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Development of a dual-tracking technique for extracting maximum power from PV systems under rapidly changing environmental conditions

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ABSTRACT

Maximum power point tracking (MPPT) is the back bone of most photovoltaic (PV) systems. The MPPT technique helps in extracting the maximum power available from a PV panel under varying atmospheric and load conditions. As the environmental conditions fluctuate throughout the day, maximum power point tracker along with the power converter forces the PV panel to deliver maximum power to the load. Performance indices like speed of convergence, accuracy, steady state losses, implementation complexity, cost, etc. determine the overall suitability of a maximum power point tracking technique. Researchers have proposed different techniques to achieve fast and accurate tracking of the maximum power point (MPP). Among these techniques, hill-climbing based algorithms are widely used for commercial and industrial applications. In this paper, the authors have developed an efficient dual-tracking MPPT technique for rapidly changing atmospheric conditions. A comparative performance analysis of several conventional MPPT techniques and this dual-tracking technique has been carried out in Matlab/Simulink environment. Validation of the proposed technique has been done by comparing its energy yield with that of a recent single-tracking technique reported in literature under a typical one-day irradiance profile. The same irradiance profile has been used to show the economic gain of the technique.

1. Introduction

The demand for electric energy is expected to grow continuously with the development of society. Bulk of this demand hitherto is met from coal fired power plants. The adverse environmental effects associated with carbon emissions from fossil fuel based plants are likely to incur severe penalties from national and international regulating bodies [1]. Therefore, for meeting the rising energy demands, the alternative resources, preferably renewable ones will be harnessed to the fullest extent. Solar, apart from wind, is the major option available for such harnessing, due to its abundance across the globe [2]. Photovoltaic (PV) systems provide numerous advantages: clean and free energy, low maintenance cost, long life, suitable for remote locations, etc. Such systems are comprised of series or parallel connected PV modules, which have a combination of series and parallel connected solar cells. Generally, the output dc voltage and current of a PV module are not at the levels required for the load. Hence, a power electronic converter is required as an interface between the load and the PV module. The power electronic converters are known to have efficiency above 90%. However, the efficiency of the PV cell and hence that of the PV module is limited to 20% due to the inherent properties of the semiconductor used. The current vs voltage (I-V) and power vs voltage (P-V) characteristics of PV cell are non-linear in nature and are highly dependent on irradiance and temperature. The maximum power is transferred to the load when the load line intersects the I-V curve of PV module at its maximum power point (MPP). Since, both the environmental conditions and the load demand change throughout the day, the optimum load line, does not necessarily intersect the I-V curve at its MPP, resulting in transfer of less power. The maximum power point tracking (MPPT) algorithm along with a power converter tries to ensure that the system's point of operation remains as close as possible to the MPP of I-V curve. A considerable loss of power occurs if the point of operation is away from the MPP. Hence, to enhance the overall efficiency of a PV system, the use of a highly efficient MPPT algorithm is essential [3].

A large number of MPPT techniques have been proposed for

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Nomenclature

A	diode ideality factor
q	electron charge
G	incident irradiance
R_s	series resistance of the PV cell
G_{ref}	irradiance at STC
R_{sh}	shunt resistance of the PV cell
I_d	diode current
R_{sho}	shunt resistance where I_{pv} is equal to I_{sc}
I_{mpp}	current at maximum power of the cell
R_{so}	series resistance where V_{pv} is equal to V_{oc}
I_o	reverse saturation current of diode
T	temperature of PV cell
I_{ph}	photo current proportional to irradiance G
T_{ref}	temperature of PV cell at STC
I_{pv}	current of PV cell
V_{mpp}	voltage at maximum power of the cell
I_{rsh}	current through the shunt resistance
V_{oc}	open circuit voltage of the PV cell at STC
I_{sc}	short circuit current of PV cell at STC
V_{oct}	open circuit voltage of the PV cell at given G & T
I_{sct}	short circuit current of PV cell at given G & T
V_{th}	thermal voltage of the solar panel having N_s cells
K	Boltzmann's constant
α_{sc}	temperature coefficient of short circuit current
N_s	cells in series
β_{oc}	temperature coefficient of open circuit voltage
P_{mpp}	maximum power of the PV cell
γ_{pmpp}	temperature coefficient of maximum power
$\widetilde{i_{pv}}$	perturbation in the current of PV cell
$\widetilde{v_{pv}}$	perturbation in the voltage of PV cell
$\tilde{d}$	perturbation in the duty cycle
V_{pv}	voltage of PV cell

tracking the MPP of PV systems. Among these, the conventional MPPT techniques: fractional open-circuit voltage (FOCV), fractional-short circuit current (FSCC), perturb and observe (P&O), incremental conductance (INC), etc. are still being widely used due to their ease of implementation and cost benefits. Though, the FOCV and FSCC MPPT techniques [4] are inexpensive and easy to implement, but are less efficient. The hill-climbing based MPPT techniques, P&O and the INC are not only inexpensive and easily implemented, but also have the added advantage of being more efficient as compared to FOCV and FSSC. Other MPPT techniques like sliding mode control [5], ripple correlation control [6] and soft computing [7] have excellent dynamic and steady state response. However, these techniques involve complex computations and thus use complex control circuitry as compared to hill-climbing based MPPT techniques to efficiently track the MPP.

Perturb and observe remains an attractive option among the various techniques just mentioned, due to its good efficiency and low cost implementation. Many researchers have performed theoretical and experimental based comparison of the commonly existing MPPT techniques [8,9], while highlighting the drawbacks of conventional hill-climbing based MPPT techniques. Failure of P&O technique to track MPP under rapidly changing environmental conditions, has been addressed by several researchers, and various improvements have been suggested to hill-climbing based MPPT techniques [10–14]. Zaheeruddin et al. suggested the use of two perturbation step sizes to improve the dynamic and steady state response of the MPPT algorithm [13]. Use of two sensors to measure the change in voltage and current was proposed in Ref. [10] to overcome the drift problem in perturb and observe algorithm for rapid changes of irradiance. A variable current perturbation based P&O algorithm was proposed in Ref. [12] to efficiently track the MPP for varying irradiance. Ahmed and Salam, proposed a dynamic perturbation step size based MPPT technique to reduce the oscillation [15]. In spite of the fact that many efficient MPPT techniques have been proposed earlier, perturb and observe is still widely used due to its ease of implementation and reasonably good efficiency. The existing single-tracking based conventional and modified P&O MPPT techniques involve perturbation of a single parameter. These techniques usually suffer from drawbacks like drift-phenomena, steady state loss, expensive control circuitry, etc. Moreover, these techniques involve complex programming and are non-versatile, i.e. may require modifications for different applications.

In this study, the authors have developed a versatile dual-tracking based MPPT technique, which overcomes the inherent drawbacks of the conventional hill-climbing based MPPT techniques. The developed technique uses inexpensive control circuitry and is easy to implement. A simulation based comparison of the proposed dual-tracking technique with the conventional/modified hill-climbing based MPPT techniques under rapidly changing profiles of irradiance and temperature is presented. In order to validate the MATLAB/Simulink model for real time conditions, the authors have evaluated the performance of the proposed dual-tracking technique by using a one–day (10 h) irradiance profile and also worked out the economic impact of the proposed technique. The rest of the paper is organized as follows: section 2 describes the PV system modeling. Section 3 explains the design and analysis of the boost converter. In section 4, various MPPT algorithms are discussed and the proposed dual-tracking technique has been described in detail. A simulation based comparison between the widely used MPPT techniques and the dual-tracking technique is shown in section 5. Section 6 covers the validation and economic analysis of the dual-tracking technique. Lastly, in section 7 conclusions are drawn based on the results presented in the previous sections.

2. PV system modeling

A single diode equivalent circuit shown in Fig. 1 was used to develop the mathematical model of solar cell. The I_{pv}-V_{pv} characteristics of this model can be formulated by applying Kirchoff's current law (KCL), as given by the following equation:

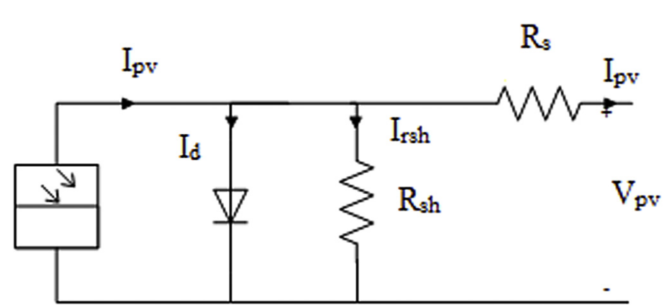

Fig. 1. Equivalent circuit of a solar cell.