Energy 107 (2016) 374–387

Contents lists available at ScienceDirect

Energy

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

Analysis of electrical mismatches in high-concentrator photovoltaic power plants with distributed inverter configurations

P. Rodrigo [a, *], Ramiro Velázquez [a], Eduardo F. Fernández [b], F. Almonacid [b], P.J. Pérez-Higueras [b]

[a] *Universidad Panamericana, campus Aguascalientes, Facultad de Ingeniería, Josemaría Escrivá de Balaguer 101, Aguascalientes, Aguascalientes 20290, Mexico*

[b] *Centre for Advanced Studies in Energy and Environment, Electronic Engineering and Automatic Department, University of Jaén, Las Lagunillas Campus, A3 Building, 23071, Jaén, Spain*

ARTICLE INFO

Article history:
Received 11 September 2015
Received in revised form
5 April 2016
Accepted 8 April 2016
Available online 3 May 2016

Keywords:
Concentrator photovoltaics
Inverter configurations
Module misalignment
Shading

ABSTRACT

Electrical mismatches have a larger impact in high-concentrator photovoltaic power plants than in conventional photovoltaic systems because of the narrow acceptance angles and the unavoidable self-shading between sun trackers. In this paper, a commercial point-focus Fresnel lens-based high-concentrator photovoltaic module is characterized outdoors and results of this characterization are used to develop a power plant model which allows electrical mismatch energy losses to be investigated. Different inverter configurations (micro, string and tracker-oriented inverters) are analyzed with it. This research offers an approach based on energy loss calculation rather than instantaneous power loss calculation as was done in the reviewed literature. Moreover, realistic 28.5 kWp trackers are analyzed rather than small trackers and a novel procedure for obtaining direct normal irradiance daily profiles is presented. From the simulations, it is concluded that micro and string inverters are very useful to minimize mismatch energy losses, reinforcing the conclusions previously published by Kim and Winston (2014). The coefficients obtained in this paper are expected to help in energy yield calculations without the need of using advanced electrical modeling, although it was found that the bigger the capacity of the inverters, the higher the uncertainty to establish electrical mismatch loss coefficients due to shading.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Grid-connected HCPV (high-concentrator photovoltaic) power plants combining dual-axis sun trackers, HCPV modules and inverters are a promising solution to maximize the energy collected from the sun, to increase the conversion efficiency of sunlight to electricity and to reduce the system investment costs [1,2]. Collected energy is maximized by the motion of the trackers following the daily solar path [3,4]. Increased efficiency is achieved by concentrating the light and by using highly efficient multi-junction solar cells [5,6]. Cost reduction is achieved by replacing expensive semiconductor material with cheaper optical devices [7].

HCPV modules mounted in these sun trackers incorporate in assembly optical elements which focus the sunlight onto small solar cells, with light concentration factors usually in the range 300–1200 suns [8]. The typical configuration for HCPV modules is point-focus and includes Fresnel lenses as POEs (primary optical elements) [9] with one lens per multi-junction solar cell. Other elements of the HCPV modules are SOEs (secondary optical elements) for light homogenization and angular acceptance improvement [10], bypass diodes for avoiding cell overheating in partially shaded conditions [11], heat sinks for keeping the solar cells within their operating temperature limits [12] and auxiliary components such as electrical connections and protection elements. These kinds of HCPV modules have reached commercial acceptance [13].

Electrical mismatch effects are present in any photovoltaic system [14]. Electrical mismatch happens when different interconnected solar cells have different electrical behavior at a specific instant. In conventional photovoltaic systems, electrical mismatch is mainly caused by manufacturing tolerances or by the presence of partial shading on the array [15,16]. The coexistence of solar cells with different I–V characteristics at a specific instant distorts the array I–V output. While the MPPT (maximum power point tracking) algorithm tracks the array maximum power, the

---

[*] Corresponding author. Tel.: +52 4499106200x7194; fax: +52 4499106200x7215.
E-mail address: prodrigo@up.edu.mx (P. Rodrigo).

http://dx.doi.org/10.1016/j.energy.2016.04.039
0360-5442/© 2016 Elsevier Ltd. All rights reserved.

Abbreviations

HCPV	high concentrator photovoltaics
POE	primary optical element
SOE	secondary optical element
MPPT	maximum power point tracking
CEAEMA	center for advanced studies in energy and environment
SOG	silicon on glass
WMO	world meteorological organization
AC	alternating current
DNI	direct normal irradiance
AM	air mass

individual solar cells do not operate at their maximum power point under mismatched conditions, resulting in power losses with respect to an ideal electrically matched scenario. This is an important cause of the gap between predicted and measured energy yield in photovoltaic systems operating in the field [17].

HCPV power plants are even more affected by electrical mismatches than conventional photovoltaic systems because of misalignment and self-shading between sun trackers. Misalignment causes relevant effects in HCPV plants because of the narrow acceptance angles of HCPV modules [18]. The main source of misalignment is the imperfect alignment of each module when mounted on the sun tracker [19], which is aggravated because of structural bending of the tracker due to weight. On the other hand, self-shading between sun trackers cannot be avoided in HCPV power plants because the modules must always be pointing to the sun in order for the optical devices to focus the sunlight on the solar cells, i.e. backtracking techniques cannot be implemented [20,21].

Distributed inverter configurations are an effective way of limiting electrical mismatch power losses [22]. A central inverter connects in a single MPPT a large amount of photovoltaic modules, which multiplies the electrical mismatch problem. Distributed inverter configurations use multiple underpowered inverters which track the maximum power points of different module subsets. These configurations can be implemented under various schemes, from high to low inverter power, the commercially available limit being the micro-inverters (or AC (alternating current) modules) [23]. Distributed inverter schemes have been recommended for HCPV power plants in recent studies because of the magnitude of the electrical mismatch losses in these systems [24]. In the present work, micro-inverters, string-inverters and tracker-oriented inverters are studied.

We analyze the electrical mismatches due to module misalignment and shading in HCPV power plants for these distributed inverter configurations. Module misalignment has been identified as the main source of optical mismatch in HCPV plants because the quality control for aligning modules at the time of installation is difficult and expensive [25]. While there are some other possible sources of optical mismatch (non-ideal characteristics of the motion of sun trackers [26], assembly defects in the manufacturing of HCPV modules [27], etc.), these have lower impact on the HCPV system performance and are beyond the scope of this paper. Shading is another important source of mismatch and will also be addressed. The analysis is conducted with the help of an HCPV power plant model developed taking into account previous experimental work carried out at the solar receiver level [28] and at the module level [11]. With this background, an experimental set-up has been used to characterize a commercial point-focus Fresnel lens-based HCPV module and results of this characterization have been incorporated to build the HCPV plant model.

The electrical mismatch problem has been widely analyzed for conventional photovoltaic systems in the literature for decades [29]. However, this problem is inherently different and more complex in HCPV systems because of the special features of this technology, such as the use of optics, the narrow acceptance angles of the modules and the different configuration of the bypass diodes (usually one bypass diode per multi-junction solar cell). Because of these difficulties and because of the novelty of the HCPV technology, the literature on electrical mismatches in HCPV power plants is scarce [24–26,30,31]. Kim et al. published three studies concerning the electrical mismatch issue in HCPV, focusing on the analysis of different inverter configuration schemes [24], optimum tracker allocation on a given land [25] and tracking control strategies to minimize power losses [26]. However, these studies are mainly oriented towards analyzing instantaneous power losses under different operating conditions and not energy losses over a period of time. Moreover, they only analyzed small HCPV sun trackers up to 3 kWp. Segev et al. analyzed silicon vertical multi-junction solar cells-based concentrator modules under non-uniform illumination [30]. In these modules, the solar cells are parallel-connected with voltage matching rather than series-connected with current matching, which allows the reduction of the electrical mismatch power losses. However, this is a rare technology and is not implemented in the typical commercial HCPV plants nowadays. Renzi et al. analyzed the performance of two small 3.5 kWp HCPV systems with typical characteristics [31]. As part of the analysis, they measured and characterized the tracking errors of the systems, but no relation was presented between the tracking errors and the misalignment power losses. However, shading power losses were not investigated in this work.

This research offers several novelties with respect to the studies reviewed. First, the analysis is focused on calculating electrical mismatch energy losses over a period of time (monthly and annual energy losses) instead of only instantaneous power losses. This way, the coefficients obtained in this work are expected to be useful for calculating the energy yield in real HCPV power plants and, in general, for helping in the design of these plants. Second, the analysis is performed under realistic 28.5 kWp HCPV trackers, and not under small trackers. This is relevant concerning the electrical mismatch issue because, as was commented, the more the number of modules connected to a MPPT algorithm, the higher the electrical mismatch losses caused by misalignment and shading. Moreover, the technology analyzed in this paper is a commercial technology so results can be applicable to existing typical HCPV power plants. Third, a novel method is presented to get direct normal irradiance daily profiles from monthly averaged radiation values obtained from meteorological databases. Such a method was not previously found in the literature and makes the methodology presented in this paper applicable to any location worldwide if monthly averaged radiation values are available for the site.

The paper is structured as follows: in Section 2, the characteristics of the HCPV module under study are presented, as well as the equipment used in the experimental set-up; in Section 3, the loss factors calculated by the model (power and energy loss factors) are defined; in Section 4, the developed model is described through several subsections: Subsection 4.1 presents the novel method for obtaining direct normal irradiance daily profiles, Subsection 4.2 presents the formulas for calculating self-shading between sun trackers, Subsection 4.3 explains the solar receiver electrical characterization and Subsection 4.4 describes the analyzed tracker and inverter configurations; in Section 5, a case-study corresponding to a typical plant configuration is analyzed with the help of the developed model; in Section 6, the analysis of results is conducted

Download English Version:

https://daneshyari.com/en/article/1730845

Download Persian Version:

https://daneshyari.com/article/1730845

Daneshyari.com