Solar Energy 173 (2018) 437–448

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Application of modified classical numerical methods for DMPPT on Buck and Boost converters

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ARTICLE INFO

Keywords:
Digital maximum power point (DMPP) tracking (DMPPT)
Classical root-finding algorithms
Photovoltaic (PV)
DC-DC converter topologies

ABSTRACT

Application of Classical Numerical Methods (CNM) for Digital maximum power point tracking (DMPPT) confronts many issues. The issues highlighted in this paper include limited range of operation, PV array dependence and accuracy of the initial guess. In order to address such shortcomings of CNM for DMPPT, Hybrid Techniques (HT) have been proposed. The HT are a combination of the modified incremental conductance method (MINC) and various modified CNM. An overview of the considered MCNM, which are applied to the photovoltaic (PV) application, has also been provided. The HT not only address the issues confronted by the CNM, but also improve the transient response time and remove the steady state oscillations for the conventional MPPT technique. In addition, for DMPPT the DC-DC converter topology under consideration cannot be treated as a black box, by ignoring the effects of the converter topology and control dynamics. Here, a theoretical analysis has been provided to ascertain the optimum performance of DMPPT applications on various DC-DC converter designs. To measure the effectiveness of the proposed HT, Boost, 2-Stage Switch Capacitor Based (2-SSC) Boost, and Optimum Buck Converters (OBC) have been employed. Simulation and experimental results are provided to validate the effectiveness of the proposed HT.

1. Introduction

Amidst the global efforts to reduce reliance on fossil-based energy in the past few decades, solar photovoltaic (PV) energy has emerged as one of the most promising renewable energy sources due to its reliability and cleanliness (Colmenar-Santos et al., 2018; Gholami et al., 2018; Guiheneuf et al., 2017; Yang et al., 2018). However, high installation expenses, dependency on weather condition and low-efficiency, remain the main drawbacks of solar PV. To increase the energy yield and increase the return on investment, various maximum power point tracking (MPPT) techniques have been proposed to ensure the PV panel can operate around the maximum power point (MPP) (Chaieb and Sakly, 2018; Al-Dhaifallah et al., 2018; Tang, 2017). In (Amir et al., 2016), a review of different MPPT techniques based on analog and digital approach was presented.

For most conventional MPPT techniques offering reliability and PV array independence, obtaining an optimized design with low steady-state oscillations, convergence at MPP and fast transient response remain the main challenge (Mao et al., 2018; Amir et al., 2017; Alik & Jusoh, 2018; Shahid et al., 2018; Al-Shetwi & Sujod, 2006). By contrast, CNM for DMPPT offer the advantages of faster transient response, convergence at the MPP and negligible steady state oscillations, yet CNM confront issues of limited range of operation, PV array dependence and inaccuracy of the initial guess (Chun & Kwasinski, 2011; Chun & Kwasinski, 2011). Over the years, various classical numerical methods (CNM) have also been utilized in digital implementation of MPPT for PV systems (Amir et al., 2016; Chun & Kwasinski, 2011; Chun & Kwasinski, 2011; Xiao et al., 2006; Kim & Kwasinski, 2014). Shortcomings of such CNM techniques, such as algorithm numerical stability, discretization error and quantization error have been explored in (Chun & Kwasinski, 2011). However, the issues confronted while implementing DMPPT for various DC-DC converter topologies, such as limited range of operation, high dependence on PV parameters and the choice of initial guess, have not been addressed. This paper attempts to address such concerns by proposing HT dependent on various MCNM and theoretically analysing the conditions for optimum performance of DMPPT by HT on various converter topologies. The HT offers lower computational complexity, faster dynamic response, easy implementation, PV array independence, accuracy of initial guess and fewer overshoots.

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https://doi.org/10.1016/j.solener.2018.07.088
Received 21 April 2018; Received in revised form 9 July 2018; Accepted 28 July 2018

Nomenclature

MPP	maximum power point
P_{mpp}	power at MPP
ΔP	change in power
V_{mpp}	voltage at MPP
V_{oc}	open circuit voltage
ΔV	change of voltage
I_{mpp}	current at MPP
ΔI	change of current
I_{sh}	short circuit current
D	duty cycle
ΔD	change in duty ratio
MPPT	maximum power point tracking
DMPPT	digital maximum power point tracking
e	tolerance error
Δ	change
OBC	optimum buck converter
2-SSC	2-stage switch capacitor based Boost converter
$\Delta P_{PV}/\Delta V_{PV}$	change in power over change of voltage
$\Delta P_{PV}/\Delta I_{PV}$	change in power over change of current
D_{max}	predefined maximum limit for the duty cycle
$\Delta P_{PV}/\Delta D$	change in power over change in duty ratio
STC	standard test conditions
INC	incremental conductance
MINC	modified incremental conductance
CNM	Classical Numerical Methods
MCNM	Modified Classical Numerical Methods
BSM	Bisection Search Method
RFM	Regula Falsi Method
NRM	Newton Raphson Method
SM	Secant Method
BNM	Brent Numerical Method
MBSM	Modified Bisection Search Method
MRFM	Modified Regula Falsi Method
MNRM	Modified Newton Raphson Method
MSM	Modified Secant Method
MBNM	Modified Brent Numerical Method
HT	Hybrid Techniques

Considering the problems of CNM, an amalgamation of various MCNM and MINC has been utilized to realize the proposed HT. As, the bisection search method (BSM) is reliable, yet converges slowly. Reliability of BSM is offset by its disappointing linear convergence. Moreover, it typically involves $\log_2 \frac{b-a}{\delta}$ iterations in order to attain a certain accuracy tolerance δ (Wilkins & Gu, 2013; Burden & Faires, 2001). Furthermore, Newton-Raphson method (NRM) remains much more efficient than BSM. However, calculation of derivative is required by NRM, which adds to its complexity (Chapra, 2012). In certain cases, if initial guess is too far away from the root, the NRM may not converge due to tangent line offshoot. However, it remains faster than BSM. By contrast, Secant Method (SM) is quick at convergence, but may diverge without reliable initial guesses (Amir et al., 2016). Furthermore, Brent's method usually converges quickly to a root, yet for occasional difficult functions, it generically requires O(n) or O(n^2) number of iterations to find a root; n being the number of steps required by BSM for convergence (Wilkins & Gu, 2013). As observed in (Chun & Kwasinski, 2011) all the numerical methods for MPPT application require predefined information for the initial guesses and closed bracketed limits. Therefore, we present HT that places a stricter bound on the search for the MPP, along with modified CNM to attain improved performance. Here, DMPPT (Mao et al., 2018; Balato et al., 2018; Luo et al., 2016) is utilized instead of analog MPPT because all the CNM and MCNM under discussion have been implemented digitally (on DSP) and previous work on MPPT by CNM is also reported to be digitally implemented (Mao et al., 2018; Chun & Kwasinski, 2011; Balato et al., 2018).

The objectives of this paper are as follows:

1. Analyse the issues of implementing DMPPT on various DC-DC converter topologies.
2. Present Hybrid Techniques with direct control offering a combination of the MINC and different MCNM techniques.
3. Comparatively analyse the proposed HT against the conventional MINC direct control technique.
4. A guide for future work on DMPPT utilizing different MCNM techniques.

The paper is structured as follows: Section 2 introduces the DMPPT and the shortcomings in implementing DMPPT on various DC-DC converters. Subsequently, Section 3 presents an overview of the considered MBSM, MRFM, MNRM, NMSM and NBNM MCNM and investigates the combination of the MINC MPPT Technique with the mentioned MCNM to offer the proposed Hybrid DMPPT techniques. Further, Section 4 presents simulation and experimental results for all the proposed Hybrid MPPT techniques under consideration. To further validate the outcomes, Section 5 offers a discussion highlighting the improved performance of HT in terms of lower computational complexity, faster dynamic response, easy implementation, PV array independence, accuracy of initial guess and fewer overshoots. Lastly, conclusion of this work is offered in Section 6.

2. DMPPT implementation on various DC-DC converter topologies

Considering direct control MPPT techniques, duty cycle (D) is taken as the main control variable. Therefore, performances of DMPPT techniques with direct control, show a trade-off between the transient response and the steady state error. Here, the primary issue remains that a constant voltage change is never guaranteed with a constant step size change in duty cycle.

A PV system can employ various DC-DC converter topologies. Here, the focus remains on the Buck, OBC (Divakar & Sutanto, 1999), Boost and 2-SSC Boost converter. In case of a PV system employing the Buck or OBC, at operating points away from the MPP the system shows smaller steady state oscillations (Amir et al., 2017), as a constant step change offers small change in voltage, however, at operating points closer to MPP large steady state response is observed, as the constant step change offers large change in voltage. For Boost or 2-SSC Boost converter the conditions are entirely opposite to the ones observed for OBC.

Fig. 1 presents the various DC-DC converter topologies utilized and Table 1 presents the system parameters for OBC and 2-SSC Boost Converter. Kyocera KC85T PV panel with parameters as shown in Table 2 has been employed to validate the effectiveness of the proposed DMPPT algorithms. Fig. 2 presents the power versus voltage (*P-V*) plots for the PV module under different irradiance conditions. Without MPPT the operating point of solar panels depends on intersection of the load line and solar panels' characteristic curve as seen in Fig. 3. Here, most of the PV panel power is wasted as the operating point is below the MPP. In addition, solar irradiance is unpredictable and varies throughout the day, so the PV system is always over-sizing between load and power source to provide a reliable system during bad weathers.

2.1. Change in voltage for high duty cycle

2.1.1. Boost converter

Fig. 1(a) presents the schematic diagram of the conventional boost