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Enhanced Extremum Seeking Maximum Power Point Tracking for PV System

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Abstract: Photovoltaic cells offer a clean, inexhaustible and pollution free source of electricity which turned attention of many researchers. The PV output is not constant in terms of voltage, so its output can't be directly fed to electricity bank or to the main grid. This makes a need for design controller, which can extract and calculate the maximum power point from the PV array at any instant. The PV array normally drives under the vague environmental disturbances and parameters, this shows that MPPT experience an indefinite stochastic fluctuations. In this paper enhanced extremum seeking MPPT controller is proposed, which has an excellent tolerance of stochastic fluctuations in nature. In the proposed MPPT algorithm, the convergence rate is not determined by unknown power map like conventional extremum seeking algorithm. The convergence and the stability prove the effectiveness of the proposed MPPT algorithm.

Key words: Photovolatic system · Extremum Seeking control · Maximum Power Point Tracking

INTRODUCTION

Among the various renewable energy sources, solar energy has turned the attention of many researchers because of its advantages like less pollution, safety and its frequent market potential. The photovoltaic (PV) array has been used widely in spacecrafts, satellites and solar vehicles and for domestic applications [1, 2]. Maximum Power Point Tracking (MPPT) is a method of directing PV array to its maximum power point. The PV cells inherent nature makes power voltage curves to depend nonlinearly on irradiation intensity and temperature [3, 4]. This is because that the operating voltage or current which maximizes the power will change with changing environmental conditions. Despite of environmental changes, MPPT system is introduced to regulate the operating voltage or current to maintain the output power at maximum level.

The rapid growth of embedded technology makes microcontroller based MPPT system a dominated approach in PV systems. Various MPPT algorithm were proposed, in which perturb and observe (PO) and incremental conductance (Income) algorithms were more common [5, 6]. In perturb and observe algorithm, to monitor the power direction a step perturbation is used in control signal. This PO algorithm is easy to implement, but it has a drawbacks of oscillating at maximum power point and fails to track in a condition where irradiance changes rapidly [7]. In IncCond algorithm, rapidly changing irradiance can be tracked, since the maximum power point is tracked by comparing the instant and incremental conductance. But due to the use of low precision sensor, error occurs at the maximum power point [8, 9]. To overcome these issues extremum seeking based MPPT algorithm were used [10-12]. This method is well suited for unknown or partially known dynamics in photovoltaic systems [13]. Perturbation signals were used as a probing signal in ES algorithm, to estimate the power map gradient and according to the estimation, control signals were updated.

Simple hardware implementation and verifiable convergence are the main advantages of ES algorithm [14, 15]. In existing ES based MPPT controller, the perturbation signals are assumed as periodic, assumption may be slightly superlative because external disturbance are typically stochastic and unknown. But the orthogonality requirement makes periodic extremum seeking complicated to multivariable cases. Another major

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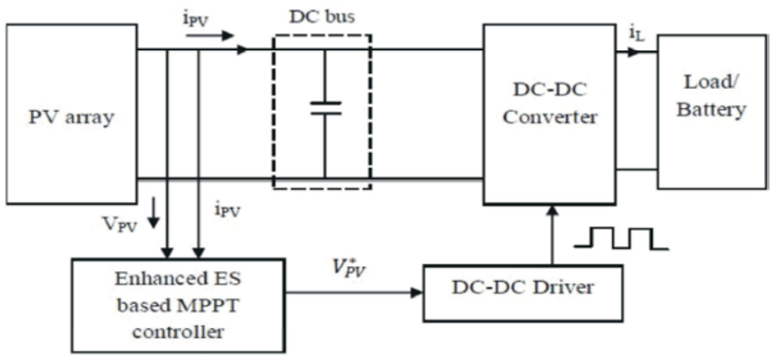

Fig. 1: System Configuration of PV System

drawback of existing ES method is convergence speed, which is generally defined by power map gradient of PV system and its system control is influenced highly by unknown and varying environmental condition. Hence to construct a MPPT control system, which is independent of environmental condition is our ultimate objective. In this paper, enhanced extremum seeking MPPT controller is proposed to overcome the drawbacks of the existing ES algorithm. The result will prove the effectiveness of the proposed MPPT controller.

Modeling of Photovoltaic and MPPT System: The PV array normally consists of numerous photovoltaic modules connected to attain the desired output power. The intensity of light varies all over the day, which moves the maximum power point to different current and voltages. Therefore, a MPPT control system is normally adopted between the load and PV module to adjust the current and voltage and to maintain the maximum output power. The proposed MPPT based PV control system schematic is shown in Figure 1. In PV panels the solar energy is converted into electrical energy through the photovoltaic effect. The conversion efficiency can be optimized by designing the MPPT control system between the load and PV panel. The MPPT control system consists of DC-DC converter, DC-DC to driver and a MPPT controller. The proposed Maximum Power Point Tracking system can be either current control or voltage control. In this paper, the MPPT control system is designed with voltage control, which also suits the current control. As the converter and DC-DC driver are relatively grown up in electrical industry, the design of control algorithm in MPPT system is a main work. Several researches were done in this area to make the improvement. Optimizing the output power with unknown power map against the external disturbance and assigning the convergence speed are the major drawbacks even after the considerable progress in this field.

Proposed Mppt Controller: In this paper, we proposed an enhanced extremum seeking MPPT controller to overcome the drawbacks of the existing ES algorithm. This controller not only has the advantages over the conventional extremum seeking method, it also deals with assigning rate of convergence. A MPPT system repeatedly requires convergence of the controller to be assigned by designer. This can be achieved by using the proposed extremum seeking algorithm. Once the power map is known, to find the maximum MPP, the following proposed algorithm can be used.

$$\frac{dP_{pv}}{dt} = -\left(\frac{d^2 f(V_{pv})}{dV_{pv}^2}\right)^{-1} \frac{df(V_{pv})}{dV_{pv}} \quad (1)$$

If the power is unknown, at that time estimator is required to approximate the $df(x) / dx$ and $df^2 (x) / dx^2$. The purpose of the proposed design controller is to estimate the first and second order power map derivatives to achieve the MPPT. Let the estimation of first order and the second derivative is denoted as $\hat{G}$ and $\hat{H}$ and the inverse second order estimation is denoted as Γ. The first and second order derivative of f is estimated by $\hat{G} = P_{pv}M(\eta)$ and $\hat{H} = P_{pv}N(\eta)$ respectively. When $\hat{Y}$ is close to 0, deriving $\Gamma = 1/H$ is normally difficult. In which the signal generator output are $M(\eta)$ and (η). In this method, output power is computed after measuring the output voltage and output current. Based on the product of stochastic signals and output power, the power map first order derivative and second order derivatives are estimated. It will go the next level, if the criteria are satisfied. Else update the output power by regulating the output voltage and duty cycle and go to the next iteration as shown in Figure 2.

Tracking efficiency, effect of PV module ageing and effects of partial shading are the major issues to be considered in MPPT controller.

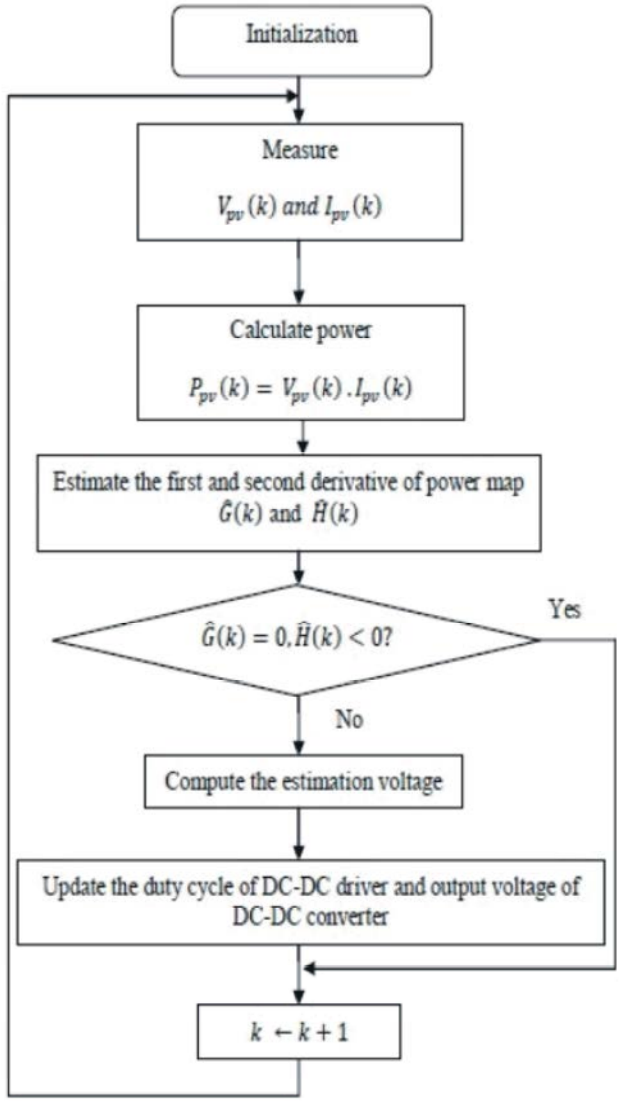

Fig. 2: Flow chart of enhanced extremum seeking MPPT method

Tracking Efficiency: In many commercial applications, tracking efficiency of the MPPT method has been the most important consideration. With the help of the following equation (2), the tracking efficiency of MPPT controller can be calculated. In which, $P_{pv}(t)$ is the calculated power produced by the photovoltaic array under MPPT algorithm and $P_m(t)$ is the maximum power that the PV array can produce.

$$\eta_T = \frac{\int_o^t P_{pv}(t)dt}{\int_o^t Pm(t)dt} \quad (2)$$

The tracking efficiency discrete definition can be as denoted as in equation (3), in which n represent the number of channels.

$$\eta_T = \frac{1}{n}\sum_{k=0}^{n} \frac{P_{pv}(k)}{P_m(k)} \quad (3)$$

The MPPT overall performance is evaluated by the tracking efficiency.

Partial Shading Effect: The rapid development of photovoltaic integrated in buildings, the partial shading effect has turned much attention in the MPPT controller. As the photovoltaic array is installed on rooftop, due to clouds and space limitation it suffers from partial shading. When subjected to partial shading, the photovoltaic system often exhibit severe local and global extremums. So in spite of tracking power map global MPP, the MPPT algorithm is supposed to have a global convergence.

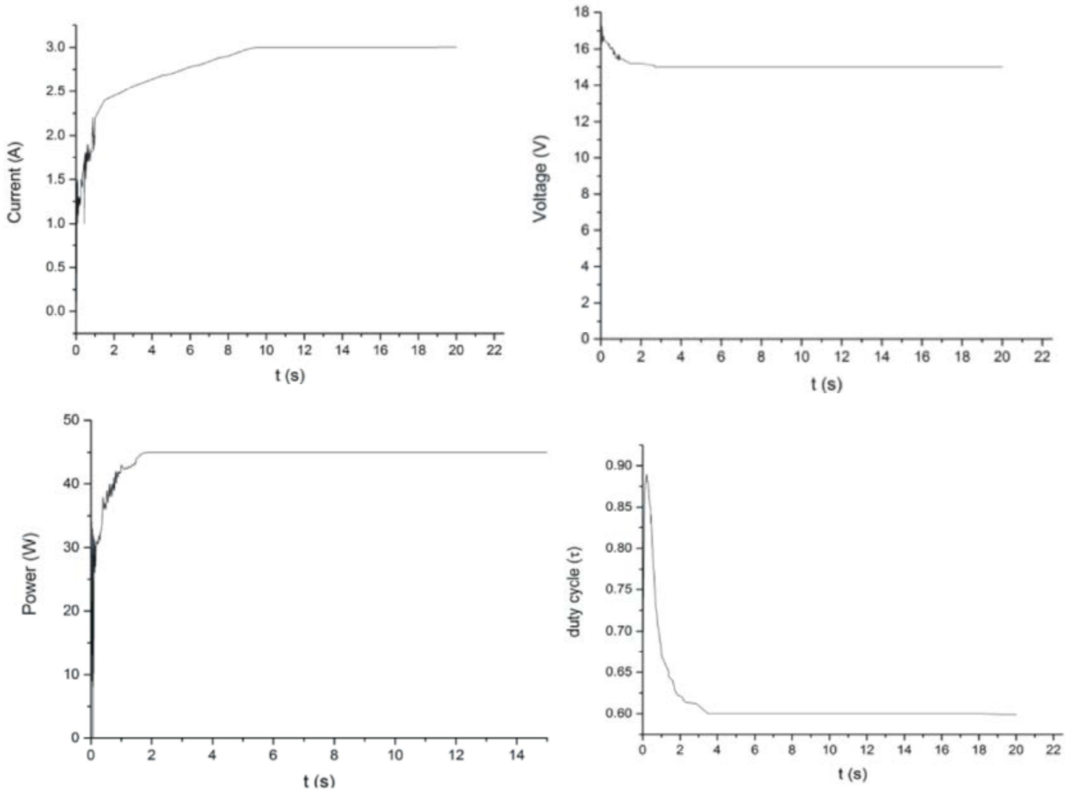

Fig. 3: Proposed MPPT controller transient under uniform irradiance

The controller which is locally stable at MPP implies that it will get trapped in local extremums and for photovoltaic systems under partial shading it might not be a good choice.

PV Module Ageing Effect: Lifetime and reliability of photovoltaic modules are the main factors in PV system performance and are dominated mainly by the effect of PV module ageing. To separate the effect of ageing from the temperature and irradiance, it is essential to evaluate the performance at the beginning. The deviation between these explains the PV system ageing. The proposed MPPT algorithm won't call for model information and with real time measurements it optimizes the power map. Thus the proposed PV module can deal the effect of ageing well.

Result and Performance Evaluation: The effectiveness of the proposed algorithm is proved by its results obtained. The light source driven photovoltaic maximum power point tracking system is adopted, to evaluate the performance of the proposed tracking MPPT algorithm under undesired irradiance. The PV panel converts solar energy into electrical energy through photovoltaic effect. The DC-DC converter and its output voltage regulation are driven by MPPT controller. The result and performance of the proposed algorithm is evaluated under uniform and non-uniform irradiance respectively.

Tracking Performance: The tracking performance of the proposed controller under uniform irradiance is considered in this section.

The simulations of the enhanced extremum seeking control algorithm were carried out in MATLAB/ Simulink. Figure 3 shows the results of the proposed MPPT controller under uniform irradiance. In the direction of maximum power point the output power is oscillated, which is perceived by the product of perturbation and power. It is to be noticed that within 4 sec, the output converges to the maximum power point. In the steady state, the output power is 46.3 W, while 47.9W is the maximum power of photovoltaic module. The tracking efficiency of the simulated enhanced extremum seeking algorithm is about 96.9%.The tracking performance of the proposed and the existing MPPT methods were compared in terms of convergence time and tracking performance. In the existing ES MPPT method, only 92.1% of efficiency is achieved and its convergence is more than 6s.

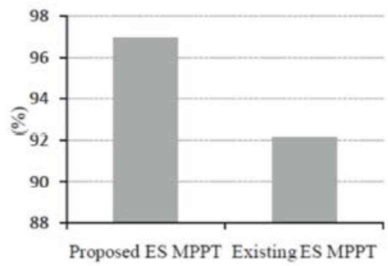

Fig. 4: Tracking Efficiency

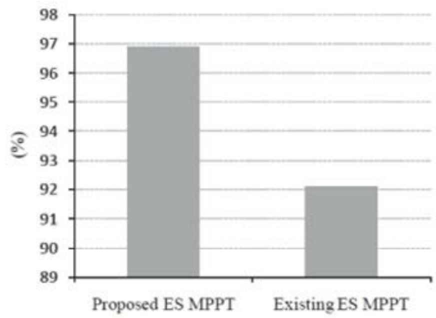

Fig. 5: Convergence Time

But in the enhanced extremum seeking MPPT method 96.9% of efficiency can be achieved and its convergence is less than 4s. In this section, under non-uniform irradiance the tracking performance of the proposed algorithm with abrupt changes is considered.

In order to demonstrate the effectiveness of the proposed MPPT system more instinctively, the statistical comparison between the existing extremum seeking and the proposed extremum seeking algorithm is shown in Figure 4 and Figure 5. From the result obtained, it is clear that both the convergence rate and tracking efficiency is more effective in the proposed MPPT algorithm.

CONCLUSION

Extremum seeking is a promising technique in extracting maximum power point from photovoltaic module. In this paper, we proposed an enhanced extremum seeking MPPT for PV system. The proposed algorithm won't call for power map knowledge and it has an advantage of good tolerance of convergence rate and stochastic fluctuations. The convergence and stability of the enhanced extremum seeking MPPT algorithm is proved rigorously. The application related topics like PV module ageing and effect of partial shading are also discussed. The result provided for tracking efficiency and convergence time of the proposed MPPT algorithm proves its effectiveness.

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