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Online dynamic conductance estimation based maximum power point tracking of photovoltaic generators

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ABSTRACT

In this paper, a novel method of maximum power point tracking of renewable energy generators is proposed, utilizing the sum of dynamic and static conductance as maximum power point tracking loop variable. This allows to formulate the maximum power point tracking problem as a typical closed-loop stabilization task of non-linear static plant with zero reference. Consequently, a simple integrative controller is shown to be sufficient to ensure zero steady-state maximum power point tracking error with easily determinable nominal dynamics. A recently revealed method of online photovoltaic generator dynamic conductance estimation allowing robust terminal voltage control is utilized. Moreover, it is revealed that the resulting maximum power point tracking loop plant is piecewise linear around the maximum power point, i.e. for given environmental conditions two different convergence rates are expected, depending on the relative value of operating voltage to maximum power point voltage. Presented analytical outcomes are verified by application of the proposed maximum power point tracking structure to a grid-connected photovoltaic generator system under robust voltage control.

1. Introduction

Over the last decade, a notable increase in energy consumption both in emergent and well-established countries has been witnessed [1]. The climb in energy prices and fossil fuel defiance, in addition to harmful pollution as a side effect of conventional generation, increased the investment and encouraged the development of renewable energy generators (REG) [2]. Nowadays, > 14% of the worldwide energy production is based on energy from renewable sources [3].

Photovoltaic and wind generators represent the most significantly growing renewable electricity generating technologies, due to ever rising efficiency, good infrastructure and relative cost competitiveness [4]. It is well known that REG electrical characteristics possess (at single unit level) a single maximum power point (MPP) for specific environmental conditions set (energy generating variable ξ and temperature T), as shown in Fig. 1 [5]. Therefore, the amount of harvested energy (and hence overall efficiency) decreases if REG operating point does not coincide with the MPP [6]. As a result, maximum power point tracking (MPPT) operation is extremely desirable for any combination of environmental conditions and load, achieved by suitable control of interfacing power converter (IPC), decoupling the REG from the load [7]. It should be emphasized that non-MPPT operation is sometimes required as well in case of isolated microgrids, there the ability of loads and storage elements to absorb power is limited [8].

MPPT algorithms has evolved significantly over the years, consequently requiring high computational power and advanced technology [9]. Established MPPT techniques are typically categorized into three main groups [10]:

- Artificial intelligent methods [11].
- Direct methods [12].
- Indirect methods [13].

The artificial intelligent method uses fuzzy logics, genetic algorithms etc. [14] for MPP determination. In direct methods, the MPP is searched by perturbing the operating point (typically using hill climbing or perturb and observe related algorithms) and spotting the resulting power gradient [15]. Indirect methods (also known as quasi-seeking) is based on mathematical rules that apply data providing by REG manufacturers or acquired from experiments for tracking the MPP

Abbreviations: REG, renewable energy generator; MPPT, maximum power point tracking; MPP, maximum power point; PVG, photovoltaic generator; IPC, interfacing power converter; IVC, input voltage controller; CC, current controller; INC, incremental conductance; DCE, Dynamic Conductance Estimator; PWM, pulse width modulation

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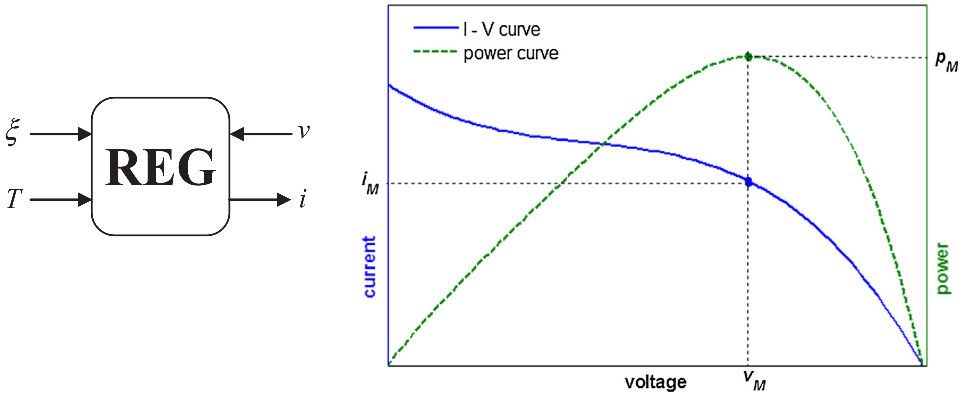
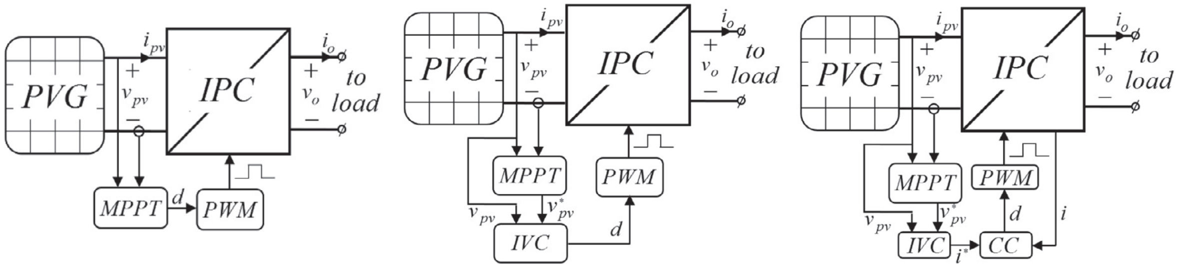
Nomenclature

		R_{SH}	equivalent shunt resistance
		R_S	equivalent series resistance
y	dynamic conductance	V_T	thermal voltage
Y	static conductance	n	number of series-connected cells
x_{MPP}	MPP value of x	η	ideality factor
x_k	value of x at k-th time step	I_0	reverse saturation current
ε	sum of static and dynamic conductances	k_b	Boltzmann constant
I_{PV}	photocurrent	q	elementary charge
I_D	recombination current	T	cell/panel temperature
C_{PV}	equivalent shunt capacitance	G	cell/panel irradiance



(a) block diagram (b) typical static electrical-side characteristics.

Fig. 1. Generalized REG representation.



(a) single-loop. (b) dual-loop. (c) triple-loop.

Fig. 2. MPPT control structures.

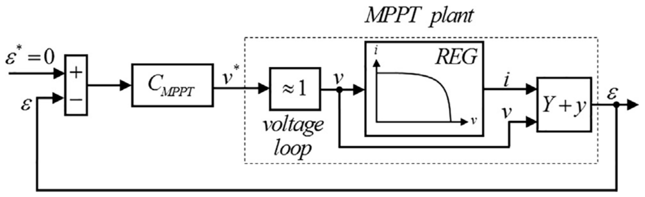


Fig. 3. Equivalent MPPT control loop.

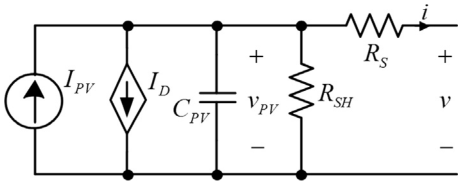


Fig. 4. REG equivalent circuit.

Table 1
Specification of the IS-160 solar panel under standard test conditions.

Characteristic	Value
Number of series-connected cells n_s	72
Maximum power p_{MPP}, [W]	160
Maximum power voltage v_{MPP}, [V]	35
Maximum power current i_{MPP}, [A]	4.57
Shot circuit current i_{sc}, [A]	4.9
Open circuit voltage v_{oc}, [V]	43.8
Temperature coefficient of v_{oc}, %/K	−0.378
Temperature coefficient of i_{sc}, %/K	0.0254

Table 2
Estimated parameters of the IS-160 solar panel (cell level) under standard test conditions.

Parameter	Estimated value
Ideality factor, η	1.0
Series resistance R_s, [mΩ]	8.0
Shunt resistance R_{sh}, [Ω]	3.25
Photocurrent I_{ph}, [A]	4.824
Reverse bias saturation current I_0, [μA]	0.33