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Energy assessment of enhanced fixed low concentration photovoltaic systems

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Abstract

In order to exploit as much as possible the surfaces apt for installation of photovoltaic (PV) systems and also to keep the unit energy cost low (without increasing meaningfully capital and operation/maintenance costs), fixed low concentration systems (LCPVs) can be adopted, such systems are normally based on flat mirrors. LCPVs can be either fixed or tracked, but in this paper the fixed solution is investigated as it is a solution that can be largely exploited in urban and suburban contexts, as well as it represents a retrofit of existing PV plant. In order to mitigate the negative effects of partial shadowing of such systems, together with dust soiling and mismatching, this paper proposes an innovative solution for fixed LCPVs based on Distributed Maximum Power Point Tracking (DMPPT) at substring level, here called Enhanced LCPV (E-LCPV).

To evaluate the energy performance improvement of the E-LCPV solution compared with conventional LCPVs, a simulation tool has been developed; it has as input the geographic, geometrical, optical and electrical characteristics of a fixed LCPV system and provides the daily production curves. The novelty of the tool here proposed is its ability to manage non-uniform irradiance conditions on a single PV module, which allows to compare the performance of the system with or without DMPPT at substring level.

Specifically, four cases have been simulated: (a) without reflector and with bypass diode (conventional PV module); (b) without reflector but with DMPPT at the substring level; (c) with reflector and with bypass diode; (d) with reflector and with DMPPT at the substring level (E-LCPV).

Comparative and parametric results are provided and discussed. Referring to Catania (Italy), results show that, in order to have advantages in using a E-LCPV, the PV module/reflector configuration should be accurately optimized in order to increase the power production, otherwise the cost of E-LCPVs can reduce drastically the advantages of using these kind of systems.

Keywords: Photovoltaic systems; Concentration; Distributed Maximum Power Point Tracking; Electrical engineering computing

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1. Introduction

With the public awareness, the need for reducing climate change and an interest in living a greener lifestyle, PV energy appears as a potential solution for the production of clean energy.

A very important feature of PV systems is that, due to their modular structure, incremental power additions can be easily accommodated. In the future, a significant number of PV systems will be installed not only on the roofs of buildings, but also wherever sunlight is available. This great expansion of PV sources especially in urban and suburban areas will allow to produce energy as close as possible to the consumption nodes. In this way, the low density power of solar energy can be really exploited.

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Consequently, it becomes crucial to increase at the same time the yearly PV energy production and the PV power. The first point can be achieved by eliminating the different causes of energy losses. While a planar PV array in an isolated landscape would see uniform insolation, when PV systems are installed in urban and suburban environments, the complex designs and landscapes of PV systems often create situations where PV panels on buildings are reached by non-uniform solar radiation, resulting in decreased system power output (Linares et al., 2009). The cause of non-uniform illumination may be due to the presence of clouds, trees, hills, mountains, buildings neighbor's houses, poles, antennas, or the shadow of one solar array on the other, etc. Moreover, in low-rise buildings, there are no significant problems, but in mixed low- and high-rise areas residents in high-rise buildings some annoying and shading reflection problems may occur. This further leads to nonlinearities in PV panel characteristics.

Whereas the increase of the yearly PV energy production can be obtained by increasing the power density, e.g. using concentration systems.

The impact of PV modules on the cost of the whole systems is decreasing more and more (Feldman et al., 2014; Gaëtan et al., 2014). Consequently, it appears that it is not cost-effective to find solutions to reduce the active PV surface, as it happens in high and medium concentration PV systems. While, LCPVs appear to be a low-cost suitable solution to increase the power density of a PV system. They also offer additional advantages compared with high-concentration systems such as single-axis tracking, reduced sensitivity to tracking errors, reduced sensitivity to changes in the incident spectrum and a larger fraction of diffuse and circumsolar resource capture (Linderman et al., 2011; Yadav et al., 2014).

Furthermore, the elevated concentration ratio put stringent constraints on solar PV cell's heat dissipation capacity (Palaskar and Deshmukh, 2014). At high values of concentration ratio there is a crucial decrease in the PV cell peak power due to high values of temperature and to the Joule effect which rapidly prevails (Kaplanis, 2014).

Low concentration methods include compound parabolic concentrators (Schuetz et al., 2011; Sellami and Mallick, 2013; Ali and Gandhidasan, 2015), V-trough concentrators (Tang and Liu, 2011; Tina and Scandurra, 2012; Bahaidarah et al., 2015) or flat planar concentrators also known as boosters (Tanaka, 2011; Andrews et al., 2011; Pavlović, 2015). In particular, the flat planar concentrators have the advantages of being inexpensive compared to both V-trough and parabolic reflectors (Andrews et al., 2011).

From our perspective on Earth, the sun is always changing its position in the sky, the exact location of the sun in the sky, in fact, depends on where you live, the day of the year and, of course, the time of day. In a fixed LCPV system, this leads to possible alignment issues due to the fixed position of the PV module and mirrors. The easiest solution is to place PV modules and mirrors on a solar tracker, ensuring a constant illumination pattern. Although the tracked LCPVs can harvest more energy, trackers cost more than the fixed tilt structures, therefore their cost can nullify the advantages of using these kinds of LCPVs. Another advantage of a fixed solution is that it can allow the installation of such systems everywhere, in already existing PV plants and also on building flat roof tops or natural and artificial basins. They can be easily attached to sides of commercial PV modules (Palaskar and Deshmukh, 2014). On the other hand, if fixed reflectors for PV modules are used, the increase of cell temperature with increased irradiance is probably the largest drawback and in a real application this has to be treated seriously (Rönnelid et al., 2000). Several different techniques for cooling the modules have been studied by others (Solanki et al., 2008; Tina et al., 2011). Anyhow, in this study, we do not concentrate on the cooling of the modules, but rather on the geometry of the module-reflector combination and on the increase of efficiency that these systems can lead to.

Moreover, although a fixed LCPV system offers a low-cost solution, it introduces irradiance non-uniformity problems. The non-uniform distribution of solar radiation on the surface of conventional crystalline silicon-based fixed LCPV modules causes power lost, due to the presence of bypass diodes. The presence of an uneven radiation in an array wrongly connected, in fact, can nullify the advantages coming from the augmentation of the radiation, since the power–voltage (P–V) characteristic of a PV string with bypass diodes under non-uniform irradiation contains multiple peaks. That means more local maximum points and therefore the optimum point of PV array is shifting far from the local maxima where the conventional controller is used to be operated. In this context, the evaluation of the real increase of yearly energy produced by a LCPV requires a detailed model of the system, especially for the electrical aspects. Different aspects of the modeling of LCPVs has been recently investigated and discussed by many researchers (Yadav et al., 2014; Palaskar and Deshmukh, 2014; Ali and Gandhidasan, 2015; Tang and Liu, 2011; Bahaidarah et al., 2015; Tanaka, 2011; Andrews et al., 2011; Pavlović, 2015; Rönnelid et al., 2000; Alboteanu et al., 2015).

The main problem to deal with when LCPVs are used is that the global maxima is dependent on the array configuration and shading patterns. In order to overcome such a drawback, in the last decades, the efforts to improve PV generation systems have originated many solutions to the power reduction caused by mismatching in the PV modules. Among these, the use of Distributed Maximum Power Point Tracking (DMPPT) DC–DC converters could be a promising technique that allows the increase of efficiency and reliability of the whole system. Using this approach, the concept is that the Maximum Power Point Tracking (MPPT) is calculated for each cell within the module; as a compromise between cost and performance, the approach here used splits a panel into 3 different substrings (Ragonese and Ragusa, 2012). The resulting