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An evolutionary approach to the dynamical reconfiguration of photovoltaic fields

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ABSTRACT

The dynamical reconfiguration of photovoltaic panels is a useful approach for fighting the detrimental effects of mismatching on their power production. The practical implementation of the method has been recently optimized by means of efficient and reliable relays. However, two problems remain still open. The first is to determine the optimal electrical connection among the panels that ensures the maximum power produced at the actual irradiance conditions, while the latter is to constrain the computation time of such optimal configuration to fit the need of real time applications.

We present an evolutionary approach to the first problem. It is designed for allowing a straightforward porting to an embedded system and it is aimed at reconfiguring photovoltaic panels, thus not modules like some other approaches do in literature. Simulation results confirm the reliability and convergence capabilities of the proposed method and encourage further work for the adoption of the algorithm in real time applications. The problem of minimizing the computation time is also addressed.

1. Introduction

The efficiency of a photovoltaic (PV) panel is actually about 15%, but in real applications this figure is even lower because of many reasons. One of the reasons occurring especially in urban context is the mismatched operating conditions at which the panels forming a PV plant work [10]. As some panels are connected in series in order to reach a voltage level that fits with the input specifications of the commercial inverters, the presence of a partial shadowing affecting some cells or other inhomogeneity among the parameters of the cells, e.g., due to aging, failures or manufacturing tolerances, might cause a significant drop in the power production [24]. Producers usually install bypass diodes in the panels for mitigating the power loss in case of mismatching, but these diodes greatly change the voltage vs. current ($V-I$) characteristic of the PV array. When the diodes enter into conduction for compensating a current mismatching among the cells of the string, the voltage vs. power ($V-P$) characteristic of the array shows more than one Maximum Power Point (MPP).

To obtain the MPP, the inverter control system is usually equipped with a Maximum Power Point Tracking (MPPT) algorithm and many methods have been proposed in the literature with the aim to find the MPP, including Fuzzy Logic and Neural Networks [23,29]. Unfortunately, such approaches lack in versatility in that PV panels operate in conditions that vary with time. As a consequence, methods like Neural Networks have to be trained periodically to guarantee an optimal MPP tracking. Moreover, while such methods perform well under uniform irradiance conditions in which only a single MPP is present, partial shading conditions described above cannot be managed by the MPPT algorithm, so that a further power drop might occur [10]. The problem can be solved by a distributed MPPT architecture, but at the price of a power processing that is active also when mismatched conditions do not occur or of an increased plant cost [2,20,31–33].

Dynamical reconfiguration of the electrical connection among the modules reduces the detrimental effect of the mismatching among modules and also allows to implement monitoring, diagnosis and prognosis functions.

Very few are the systems available on the market that allow to dynamically change the series/parallel connection among the panels in order to maximize the power produced by the PV field, as the one described in [34]. In the very recent literature, instead, some methods and techniques have been proposed, this being the confirmation of the interest of the scientific community into an approach that is very promising with respect to the existing ones (e.g. [19,30]). Some recent patents have also appeared (e.g. [26]).

Some algorithms are based on the estimation of the irradiance at which the panels in the PV field work. Such methods are inaccurate, because they cannot take into account the real operating conditions of the panels and also the possibility that some of their sections work differently. Thus, such methods do not allow to

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implement an effective monitoring of the field. Other approaches assume that detailed measurements are periodically performed on each panel. This approach allows to determine more accurately the new configuration to be entered and to collect data on which a diagnostic method for determining the panels state of health can be devised [6]. The drawback is the need of acquiring the electrical data concerning the panels behavior periodically. Nevertheless, the power loss deriving from the above drawback can be greatly reduced by suitably optimizing the measurement process.

The method proposed in this paper aims at maintaining high efficiency of the PV system in any conditions, including partial shading. The reconfiguration procedure has a first step consisting in the acquisition of the $V-I$ characteristic of each panel in the PV field by means of a suitably controlled dc/dc converter. Once such characteristics are available, an optimization procedure determines the new connection among the PV panels ensuring that the maximum power is extracted from the PV field. Finally, a processor controls a set of switches for settling the new electrical configuration of the PV panels. The whole procedure is repeated periodically.

The first step needs few milliseconds per panel, this time having a lower bound depending on the internal capacitance of the cells the panel is made of. The third step depends on the type of relays used, but it is not expensive in terms of time. Instead, the second step, devoted to the computation of the best configuration to enter, might be very time consuming because the number of possible connections among the panels is be very high. The price to pay for a long computation time is that the PV field remains in an electrical configuration that is not the best one for the actual operating conditions of the panels, e.g., for the actual shading pattern affecting the PV field. The computation of the new configuration would not be a prohibitive task for a personal computer, but on-field applications require low costs and, thus, the employment of embedded systems, e.g. micro-controller, digital signal processors or field programmable gate arrays.

We propose the use of an Evolutionary Algorithm (EA) for implementing the second step, i.e., to determine the best configuration of the panels of the PV field. The algorithm has been studied and designed for requiring low amount of memory and computation resources, with a high convergence capability and repeatability, so that it can be implemented on an embedded system almost straightforwardly. The algorithm is validated through the use of $V-I$ characteristics obtained by PV panels physical models. The performances of the algorithm are documented by using a number of different scenarios occurring in real conditions.

To the best of authors' knowledge, EAs have been mainly used either to solve the MPPT problem under partial shading conditions for different PV fields fixed topologies [28,22,8,18] or to design under static conditions large photovoltaic systems as well as hybrid energy systems [13,16], including a number of renewable and classical energy sources, like wind or diesel.

The motivation behind the use of EAs for dynamical reconfiguration of PV fields is that they perform well when the objective function is non-linear, as it occurs to the output characteristic of PV fields when their modules work under mismatched conditions. The problem complexity increases since each energy source has its own operating constraints and no deterministic algorithm could be effectively used to find the optimal solution in practical computation times.

2. Dynamical reconfiguration of photoVoltaic panels

2.1. PV field topology

Before discussing the PV panels reconfiguration process, we have to introduce the PV field topology we refer to. To this aim, we assume that each PV panel is made of a number of cells connected in series. Such cells are divided into a number of groups, named *modules*, each

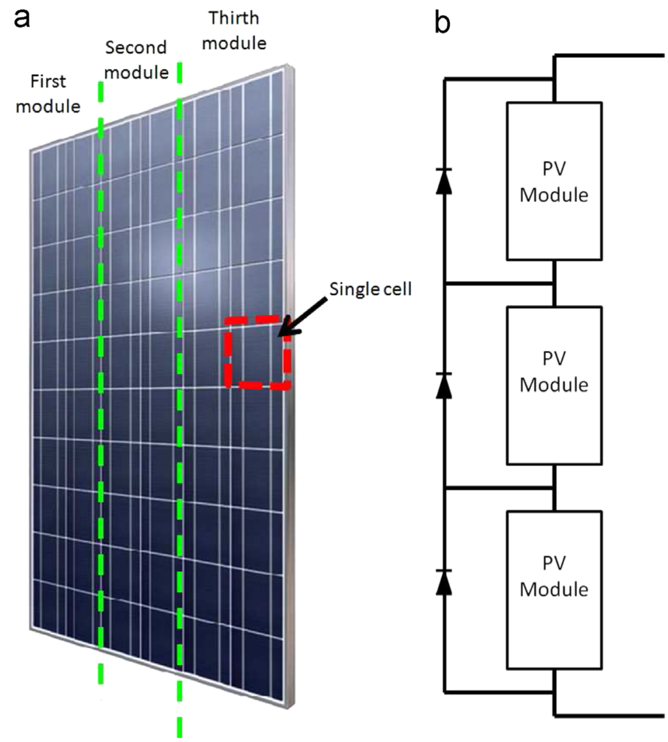

Fig. 1. PV panel: 1(a) reference model and 1(b) its electrical scheme.

one having a bypass diode connected in anti parallel for minimizing the mismatching effects. Although the panels are physically arranged into a matrix, as shown in Fig. 1, the electrical connection among them can be of different types. Here, the electrical topology of the PV field is assumed to be of series–parallel type. In other words, some panels are series-connected, forming *strings*, in order to reach a voltage complying with the inverter input specifications. Then, the PV strings are parallel-connected in order to increase the generated current and meet the inverter specifications in terms of power. As a consequence, a series–parallel topology composed by N_p panels organized into N_s electrically parallel connected strings is considered. Thus, a PV panel belongs to one and only one string or, under particular irradiation conditions, it is disconnected from the PV field. According to the above topology, each arrangement of the panels into the strings represents a configuration of the PV field.

2.2. Photovoltaic panels reconfiguration process

The reconfiguration process adopted takes place periodically during the day and consists of three phases as follows:

1. In the first phase a suitably controlled dc/dc converter allows the acquisition of the $V-I$ characteristic of each panel in the PV field. In particular, to the aim of computing the new electrical configuration to be settled in order to let the PV field produce the maximum power, it is assumed that a shading pattern for each PV panel is given. The shape of the shadow is defined and, by means of a simple and intuitive geometrical algorithm, the irradiance condition for each PV cell of each panel is calculated.

In order to assign a unique irradiance value to each cell, the following assumptions have been done.

The solar irradiance of partially shaded cells G_{cell} has been related to the irradiance received by the non-shadowed cells, to the shading percentage and to the shadow opacity, as follows:

$$G_{cell} = (1 - SO \cdot SP) \cdot G_{max} \quad (1)$$