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# Efficient MPPT control for PV systems adaptive to fast changing irradiation and partial shading conditions

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**Abstract**

This paper presents a novel high performance controller to track the maximum power point (MPP) of a photovoltaic (PV) module under fast irradiation change and partial shading conditions. A DC–DC boost converter is selected as the power conditioning unit (PCU) to coordinate the operating point of the system with the maximum power point of the PV module. The proposed algorithm uses a scanning technique to determine the maximum power delivering capacity of the panel at a given operating condition and controls the PCU to extract the same from the PV panel. The proposed method is implemented, analyzed and verified in MATLAB/Simulink software. The method proposed is compared with two other methods, perturb and observe (P&O) and incremental conductance (INC) under the same operating conditions. The proposed method is also experimentally verified using an Agilent Technologies E4362A solar array simulator integrated to the grid with the help of a digitally controlled high voltage DC–DC and DC–AC converters. Simulations as well as experimental results are presented for fast change in irradiation and partial shading conditions. The results obtained clearly show that the proposed method is simple to implement with minimum tracking time and high tracking efficiency proving superior to the other two methods.


*Keywords:* Maximum power point tracking; Photovoltaic panel characteristics; Partial shading; Scanning

## 1. Introduction

Power generated using PV technology is increasing, this increase can be witnessed clearly from 100.0 GW production in 2012 to 139.0 GW productions in 2013. The total PV generation is estimated to be 10% of total power generation before 2030 (Renewables Global Status Report, 2014). The impediments faced by this low maintenance, fuel, noise and pollution free system are installation cost and efficiency. The installation cost is going down with improvements in panel fabrication technology and advances in PV physics. The highest efficiency of a commercially available solar panel is about 14–19%. So, the utilization efficiency of a panel should be improved by extracting the maximum power available under all operational conditions dynamically. This can be done by using a maximum power point tracking (MPPT) controller.

There are many MPPT algorithms that have been proposed and compared with the known methods (Esram and Chapman, 2007; Kamarzaman and Tan, 2014). The most widely used are perturb and observe (P&O) and incremental conductance (INC) algorithms (Zegaoui et al., 2011a, 2011b). These algorithms provide

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good results for stable and slow varying irradiation and temperature changes. A major drawback of these algorithms is that the system oscillates about the MPP and fails under partial shading condition, when multiple peaks comes into play. The INC method is a bit more sophisticated and gives a stable MPPT compared to P&O. This algorithm holds well as long as $\Delta P/\Delta V$ provides the accurate measure of the distance from the maximum power point, which is true only for slow changes in irradiation. There is always a trade-off between accuracy and speed for these algorithms, so modifications are made to address these issues (Liu et al., 2014, 2008; Femia et al., 2009; Tey and Mekhilef, 2014). The algorithms based on PV module MPP locus characterization (Scarpa et al., 2009; Liu and Huang, 2011) and single parameter control (Yang and Liu, 2010) made quite an impact in tuning the approach of MPPT in a different direction. These gave satisfactory results based on the constraints imposed on them, but the complexity of the design and implementation proved disadvantageous. Other widely used MPPT techniques are the constant voltage (CV) and constant current (CC) (Masoum et al., 2002; Yu et al., 2004; Lee et al., 2003; Mutoh and Inoue, 2007; Patel and Shireen, 2011). CV and CC are based on the fact that the MPP voltage and MPP current bear approximate linear relationship with open circuit voltage and short circuit current respectively. These methods offer very fast tracking but the linear approximation may result in a slight deviation from the actual MPP. Also there is a power loss when the circuit is short circuited for obtaining the proportionality constant $k$ which is temperature dependent.

PV installation in urban regions led to a new problem called shading. Shading effects are detrimental to efficiency since it diminishes the output power drastically. The shading problem arises due to the presence of clouds, dust, trees or any other obstacle in the path of the sun's irradiation. These obstacles give rise to non-uniform irradiation incidence on the PV panel. Any PV panel exhibits a multiple peak $P$–$V$ curve under non-uniform irradiation condition (Picault et al., 2010). Many algorithms were proposed to find the MPPT under shading condition (Gao et al., 2009; Patel and Agarwal, 2008; Chao, 2014; Anula and Saroj, 2013; Liu et al., 2013; Alajmi et al., 2013; Ouahib et al., 2014; Kimball and Krein, 2008; Zhou et al., 2011; Bidram et al., 2012; Kotti and Shireen, 2012) with the aim to avoid the local maxima of the power while tracking the global maxima corresponding to the irradiation condition.

The power delivered by a non-uniformly shaded PV array at the global maximum is always lower than the sum of individual PV modules maximum power delivering capacity at that particular incidental irradiation (Solar Edge Technologies, 2012). Generally, the solar cells in a PV module are arranged in series and their different series and parallel configuration give rise to the PV system. The connection of PV cells in parallel to overcome the effects of shading proposed in (Gao et al., 2009) is only suitable for low power systems.

In (Patel and Agarwal, 2008) the MPPT method implemented is on the basis of some critical observations of the PV panel characteristics obtained from various experiments. These assumptions may fail under conditions that are different from the experimental conditions. The MPPT methods based on particle swarm optimization (Chao, 2014; Anula and Saroj, 2013) neural network (Liu et al., 2013), fuzzy logic control (Alajmi et al., 2013; Ouahib et al., 2014) ripple correlation control (Kimball and Krein, 2008), stochastic algorithm based on chaos search theory (Zhou et al., 2011) show significant improvement in tracking the global maximum. But the increase in complexity of the algorithm increases the complexity of the digital controller to implement the tracking of the MPP (Bidram et al., 2012).

The method proposed in this paper is an attempt to avoid the constraints or disadvantages posed by the earlier discussed methods. The approximations seen in CV and CC methods does not exist and the power loss in sensing the maximum power is reduced. The fast irradiation, temperature and load change does not affect the efficiency of the algorithm as seen in HCS, P&O and INC and even the global maximum is found under shading conditions through scanning. With the proposed algorithm, the overall constraints mentioned in tracking the global maximum under shading conditions are avoided resulting in an accurate convergence to the MPP. This is achieved with a boost converter circuit and a simple DSP controller without adding any complexity to the PV system. A similar time dependent method is presented in (Kotti and Shireen, 2012) with simulation results only. In this presented paper, the frequency of scanning process is reduced by making it dependent on change in operating conditions like irradiation, load and not on time. The simulation and experimental results provides the practical validation of the proposed controller.

## 2. Modeling of the PV system

The PV system considered comprises of a two stage power conversion model. The DC–DC or the boost converter performs the MPPT and a hysteresis current controlled H-bridge inverter controls the dc link voltage and synchronizes the PV output power with the grid. An equivalent PV model is modeled in SimPowerSystems/MATLAB for simulation. Fig. 1 shows the variation in characteristics of the PV panel considered with change in irradiance, while the temperature is held constant at 25 °C. Table 1 gives the specifications of the solar panel considered and Table 2 gives the specifications of the power converters in the system. The Agilent Technologies E4362A solar array emulator integrated to the grid with the help of a digitally controlled high voltage DC–DC and DC–AC converters is used as the solar panel in the experimental setup.