams rather than solid streams, whenever possible. The Handbook lists safe distance values between the nozzle and live electrical equipment, for various nozzle sizes, resulting from studies by several authorities, but all these studies are based on AC high voltages. Furthermore, the Handbook itself says that these safe distance values are not wholly consistent, because the results of different tests vary.

Also IEEE Standard 979–1994 [3], in the presence of energized equipment at high AC voltages, recommends the use only of spray-type nozzles at the minimum distance from the equipment of 3 m, but this Standard just considers solid streams generated by large nozzles (29–38 mm), at high pressures (5–7 bar) and high water flow rates (750–950 l/min).

Other values for the safe distance to electric lines for various high AC voltages are given in an old circular written by the State of Illinois—USA [5], which analyses the influence of different water resistivities on the evaluation of the safety distance. However, this report only considers solid streams generated by just one nozzle of 30 mm.

Three other studies were performed by [6,8] and [12] on the risk of electric shock to fire fighters working next to electrical equipment, especially as regards the use of solid hose streams, used for large fires, near high voltages involved in electrical transmission and distribution. In particular, the influence of pressure and nozzle diameter on stream current and the safe distances to be respected were analyzed.

On the other hand, as for as concerns DC power and voltages, typical of a PV system (600–1000 V), part of the Research Project: 'Firefighter Safety and Photovoltaic Installations' performed by

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Underwriters Laboratories (UL) [7] is dedicated to evaluating, by experimental tests, the safe distances to be respected during firefighting involving PV Systems. The safe distance values of this study are compared with the results of the present work.

Finally, the German Research Project about fire safety regarding PV systems [13,14] ought to be mentioned; part of this project is dedicated to a series of tests with the goal of verifying the requirements from 'VDE 0132' [4] concerning the safety distances to respect during fire fighting where energized systems are concerned, in order to avoid the risk of electrocution. In particular, according to this German Standard, the distances which have to be observed, at low voltage DC (<1.5 kV), are 1 m for a spray jet and 5 m for a full water jet, although both the jets are generated by a particular nozzle which is the multi-purpose branchpipe 'DIN 14365'.

From this literature survey, it transpires that safety distances strongly depend on the type of nozzle, on the pressure and on the water flow rate. Thus, the objective of this work is to determine the safe distances from which a water stream may be directed against PV systems during firefighting and the study focuses on the Italian contest, considering the most common types of nozzles used in Italy.

2. Materials and methods

The electric shock hazard due to application of water is dependent on voltage, distance, water pressure, mass flow rate, conductivity, geometry and dispersion of the suppression stream [1].

As for as concerns water, by nature it is not a good conductor [5], but dissolved minerals and impurities increase its conductivity and their amount vary with location (see Table 1). To this end the resistivity of the water used in the experimental tests has been measured. By applying a voltage at the end points of a pipe full of water and by measuring the current, it has been estimated a resistivity of about 46 Ω m.

The form in which water is used (pattern, droplet size and flow rate) has been also investigated. To this end it has been used the two types of nozzles most diffused in Italy:

- a branchpipe type, whose nozzle diameter is 9 mm and that can produce jets or spray patterns;
- a pistol-grip type whose nozzle is adjustable from a solid stream to a wide fog that is produced with spinning teeth.

The voltage source used in the experimental tests is a DC power supply of 250.5 V. The positive pole of the power supply is connected to the nozzle, while the negative pole to a target, constituted by a 48×48 cm^2 metal square grid, surrounded by a PVC pipe and mounted 1.5 m from ground. Fig. 1 shows the target which has been used for the experimental measures.

Table 1
Typical electrical conductivity and resistivity in Italian waterworks.

Town	Conductivity [μS/cm]	Resistivity [Ω m]
Aosta	400	25.0
Torino	412	24.3
Genova	283	35.3
Milano	602	16.6
Bolzano	300	33.3
Trento	600	16.7
Trieste	344	29.1
Firenze	497	20.1
Perugia	464	21.6
Ancona	525	19.0
L'Aquila	300	33.3
Roma	650	15.4
Napoli	720	13.9
Campobasso	452	22.1
Bari	377	26.5
Potenza	365	27.4
Palermo	791	12.6
Cagliari	335	29.9

Fig. 1. Target used for experimental test.

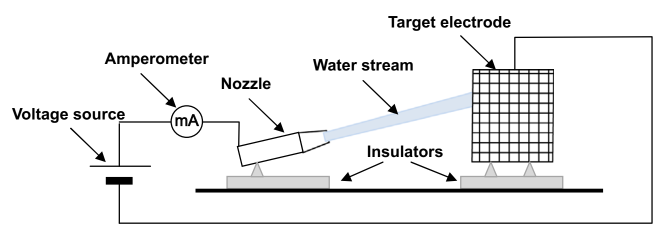

Fig. 2. Experimental set-up.

The current flowing in the circuit (see Fig. 2) has been measured using the two types of nozzle, under different water pressures (1.5, 2, 3, 4, 5, 6 bar) and different distances between the nozzle and the target (60, 90, 120, 150, 180 cm).

First, in order to check the measured values, current values have been measured in two ways: both by an amperometer TEK DMM870 and by a voltmeter Mastech MY65 coupled with a shunt resistance. Percent error between the two kinds of measures never exceeds 3%.

Subsequently the set of experimental measures has been obtained by the voltmeter coupled with the shunt resistance, due to the lower systematic error they provide.

3. Results

3.1. Solid stream: Determination of leakage DC currents through water jets

Tables 2 and 3 show the circulating current and the flow rate values depending on the different distances and pressures for the two types of nozzle (see Figs. 3 and 4).

As far as concerns the 'Pistol-grip' nozzle, the outlet opening is ring-shaped. Thus, an 'equivalent' diameter, of about 16 mm, has been estimated by measuring pressure and flow rate values at the nozzle (see Table 3).

During each experimental test, under the same operating conditions, current values have been measured for about 10 s