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Modeling and Simulation of Hybrid Maximum Power Point Tracking for Solar Power System

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Authors' contributions

This work was carried out in collaboration between both authors. Author YS designed the study and structure of article, performed the finish editon. Author AJ performed the analysis, the first draft of the manuscript, managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

This paper presents, a Hybrid Maximum Power Point Tracking (HMPPT) controller for solar power system is modeled using MATLAB Simulink. The model consists of PV module, boost converter, and HMPPT controller and load. The proposed hybrid method is a maximum power coefficient (K_P) and modified hill climbing MPPT method. The boost converter model is allowed the input voltage of the converter, i.e. output voltage of PV is changed by varying the duty cycle, so that the hybrid maximum power point could be tracked when the environmental changes. The increasing efficiency of the solar power system is important engineering task. From the experiment, the developed model comforms with the circuit model provided by MATLAB Simulink Power Simulation. The power system was simulated in single (autonomous) power system worked on own load with R=25, 50, 100 Ohm dependence P_{out} from duty cycle D. Existing methods of maximum power point tracking of such systems not always can to search surely for maximum power point if there are existing some local maximums of power. It can be if illumination of few non-oriented solar panels are different. Further, the simulation results show that the developed model performs well in tracking the hybrid maximum power point of the PV module using modified hill climbing (HC) Algorithm and maximum power coefficient (K_P).

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Keywords: Hybrid MPPT methods; photovoltaic; boost converter; model Simulink.

1. INTRODUCTION

Green technology is one of the most renewable and clean energy sources. It attracts the human 's attention because of its clean power, cost reduction, continuity and reliability. It aims at finding ways of producing energy that does not deplete natural sources of energy [1-2]. It refers to the alternative technology which reduces fuel use and expects less damage to living things and environment. One of the most important renewable energy sources is solar radiation.The solar PV panels have a non-linear characteristic curve which means output power of PV arrays is always changing with environmental conditions the point of maximum power (Pmpp) shifts its position.Therefore, a fixed operating point cannot be enforced on a PV system. [3-4].

An important consideration in achieving high efficiency in the PV power generation system is to match the PV source and load impedance properly for any weather conditions, thus obtaining maximum power generation [2-5].

Some hybrid methods are used so as to match the source and load properly, thereby increasing the efficiency of solar cell [6]. The hybrid methods, which are those that combination of indirect and direct methods,estimates a value by indirect method, tracks using perturbations towards MPP using direct methods and faster convergence rate [7-13].

Maximum power coefficient is a new method, which is the product of multiplication the open circuit voltage coefficient K_V (the ratio of actual voltage to open circuit voltage V_{OC}) and the short circuit current coefficient of K_I (the ratio of the actual current to short circuit current I_{SC}) [14-17].

The most MPPT method of the available PV systems operate on hill climbing method owing to its high precision, simple structure, direct investigation of power, high reliability, and independence from sensors such as radiation and temperature sensors [17-24]. This method has three major disadvantages:Firstly tracking local peaks of the solar array voltage-power curve, secondly oscillations around the MPP and thirdly low speed. A DC to DC boost converter is needed for implementing HMPPT. The DC-DC converter deliver the maximum power from PV module to load by adjusting the duty cycle and able to distribute a maximum power when load is changes [25]. The proposed hybrid method is a maximum power coefficient (K_P) and modified hill climbing MPPT method. The paper is organized as follows. Section 2 general configuration of solar power system. The briefly explains the modeling of solar PV array in section 3. The proposed algorithm is presented in section 4. Section 5 the briefly explains the DC-DC boost converter the testing procedure adopted for the proposed algorithm. Section 6 discusses the simulation results. The section 7 the conclusion of the paper.

2. GENERAL CONFIGURATION OF SOLAR POWER SYSTEM

A typical configuration of solar power system is shown in the Fig. 1.

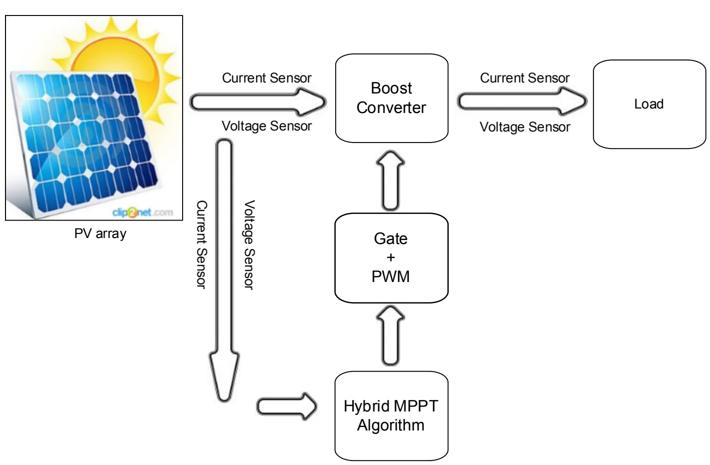

Fig. 1. General block diagram of configuration of solar power system

3. MODEL OF SOLAR PV ARRAY

Analyzing the physical model, a photovoltaic cell can be modeled as a current source connected in parallel with a single diode for its simplicity. Current source produces a constant current, this current is proportional to the intensity of the light falling upon the cell. A general mathematical description of current-voltage output characteristics of a PV cell has been studied for over the last few decades to improve the efficiency of solar PV module [23-28]. The output obtained from the module is variable DC voltage, this voltage depends upon the solar radiation intensity and temperature. The leakage of the semiconductor junction is represented as the parallel resistance R_p of PV cell and the connection between cells are modeled as a small series resistance R_S [2,7,9-11,13,15, 26-42]. The simplest equivalent circuit of the general model, is shown in Fig. 2. [2,7,9,11,13,15,26-47].

From the circuit in Fig. 2 the output panel current can be expressed as equation 1 [2,7,9-11,13,15,26-36,44].

$$I = I_{ph} - I_d - I_p \tag{1}$$

Where

I: PV module terminal current (A), I_{ph}: Photovoltaic current or light-generated current (A), I_d: Shockley diode equation, I_p: Current of parallel resistance (A).

According to the model of a solar cell, the relationship between the cell`s current and voltage, and by applying Kirchhoff's law, we can determine the voltage-ampere dependency of the photovoltaic cell, can be expressed as equation 2 [2,7,9-11,13,15,25-47].

$$I = I_{ph} - I_s \cdot \left[exp\left(\frac{q\,(V + I \cdot R_s)}{AK_B\, T_C}\right) - 1\right] - \frac{(V + I \cdot R_s)}{R_p} \tag{2}$$

Where

I_s: The diode saturation current or cell saturation of dark current (A),q: The electron charge (1.602×10^{-19}) (C), K_B: The Boltzmann constant (1.38×10^{-23}) (J/K), T_C: The cell working temperature (K), A: The diode factor (1…1.6), V: The PV module terminal voltage (V).

When R_s is assumed to be zero. That is, no series loss. The photocurrent mainly depends on the solar isolation and cell's working temperature, which is described as equation 3 [2-7,10,13,15,25-28,33-35,39,42,44].

$$I_{ph} = \left[I_{sc} + K_I \cdot \left(T_C - T_{ref}\right)\right] \cdot \frac{G}{G_{ref}} \tag{3}$$

When I_{SC} is the short-circuit current at a (25 °C and 1000W/m^2); K_1 is the cell's short-circuit temperature coefficient, T_{ref}, the reference temperature [in Kelvin], respectively, G and G_{ref} , the radiation and radiation at standard test condition (1000W/m^2), respectively. On the other hand, the diode saturation current (I_s) dependence with the temperature can be described as equations 4 and 5, respectively [2-7,10,13,15,25-28,33-35,39,42,44,46].

$$I_s = I_{rs} \cdot \left(\frac{T_C}{T_{ref}}\right)^3 \cdot exp\left[\frac{qE_g}{AK_B}\left(\frac{1}{T_{ref}} - \frac{1}{T_C}\right)\right] \tag{4}$$

$$I_{rs} = \frac{I_{sc}}{exp\left[\frac{qV_{OC}}{AK_B\, T_C N_S}\right] - 1} \tag{5}$$

Where I_{rs} is the reverse saturation current at reference temperature and solar radiation; E_g is the band-gap energy of the semiconductor material and A is the ideality factor, depends on cell`s manufacturing technology.

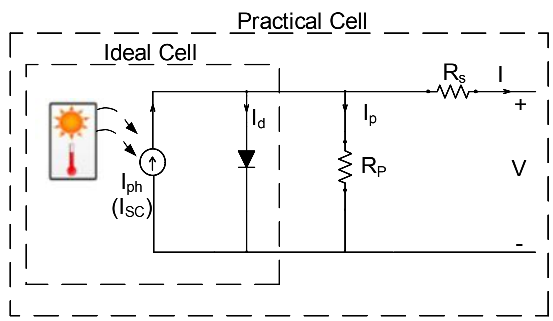

Fig. 2. Equivalent circuit of photovoltaic cell

The solar photovoltaic array is formed by a series-parallel combination of appropriate solar cell to provide electric power demand of the consumers. Np represents the cells interconnected in parallel and Ns shows the cells interconnected in series as shown in Fig. 3, the relationship between the output current and voltage is expressed as equation 6 [2-7,10,13,15,26-27,29-42,47].

$$I = N_p I_{ph} - N_p I_s \cdot \left\{exp\left[\frac{q}{AK_B T_C}\left(\frac{V}{N_S} + \frac{I \cdot R_s}{N_P}\right)\right] - 1\right\} - \left(\frac{\frac{N_P V}{N_S} + I \cdot R_s}{R_P}\right) \quad (6)$$

Solar array has been simulated in MATLAB to investigate the characteristic curves subject to working temperature and atmospheric irradiation condition. Four solar module are connected in series to form panels and, as it appears in Fig. 4. Each module exposed to light source.

4. PROPOSED ALGORITHM

The proposed algorithm is shown in Fig. 6. It is a two stage MPPT method that has the maximum power coefficient (K_P) method as the first stage and modified hill climbing as the second stage. The hybrid methods consist of indirect method and direct method. Indirect method is new method maximum power coefficient (K_P) and direct method modified hill climbing.

The maximum power coefficient (K_P) method which is the product of multiplication the open circuit voltage coefficient K_V (the ratio of actual voltage to open circuit voltage V_{OC}) and the short circuit current coefficient of K_I (the ratio of the actual current to short circuit current I_{SC}) [3,7,14-17].

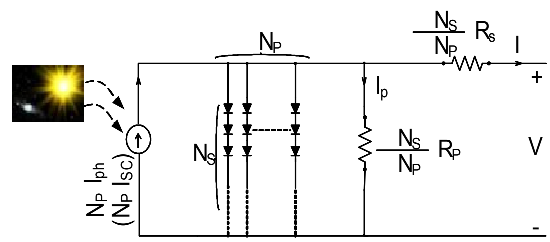

Fig. 3. Equivalent circuit model of solar PV array

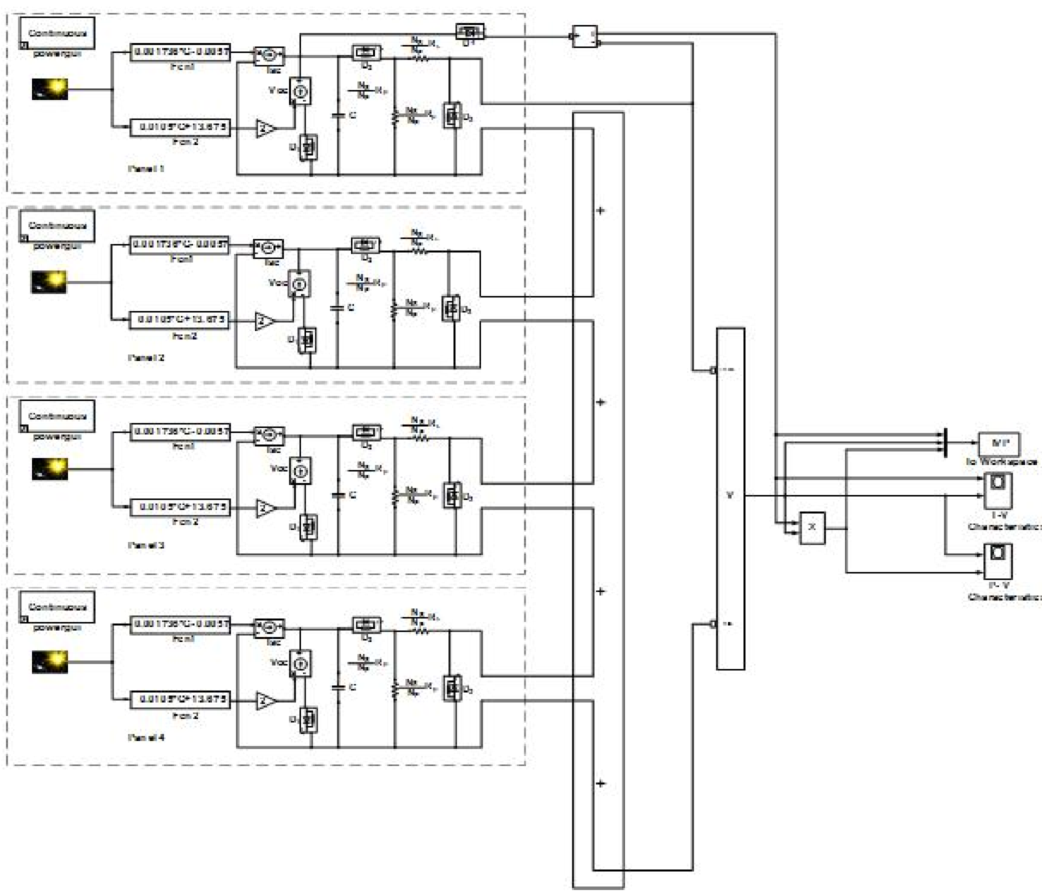

Fig 4. Simulation diagram for of PV array built in SimPowerSystems

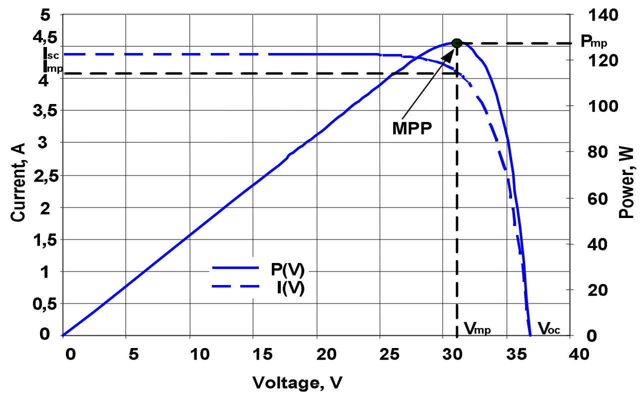

Fig 5. Characteristics curve of a typical PV cell

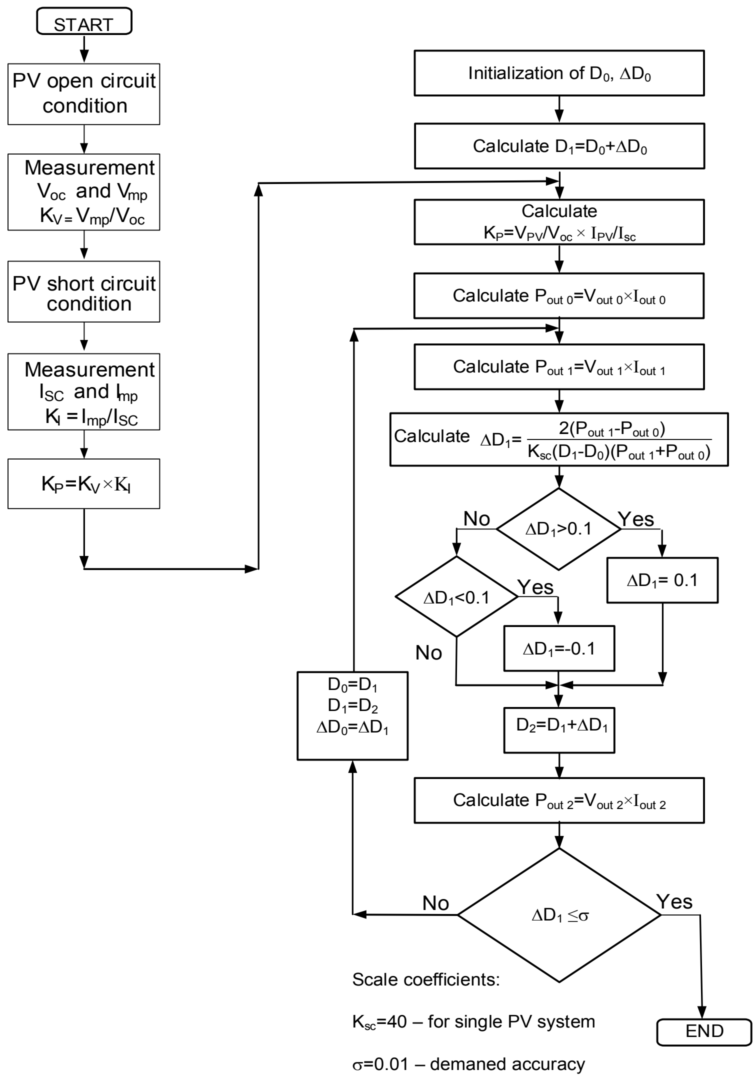

Fig. 6. Flowchart of hybrid MPPT algorithm

Hill climbing (HC) technique is widely applied in MPPT controllers because of their simplicity and simple usage. In this method, the duty cycle of the power converter can change and the power is absorbed from the array compared to the previous stage. If power increases, the duty cycle changes to the previous direction and if power decreases, the duty cycle changes to the opposite direction [17-24,31-33].

5. DC-DC BOOST CONVERTER

Boost converter is one of DC-DC converter type which is used to convert step up the input voltage of the converter. Fig. 7 shows the topology of boost converter which consists of power switch S, diode D, inductor L, and input/output capacitors C1,C2. Insulated Gate Bipolar Transistor (IGBT), is selected as power switch S, due to high frequency and high voltage application.The boost converter is responsible for tracking maximum power available at the PV array and deliver the maximum power from PV module to load by adjusting the duty cycle and able to distribute a maximum power when load is changes. The proposed algorithm is tested using simulink as shown in Fig. 7. A boost converter is designed to interface the PV panel with the load [25-29,31-32,41-42,45,47].

6. SIMULATION RESULTS

The power system was simulated in single (autonomous) power system worked with different loads R=25, 50, 100 Ohm. Dependence P_{out} from duty cicle D for single load. The calculation is performed for four series panels, which are presented in Fig. 4.

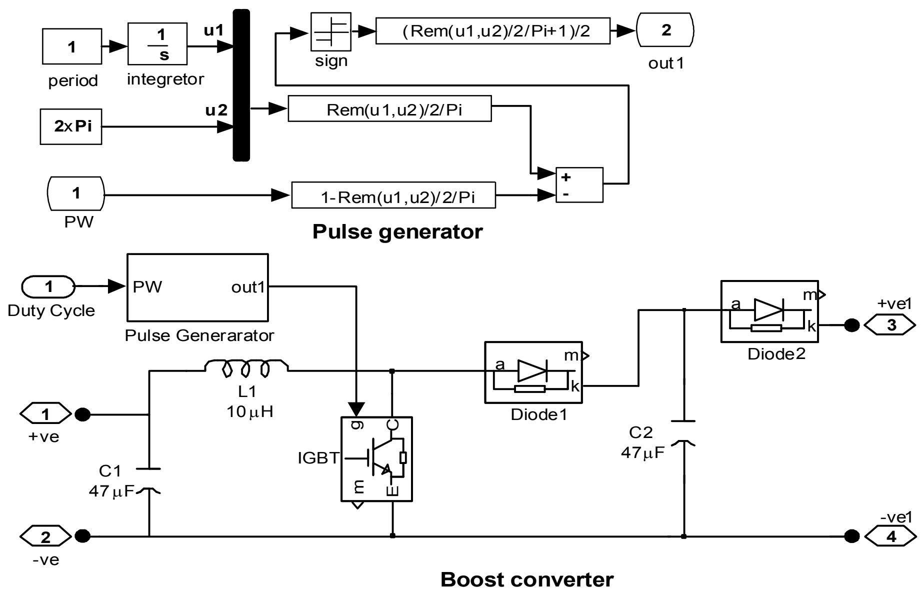

Fig. 7. Simulink-model of Boost DC-DC converter

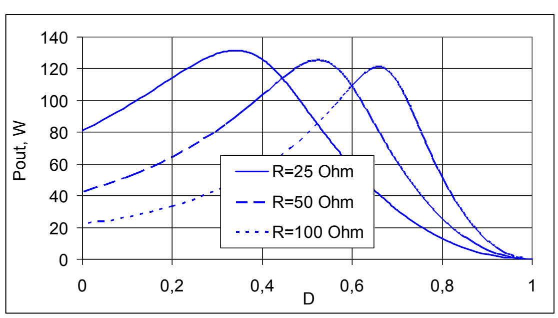

Fig. 8. Dependence P_{out} from duty cycle D for single system

This function can be used for calculation of ΔD_i but needed in scaling and cropping. Scaling is performed on the value of P_{out} and scale coefficient K_{sc}.

$$\Delta D_i = \frac{P_i - P_{i-1}}{D_i - D_{i-1}} \times \frac{2}{P_i + P_{i-1}} \times \frac{1}{K_{sc}} \quad (7)$$

Where Pi, Pi-1 - present and previous measured values output power; Di, Di-1 – the present and previous values of duty cycle pulses. To ensure the stability of the algorithm the incremental value is confined to the interval [-0.1, 0.1].

$$\Delta D_i = \begin{cases} -0.1 & \text{if } \Delta D_i \le -0.1 \\ \Delta D_i & \text{if } -0.1 < \Delta D_i < 0.1 \\ 0.1 & \text{if } \Delta D_{i+1} \ge 0.1 \end{cases} \quad (8)$$

The function dP_{out}/dD with different loads R=25, 50, 100 Ohm is shown on Fig. 9. and Modified function for calculation of ΔD_i is shown on Fig. 10.

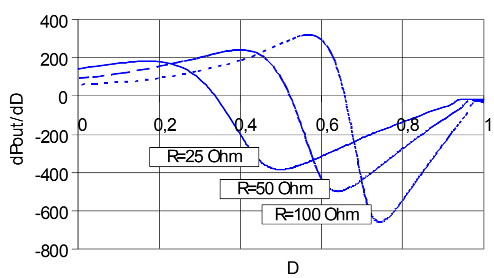

Fig. 9. Dependence dP_{out}/dD from duty cycle D for single system

Recommended value of the scaling coefficient: K_{sc}= 40 – for systems running on a single load. These values are determined by the width of the ΔD_i function transition area from -0.1 to 0.1 which must be more wide than 0.1 and still very well.

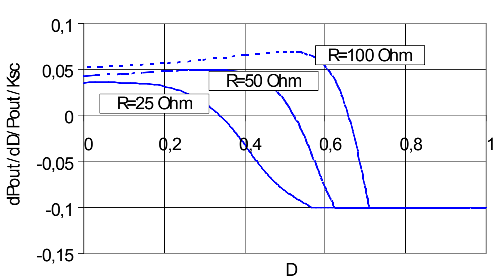

Fig. 10. Modified function for calculation of ΔD_i for single system

7. CONCLUSION

This paper presents the modeling of maximum power point tracking (MPPT) hybrid method based on modified hill climbing (HC) method and controling of power coefficient. The aspect of the method is choosing initial point through power coefficient which is the product of multiplication the open circuit voltage coefficient K_V (the ratio of actual voltage to open circuit voltage V_{OC}) and the short circuit current coefficient of K_I (the ratio of the actual current to short circuit current I_{SC}). And next tracking by using of special function through digital differentiation of measured values of output power with scaling on actual power and special empirical coefficient. The simulation results revealed robust tracking of the global maximum power at a sufficiently rapid convergence.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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