Case Studies in Fire Safety 3 (2015) 1–16

Contents lists available at ScienceDirect

Case Studies in Fire Safety

journal homepage: www.elsevier.com/locate/csfs

Safety issues in PV systems: Design choices for a secure fault detection and for preventing fire risk

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ARTICLE INFO

Article history:
Received 6 July 2014
Received in revised form 25 November 2014
Accepted 30 November 2014
Available online 18 December 2014

Keywords:
Electrical faults
Fire risk
International Standards
PV systems
Protection devices
Safety

ABSTRACT

Photovoltaic systems have played a key role over the last decade in the evolution of the electricity sector. In terms of safety design, it's important to consider that a PV plant constitutes a special system of generation, where the Direct Current (DC) presence results in changes to the technical rules. Moreover, if certain electrical faults occur, the plant is a possible source of fire. Choices regarding the grounding of the generator and its protection devices are fundamental for a design that evaluates fire risk. The subject of the article is the analysis of the relation between electrical phenomena in PV systems and the fire risk related to ensuring appropriate fault detection by the electrical protection system. A description of a grid-connected PV system is followed firstly by a comparison of the design solutions provided by International Standards, and secondly by an analysis of electrical phenomena which may trigger a fire. A study of two existing PV systems, where electrical faults have resulted in fires, is then presented. The study highlights the importance of checking all possible failure modes in a PV system design phase, to assess fire risk in advance. Some guidelines for the mitigation of electrical faults that may result in a fire are finally provided.

Introduction

The energy generated by photovoltaic (PV) systems have played a key role over the last decade in the evolution of the electricity sector, offering a unique opportunity for the growth of mixed production of electricity on a large scale [1–3]. The energy produced by PV systems in Europe, which currently amounts to 4% of peak demand on the continent (with 51 GW installed), could reach a maximum of 25% of European demand in 2030, contributing greatly to the reduction of greenhouse gas emissions and decreasing use of fossil fuels [4,5]. The need for specific Standards to provide clear and practical guidelines for the design of safety in a PV system, and to regulate the connection to the public network became mandatory.

Concerning the design of safety, it's particularly important to take into account that a PV plant constitutes a special system of generation in which the presence of Direct Current (DC) results in changes in the application of general technical rules, and the system itself is a possible source of fire should certain electrical faults occur. Choices regarding the layout

Abbreviations: AC, Alternative Current; DC, Direct Current; GFPD, Ground-fault Protection Device; IMD, Insulation Monitoring Device; PV, photovoltaic; RCD, Residual Current Detector; RCM, Residual Current Monitor; SPD, Surge Protection Device.

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http://dx.doi.org/10.1016/j.csfs.2014.11.002
2214-398X/

of the system, the grounding of the negative pole of the DC side and the means of protection are fundamental for the design of a system that accounts for the risk of fire.

The specification for the safe design of a PV system is currently defined by International Standards: NEC 2011 and UL1741 for the countries of North America [6,7]; IEC 60364-7 and IEC 62257-7 for the countries of the European Community [8,9]. To date, the questions relating to the start of a fire in case of electrical failures in PV systems have been solved according to the type of system and through the study of real cases, although some Standards do not refer to the problems, while others have not been updated in relation to the use of the newest protective equipment. The problem of fire in PV systems for electrical faults is therefore still open and worthy of attention.

The subject of this article is the analysis of the relationship between electrical phenomena, that can occur inside of a PV system, and the related means of protection (depending on the system architecture), that can determine the occurrence and development of a fire. For this purpose, in Section “Grid-connected PV systems”, a brief description of the elements of a typical grid-connected PV system is followed by a detailed analysis of the design solutions provided by different International Standards and a comparison of the safety performance of these solutions. In Section “PV power plant: fire risk and safety issues” the authors report on electrical phenomena which may trigger a fire in an electrical system, and set these phenomena in the context of a specific case of a PV plant. Section “Two case studies: fire risk from electrical faults in grounded PV plants” includes the analysis of two case studies of existing PV systems, in which there has been an electrical fault resulting in the development of a fire: this analysis highlights the importance of checking all possible failure modes in a PV system in the design phase, in order to assess the risk of fire in advance. Section “Conclusions” summarizes the conclusions and provides some guidelines for the mitigation of the problems associated with specific electrical faults that may result in a fire.

Grid-connected PV systems

PV systems are distinguished in terms of their working conditions in relation to the grid in stand-alone and grid-connected PV systems. The first systems are not the objective of this paper and so they are not here described. The second systems are the objective of the analysis and so a description of their main components and layout is provided.

The grid-connected PV systems are connected to large independent grids (typically public) and can feed power either directly into a residential or commercial building or back into the grid. Its main components in the DC side and the AC side are represented in Figs. 1 and 2. They are: PV generator, consisting of panels connected together in series/parallel configuration to form strings, that can constitute either one array or multiple sub-arrays; inverter, equipped or unequipped with a high or low frequency transformer; possible storage system (typically electrochemical, as batteries); grounding system; devices protecting against over-current in the DC and AC side; Surge Protection Devices (SPD); interface system to the grid. A PV system can include one or more generators, according to the power produced.

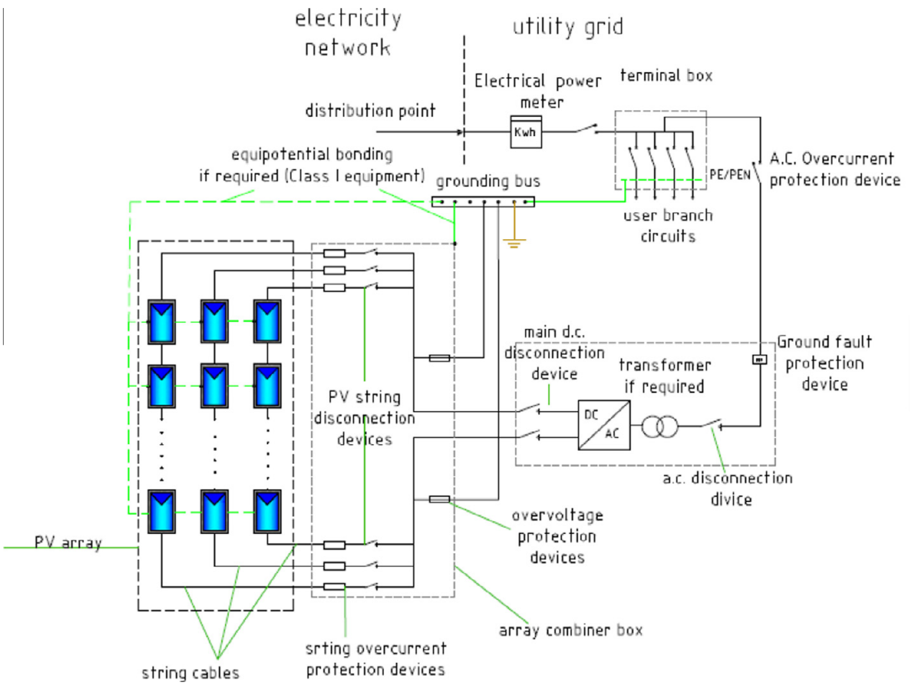

Fig. 1. Typical PV system layout with one array.