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Variable Step-Size Modified P&O-based MPPT Algorithm for the Photovoltaic Systems

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Abstract – The utilization of renewable energy sources is being enlarged daily to meet the escalating energy needs around the world. Solar energy, like other renewable energy sources, occupies an important place in the energy generation sector. Since it is important to increase energy efficiency in photovoltaic (PV) systems, maximum power point tracking (MPPT) is performed with one type of variable step-size P&O algorithm in this paper. The whole system modeling, the design of the presented MPPT algorithm and the tests are performed in the MATLAB/Simulink simulation environment. Also, the system is created with a configuration that includes a PV panel, input filter, boost converter, and load. On the other hand, an irradiance change profile including step changes, linear increasing and linear decreasing levels is created and tests are carried out by running this MPPT algorithm. According to the obtained results, it seems that the power capture from the PV system has been successfully achieved.

Keywords – P&O Algorithm, maximum power point tracking, modified peak seeking algorithm, photovoltaic system.

I. Introduction

The demand for renewable energy-based power generation systems is increasing rapidly day by day as a result of the increase in global warming caused by the greenhouse effect and fossil fuels may be depleted in the near future [1]. Among these renewable, clean, and efficient energy sources, type of the photovoltaic (PV) energy is popular due to its low maintenance costs and simplicity of design [2].

Photovoltaic cells convert the radiation from the sun into energy in electrical form. However, a single cell cannot produce sufficient output voltage and current. Therefore, a group of PV cells is connected with series and parallel ways to structure a PV panel in order to obtain high output voltage and high output current [3]. The electricity produced from PV Panels varies in relation to the intensity of the irradiance and the ambient temperature [4]. Since photovoltaic modules have non-linear character in terms of current, voltage and power curve, it becomes essential to use maximum power point tracking (MPPT) methodologies to acquire the peak power from the system [5].

Examining the literature and industrial studies, it can be seen that various types of MPPT methodologies can be implemented in PV systems. These can be classified as classical, intelligent, optimization-based and hybrid methods. Classical MPPT methods are often preferred because of their simple design and effective results. Perturbation and observation (P&O), lookup table-based MPPT and incremental conductance (InC) are some of the classical MPPT methods [6]. On the other hand, artificial neural networks (ANN) and fuzzy logic controllers (FLC) can be utilized as intelligent MPPT methods with high accuracy and fast response [7]. Optimization approaches such as ant colony, artificial bee colony, particle swarm and grey wolf can be operated in MPPT search [8]. Moreover, there are hybrid techniques that combined classical, intelligent or optimization-based approaches.

A significant matter in the PV systems is the design and use of suitable converter topologies that can provide the necessary power conversion. The PV module generally needs a DC-DC converter to be operating at the maximum power point (MPP). Thus, the maximum power can be achieved by operating the system at a specific point by adjusting the output voltage of the PV module via converters. Naturally, various types of converters can be used. A boost or a buck converter can be used for increasing or decreasing of the output voltage (load voltage), respectively. On the other part, a buck-boost converter is also preferable when it is desired to regulate a wide range output voltage [9]. In addition to these, it is seen that ZETA and SEPIC converters, which can allow fewer switching losses, can also be included in PV systems [10]. However, the boost converter can be usually operated instead of a transformer, and to increase the voltage range or in order to obtain a specific desired output voltage with fewer modules. In addition, it can be preferred due to its high efficiency, high voltage gain and simple structure. Therefore, the configuration of PV system in this study is designed in a way that includes a PV panel, boost converter, input filter, and load. On the other hand, it is aimed to obtain the maximum power from the PV system by regulating the switching-signal of the boost converter with the variable step-size modified P&O-based MPPT algorithm.

The remainder of this paper is organized in four parts. First, the modeling of the PV system configuration, photovoltaic cell, module and boost converter is detailed in Section II. And then, the MPPT method presented in this paper is mentioned in detail in Section III. In addition, the simulation results carried out under the irradiance change profile including step changes, linear increasing and linear decreasing levels are included in Section IV. Lastly, the conclusion is introduced in Section V.

II. Modelling of PV System Configuration

PV system configuration is comprised of a PV panel, input filter connected to the panel, boost converter and load, which can be shown in Fig.1.

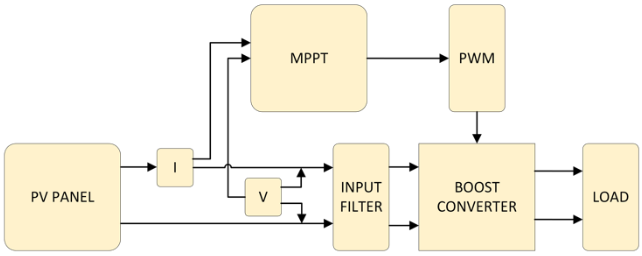

Fig. 1 PV system configuration.

A. The Modelling of PV Module

A PV module is emerged by connecting PV cells in series or parallel. The ideal PV cell model can be modeled as a photosensitive current source. Here, it is benefitting from Ref [11] for modeling the PV cell. At the same time, the current expression for the PV cell is defined as in (1).

$$I_{PV} = I_{PH} - I_D - I_{SH} \quad (1)$$

where, I_{PH} defines the photo current, while I_D symbolizes the diode current. Also, I_{SH} is the shunt current passing through the shunt resistance, which is expressed as follows.

$$I_{SH} = \frac{V_L + R_S I_S}{R_{SH}} \quad (2)$$

where, R_{SH} describes the shunt resistance, R_S is the series resistance, I_S is the current through the series resistance and V_L is the voltage on the load.

The photo current I_{PH} also changes in the direct proportion to the irradiance level and can be stated as follows.

$$I_{PH} = \frac{[I_{SC} + K_i(T_0 - 298)]G}{1000} \quad (3)$$

where, G symbolizes the solar irradiance in *W/m²*, K_i is defined as the temperature coefficient of the short-circuit current. Also, I_{SC} is the short-circuit current at nominal test conditions, which is 1000 *W/m²* and 25 *℃*. On the other hand, T_0 is the value of the nominal temperature.

Expression of the diode current I_D is given as below.

$$I_D = I_0 e^{\left[\left(\frac{V_{PV} + I_{PV} R_S}{V_t \alpha}\right) - 1\right]} \quad (4)$$

where, I_0 defines the saturation current of the diode, V_t is the thermal voltage, α is described as the ideality factor.

Moreover, the definition of the diode saturation current I_0 is represented as follows. Herein, E_g is the bandgap energy of the solar cell material. In addition to this, I_{0x}, q and k are also defined as the nominal saturation current of the diode, the charge amount of the electron and the boltzmann coefficient, respectively.

$$I_0 = I_{0x} \left({}^{T_0}/_{T}\right)^3 e^{\frac{qE_g}{\alpha k\left({}^{1}/_{T_o} - {}^{1}/_{T}\right)}} \quad (5)$$

The authors have selected a highly efficient solar panel as Kyocera KC200GT in order to use it in this paper by utilizing data presented in [3]. In addition, I-V variation characteristics for the PV module at the various irradiance levels are demonstrated in Fig. 2. On the other hand, P-V variation characteristics are similarly presented here in Fig. 3.

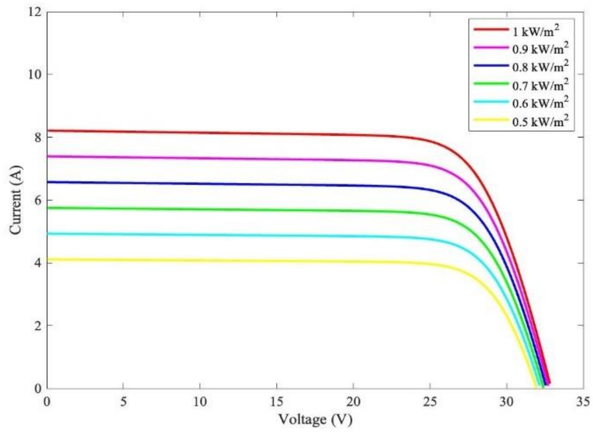

Fig. 2 PV module I-V characteristic under different irradiation.

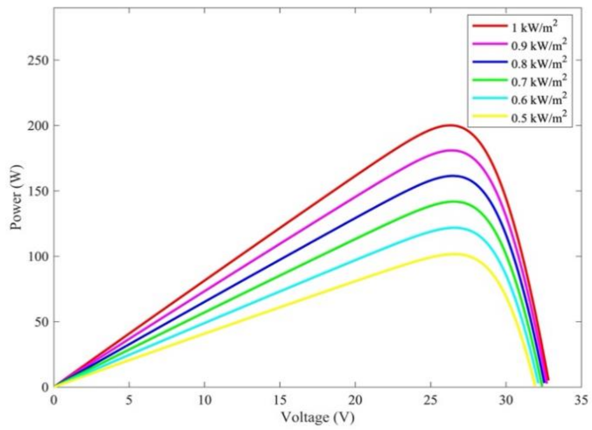

Fig. 3 PV module V-W characteristic under different irradiation.

B. Modelling of Boost type DC-DC Converter and Load

In PV systems, a boost converter (BC) is generally connected between the module and the load. The objective of this is to increase the voltage in the output of the PV module to a higher level, and thus a boost converter is used in this study. Here, in order to manage the PV module at the maximum power point, Ref. [12] has examined in detail the boost converter design and parameters can be defined in the light of the given information.

The following definition represents the relation between the output and input voltage of the converter or, it is briefly expressed voltage on the load and output voltage of the PV module, respectively.

$$\frac{V_L}{V_{PV}} = \frac{1}{1-D} \tag{6}$$

where, D symbolizes the duty ratio for the boost-type power converter.

Moreover, from the principle of power conservation, a relationship with the input and output current of the converter is defined similarly below.

$$\frac{I_L}{I_{PV}} = 1 - D \tag{7}$$

$$V_L = I_L R_L \tag{8}$$

From here, the expression for PV output voltage can be rearranged as follows.

$$V_{PV} = I_{PV}(1-D)^2 R_L \tag{9}$$

Parametric data for the whole system configuration including the PV module, the boost converter and load are listed in detail in Table 1.

Table 1. System Specification.

	Descriptions of PV system	
	Parameter	***Value***
PV Module	Max. power	200.143 *W*
	Open-circuit voltage	32.9 *V*
	Short-circuit current	8.21 *A*
	Max. current	7.61 *A*
	Max. voltage	26.3 *V*
	Number of series cell	52
Boost Converter	Input Filter Capacitor	52.73e-6 *F*
	Switching frequency	10 *kHz*
	Inductor	65.3e-6 *H*
	Capacitor	35.5e-5 *F*
Load	Resistance	80 *ohm*

III. MPPT Method

A classification for different types of MPPT methods can be made into the four groups by using Ref [8], which can be presented as in Fig. 2. These are classic, intelligent, optimization-based, and hybrid MPPT methods.

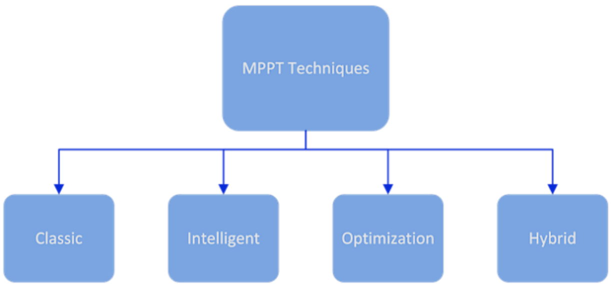

Fig. 4 Classification of the MPPT methods.

A. Classic P&O Algorithm

The classical type of perturb and observe (P&O) methodology compares variation of power and voltage on the PV characteristic curve. And then, this algorithm tries to seek the peak value, at which maximum power occurs, by slightly changing the state of the voltage or duty ratio. However, the step-size at change is constant in this method. In addition, algorithmic diagram of classic P&O methods is given in Fig.5.

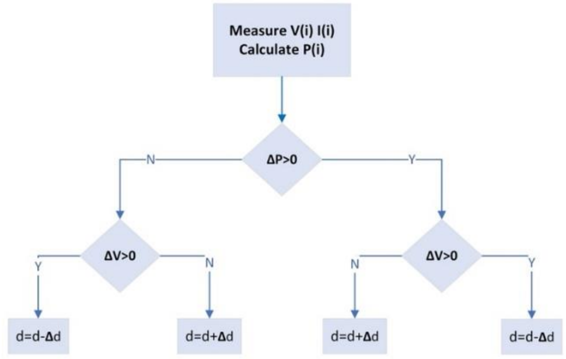

Fig. 5 Classic P&O method.

B. Variable Step-Size Modified P&O-based MPPT Algorithm

A modified method is used here considering that it can be given better performance as a result of making some changes on the classical P&O algorithm. This methodology changes step-size in terms of the current variation and then, the power variation is compared with a fixed-limit power change and it is used as the step-size multiplier [13]. Algorithmic diagram of this enhanced methods can be seen in Fig.6 and revised parts according to previous methods is demonstrated in here.

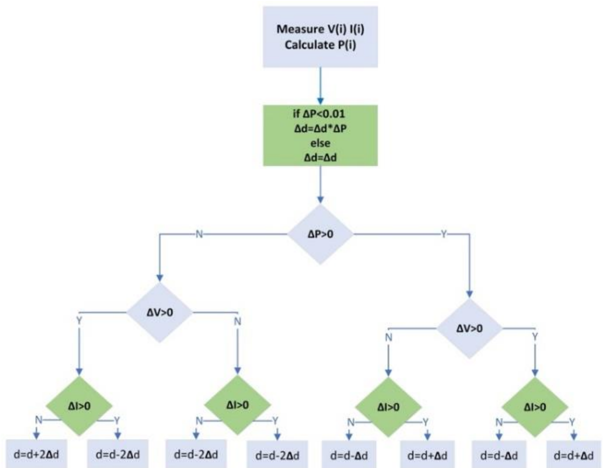

Fig. 6 Modified-MPPT Algorithm.

Examining this algorithm, it can be seen that the power is calculated by using the voltage and current values for each loop. And then, arrangement of the duty ratio is made by comparing the change of power, voltage and current with the previous cycle. Moreover, in cases where the power change is less than 0.01, the step-size is further reduced by multiplying the power change-rate. Thus, the sensitivity of MPPT searching has been increased and the accuracy of the results is increased.

IV. Simulation Results and Discussion

An irradiance change profile including step changes, linear increasing and linear decreasing levels is created range of 500 W/m^2 and 100 W/m^2, which can be shown in Fig. 7.

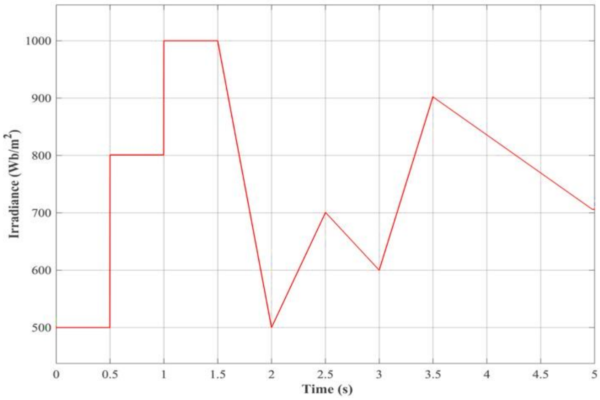

Fig. 7 Irradiance change profile considering for tests.

All tests under this irradiance change profile are performed in the MATLAB/Simulink environment. In addition, acquired results for the input voltage and input current and power of the PV module, the duty ratio of BC, and voltage, current and power on the load in converter output are given, respectively.

Fig. 8. presents variations in the output voltage of the solar module. From here, it can be seen that it is between 25-29 V according to changing irradiance levels. Otherwise, the output current of this module is depictured in Fig. 9. Herein, it can be understood that it is changed to the range of 3.7 A and 7.6 A.

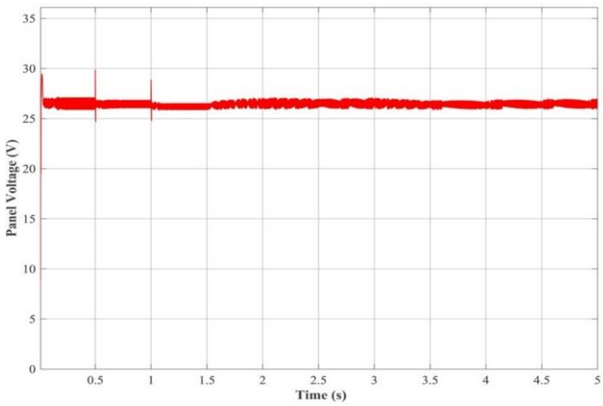

Fig. 8 Change of the PV module voltage.

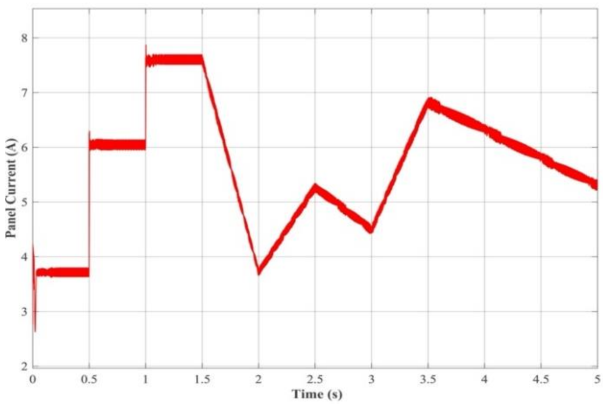

Fig. 9 Current changes of the PV module.

In addition, the variations in the output power of the PV module are shown in Fig. 10. From here, it can be understood that this MPPT algorithm is operated effectively according to the obtained results. Also, Fig.11 presents variations in the duty ratio changing with regard to irradiance levels determined by this MPPT algorithm. On the other hand, the change in the converter output voltage is seen in Fig. 12. It is understood that the voltage on the load contains fewer ripples than the PV module output voltage. Also, the variation of the converter output current is shown in Fig. 13. From here, the change of the output power on the load can be obtained as in Fig. 14. It can be shown here that the output power has smooth transitions.

Also, Fig. 15 depicts the diagram for the performed PV system simulation.

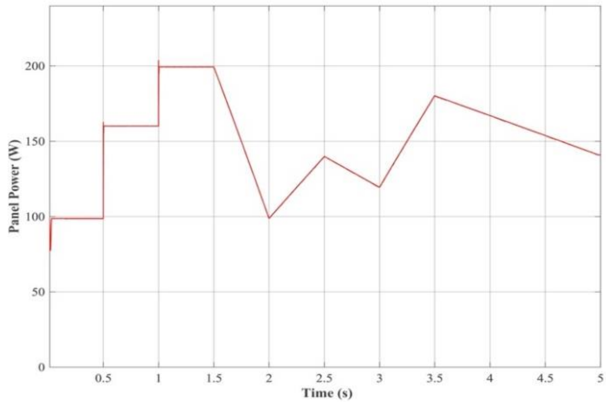

Fig. 10 Change of power in the PV.

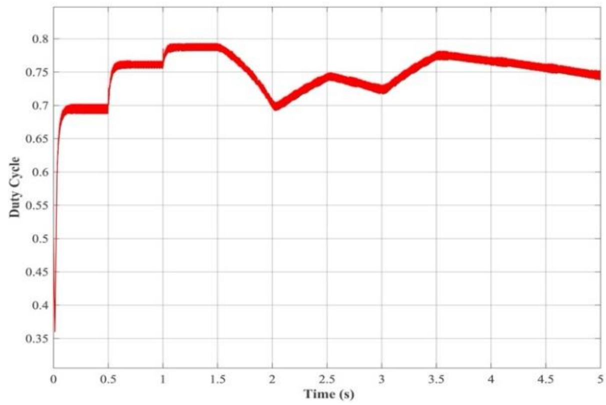

Fig. 11 Change in the converter duty ratio.

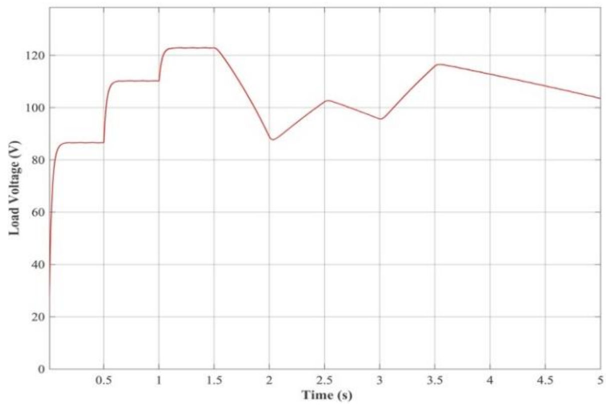

Fig. 12 Change in the load voltage.

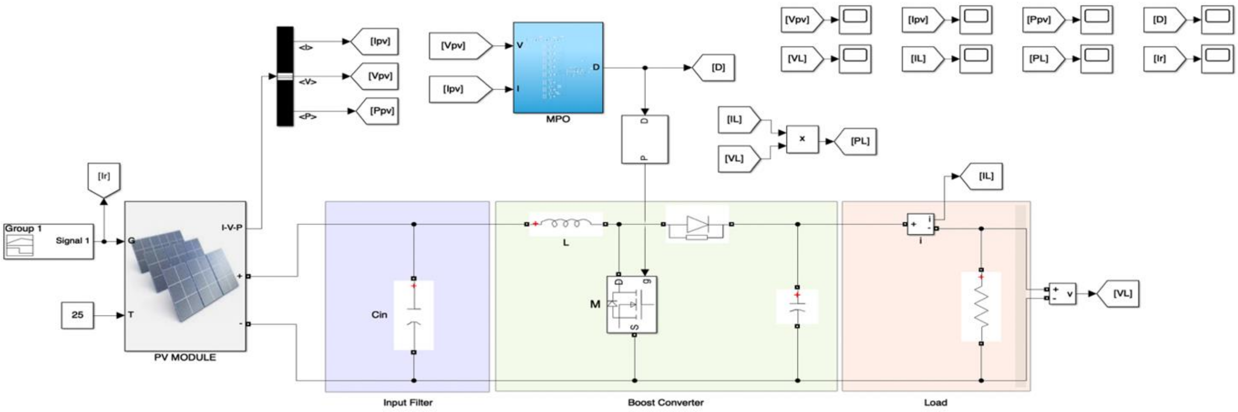

Fig. 15: Simulated PV System model.

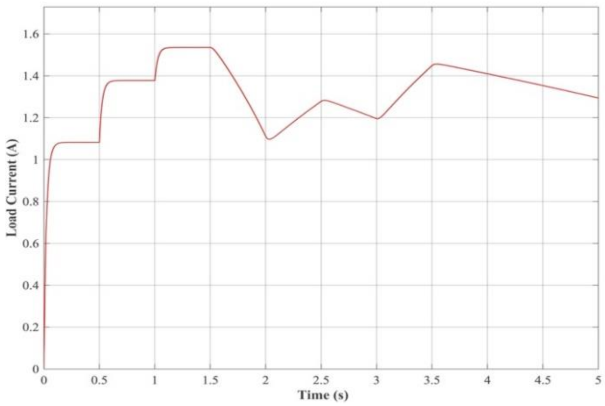

Fig. 13 Change of the load current.

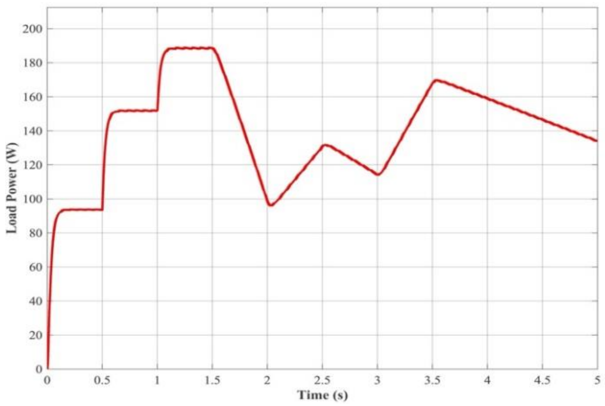

Fig. 14 Change of the output power on the load.

V. CONCLUSION

This paper presents the MPPT control of the PV system, which is performed by employing a variable step-size modified P&O-based MPPT structure. The modeling of the PV system configuration and validation tests are carried out in a simulation environment. In addition, comprehensive analysis is made under the irradiance change profile including step changes, linear increasing and linear decreasing levels. Here, the duty cycle of the BC is regulated via this MPPT algorithm. According to the obtained results, it can be shown that MPPT control of the PV system with the presented approach is successfully performed under mentioned irradiance change profile.

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