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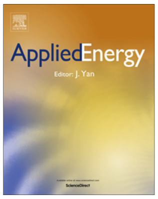

Photovoltaic optimizer boost converters: Temperature influence and electro-thermal design

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HIGHLIGHTS

- The influence of temperature on DC–DC converter devices properties is considered.
- An electro-thermal design method for PV power optimizer converters is proposed.
- The electro-thermal design method proposed is applied to DR boost and SR boost.
- Efficiency results of the designed SR converter and DR converters are presented.

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ABSTRACT

Objective: Photovoltaic (PV) systems can operate in presence of not uniform working conditions caused by continuously changing temperature and irradiance values and mismatching and shadowing phenomena. The more the PV system works in these conditions, the more its energy performances are negatively affected. Distributed Maximum Power Point Tracking (DMPPT) converters are now increasingly used to overcome this problem and to improve PV applications efficiency. A DMPPT system consists in a DC–DC converters equipped with a suitable controller dedicated to the Maximum Power Point Tracking (MPPT) of a single PV module. It is arranged either inside the junction-box or in a separate box close to the PV generator. Many power optimizers are now commercially available. In spite of different adopted DC–DC converter topologies, the shared interests of DMPPT systems designers are the high efficiency and reliability values. It is worth noting that to obtain so high performances converters, electronic components have to be carefully selected between the whole commercial availability and appropriately matched together. In this scenario, an electro-thermal design methodology is proposed and a reliability study by means of the Military Handbook 217F is carried out.
Method: The developed DMPPT converters design method is constituted by many steps. In fact, beginning from installation site, PV generators and load data, this process selects power optimizers commercially available devices and it verifies their electro-thermal behavior to the aim to identify a set of suitable components for DMPPT applications. Repeating this process many times, many different feasible solutions can be found. An elaboration step follows to the "optima" power optimizer recognition among the whole obtained converters. In this case, a multi-objective optimization, consisting in the maximization of the solutions European efficiency and in the minimization of their cost, is executed and all not dominated solutions with respect to at least one of the two objectives are selected. The strength of the described method is represented by accurate PV generators and optimizer devices models. In detail, in the developed models particular attention is reserved to the thermal factor and to the quantification of the temperature action on devices parameters and performances. In fact, in such multiple and continuous changing working conditions, the temperature influence on components behavior can considerably vary their properties causing the whole converter performances worsening. The other important aspect, the converter reliability, is estimated by the reliability prediction model Military Handbook 217F.
Results: The proposed tool is applied to Diode Rectification (DR) boosts and Synchronous (SR) boosts design. To completely characterize the obtained solutions their efficiency, cost and reliability performances are evaluated. In detail, Pareto fronts in terms of European efficiency and cost are identified for the SR and DR cases. Among the whole not dominated solutions, a SR converter characterized by a European efficiency of 97.1% and a DR boost characterized by a European efficiency of 95.5% are chosen.

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Nomenclature

b	empirical coefficient determining the rate that module temperature drops as wind speed increases
c	power optimizer cost in $
G	solar irradiance on module in W/m^2
G_o	reference irradiance, 1000 W/m^2
P_d	MOSfEF dissipated power in Ω
R_{DS}	MOSFET drain–source resistor
$R_{\mathrm{DS\_25°C}}$	MOSFET drain–source resistor at 25 °C
R_L	inductor series equivalent resistance in Ω
$R_{\mathrm{L\_25°C}}$	inductor series equivalent resistance at 25°C in Ω
R_{thja}	MOSFET junction to ambient thermal resistance in Ω
T_1	empirical coefficient determining upper temperature limit at low wind speeds, in °C
T_2	empirical coefficient determining lower temperature limit at high wind speeds, in °C
T_{a}	ambient temperature in °C
T_{cell}	cell temperature in °C
T_{j}	MOSFET junction temperature in °C
T_{r}	inductor temperature rise in °C
T_{t}	back-surface module temperature in °C
T_{L}	inductor temperature in °C
$T_{\mathrm{PV\_MAX}}$	maximum PV module temperaturein °C
V_{th}	MOSFET threshold voltage in V
$V_{\mathrm{th\_25°C}}$	MOSFET threshold voltage at 25 °C
w	MOSFET threshold voltage wind speed measured at standard 10-m height in m/s

Greek letters

α	Temperature coefficient of resistance in °C^{-1}
η_{eu}	European efficiency

Abbreviation

CCM	Continuous Conduction Mode
DCM	Discontinuous Conduction Mode
DMPPT	Distributed Maximum Power Point Tracking
DR	Diode Rectification
MPP	Maximum Power Point
MTBF	Mean Time Between Failure
MPPT	Maximum Power Point Tracking
NOCT	Nominal Operating Cell Temperature
PV	photovoltaic
SR	Synchronous Rectification

Their cost is comparable and equal about to $11. Then their reliability performances are evaluated by means of the Military Handbook 217F Notice 2. The carried out analysis shows that, for the same device cost, the SR solution represents the best one if efficiency is the most critical aspect. DR boost is, instead, the optimum solution if reliability represents the tighter requirement.

Conclusion: The proposed DMPPT converters methodology permits to design families of feasible power optimizers. This process is applied to two boost versions, so two sets of power optimizers are obtained and a trade-off solution is chosen for each set. To correctly select the more suitable optimizer, a characterization in terms of efficiency, cost and reliability is carried out. In detail, the SR optimizer is characterized by lower losses and higher efficiency than the DR one. On the other hand, the DR boost results more reliable than the SR converter. So the optimum solution has to be chosen on the base of the most critical requirement.

Practical implication: The developed method can represent a useful tool to design DMPPT optimizers able to assure high level performances in terms of economical and technical aspects. It can be applied to many commercially available PV generators and, without loss of generality, it can be used with different DC–DC converter topologies.

1. Introduction

In the next future, a great expansion of photovoltaic (PV) sources is predicted especially in urban and suburban areas, in such a way 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. Consequently, it becomes crucial to increase at the same time the PV power and the yearly PV energy production. The former point can be obtained by increasing the power density, e.g. decreasing the pitch in sheds or using concentration system, whereas the latter can be achieved by eliminating the different causes of energy losses. There is a phenomenon that impacts greatly both aspects: it is shading. Shading that is an intrinsic dynamic phenomenon that can vary spatially and with time, it has to be accurately modeled in such a way to evaluate the amount of power losses [1]. This problem could be overcome by means of an automatic reconfiguration of the PV arrays layout by means of an adequate a strategy for the maximization of the output power of PV systems under non homogeneous solar irradiation [2]. In fact, in general PV systems modules can operate in non-uniform conditions of irradiance and temperature. The problem of thermal mismatch has a minimal impact when cells and module series connections are adopted; otherwise the irradiance mismatch has the greatest impact [3–5]. To overcome or, at least, considerably reduce mismatch and shading losses in PV systems, distributed power electronics, such as micro-inverters and DC–DC converters, can be adopted [6–8]. Under partially shaded conditions, the use of distributed power electronics can recover between 10% and 30% of annual performance loss or more depending on the system configuration and type of used devices [3,4]. Of course, when the impact, in terms of duration and extension, of the aforementioned negative phenomena is limited, the use of distributed power electronics does not appear economic. However, additional value-added features may also increase the benefit of using per-panel distributed power electronics. These addition services are mainly related to the development, at the same time, of a distributed monitoring and control system, as well as diagnostics and PV generator reconfiguration features.

A solution to such a problem consists in the use of a MPPT module converter [9–11] carrying out the MPPT for each module (DMPPT). Many DC–DC topologies [9–13] can be adopted (boost, buck, etc.) for DMPPT applications. Among these, the boost converter represents a good trade-off solution between the limited number of devices needed and the achievable performances.