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Design of a DC to DC Converter for a Residential Grid Connected Solar Energy System †

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Abstract: This article presents an investigation of a PV solar system based on Maximum Power Point Tracking (MPPT) using one of the artificial intelligence control techniques. To avoid the problems of the traditional P&O method, the optimization tool of Particle Swarm Optimization (PSO) is proposed to be employed with a Perturbation & Observation (P&O) technique with added PI controller (PSO + PI + P&O). This proposed method achieved the optimal operating variables of a photovoltaic (PV) module in terms to mitigate the issue of partial shading weather conditions. A DC/DC boost converter is designed to be switched based on the corresponding duty cycle according to the parameters provided by the IV characteristics to obtain the desired MPP. It is observed from the results that the proposed PSO + PI + P&O showed excellent improvement. Moreover, better performance was achieved in terms of extracting the maximum unique power point between both variables of current and voltage generated from the PV. The proposed MPPT control method was implemented in MATLAB/Simulink. The testbed of the suggested method was approached and highlighted the high efficiency compared to the conventional P&O as well as the PI controller based on P&O methods.

Keywords: DC-DC boost converter; photovoltaic system (PV); particle swarm optimization (PSO); perturb and observe (P&O); maximum power point tracking MPPT; PI controller

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1. Introduction

The partial shading of weather conditions is still the main challenge in generating a power supply with high efficiency from a PV system. This phenomenon causes a drop in power energy from the PV system during its operation. In the last decades, Oversizing of PV arrays was a solution to provide a sufficient power supply demand for the consumer. Nevertheless, the cost of solar panels will be much increased. To mitigate this problem, a technique called MPPT was innovated to predict the maximum point of the power. The work performance of this technology was achieved to extract the MPP up to 97% of the designed PV system [1]. The duty cycle of a DC to DC boost converter can be considerably affected by the variant of MPPT. Several researchers have introduced some MPPT algorithms to tackle the main MPPT issues in regards to the shading conditions and improve the efficiency of a PV system due to the non-linear power generation behavior between IV characteristics [2]. Reference [3] clarifies that the traditional MPPT method based on the P&O algorithm repeats the process between the current and voltage of PV is continuous until the reliable value of MPP is reached. The drawback of this classical method showed its incapacity already to maintain extracting the maximum power point under shadowing weather conditions. This increases oscillation and power outage of the assumed PV system [4,5]. PI controllers were proposed by [6,7] to overcome the issues of the classical P&O technique, the feedback error of IV characteristic was controlled by using a PI controller instead of the perturbation step size of the P&O method. The results showed the suggested PI control could achieve a fast extraction of MPP and reduce the oscillation of the rated power compared to the conventional P&O method. Although the drawback of the P&O algorithm was eliminated, the extended PI controller is likely to be substantially more difficult to tune the parameters based on trial and error technique. In such a case, the MPP of a PV system is not granted successfully towards the perturbations of the shading condition. To face this issue, various optimization tools were employed in a PV system to interconnect with the control loop to obtain a design of PI controller with optimal parameters. PSO has been used intensively as an optimization tool for a wide range of applications due to its features in terms of simple structure, high reliability, easy implementation, and has got the merit that only small parameters can be adjusted. Several studies [8,9] concluded that the PSO technique has given a better result in terms of extracting the MPPT compared with P&O.

This paper proposed a PSO optimization algorithm based on the MPPT technique. In addition, this assumed method was investigated and compared to other MPPT methods by using MATLAB/Simulink. The results were analyzed and compared with the classical MPPT techniques. The suggested method provided an optimum value of extracted maximum power throughout the range of the data given.

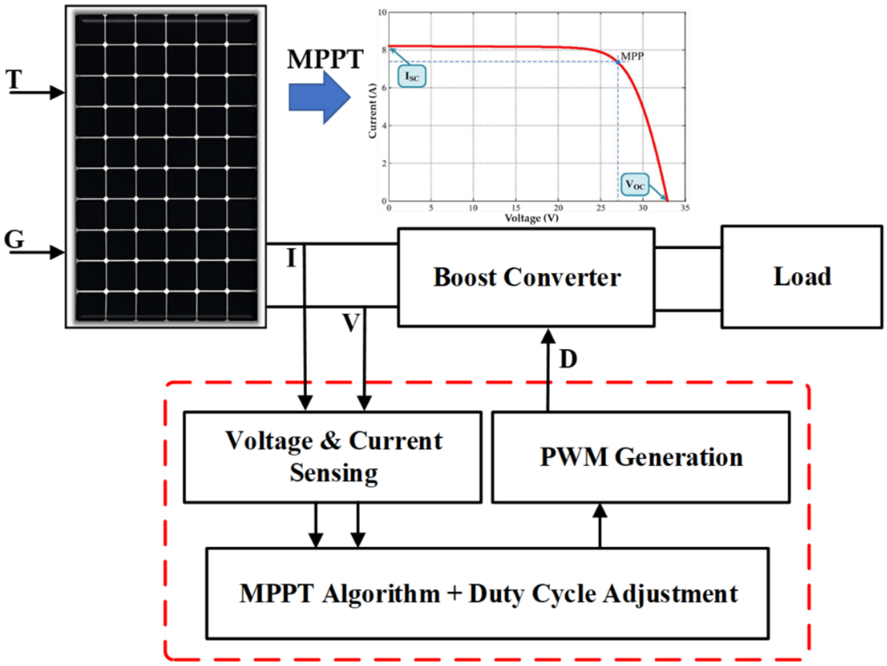

Figure 1. scheme of a PV system.

2. System Design

The photovoltaic system is composed of four stages as described in Figure 1. The first part is represented the energy source based on PV arrays, the second component is a boost converter, the third assembly is acting as the load of the proposed system, and the fourth section is the control scheme according to the development of MPPT.

2.1. PV Design

Initially, the sizing of PV modules is the first step in the design to provide a desired value of the rated power based on IV characteristics according to the assumed load. The variables of the PV modules; Ipv and Vpv are connected to a DC control loop called MPPT. Its purpose is to track and extract the unique point of the largest power generating region from the PV panels [10,11]. Moreover, the fill factor is an essential measure component to determine the efficiency of a PV module based on the constructed material of the module [12] is illustrated in equation (1)

$$FF=\frac{V_{mp}\times I_{mp}}{V_{OC}\times I_{SC}} \quad (1)$$

This static performance can be demonstrated in the following mathematical equation (2) obtained by fundamental electrical theory (Kirchhoff's current law) in Figure 2.

$$I_{ph}=[I_{SC}+K_1\times(T-T_r)]\times G/T \quad (2)$$

The Corresponding parameters of the above equation are described as follows;
I_{ph} the photo current, I_{SC} the current short circuit, R_S series resistance
K is the Boltzmann's constant (1.381×10^{-23} J/K), R_{Sh} Shunt resistance,
T temperature in Kelvin (K), V_{co} Voltage open circuit and G irradiance in W/m^2

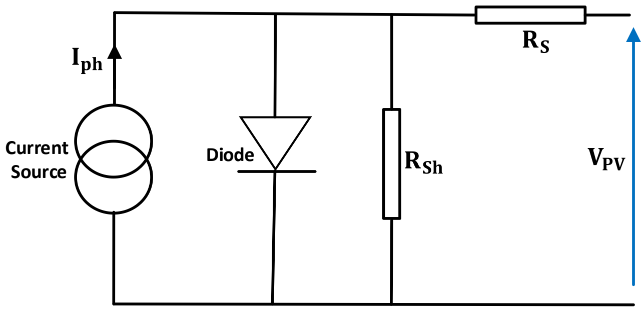

Figure 2. Equivalent Circuit of PV panel.

SHARP PV module (ND-Q250F7) with 60 cells in series was selected as the power supply of the PV system. Table 1 illustrates the electrical specification of the PV given by the manufacturer.

Table 1. Electrical Characteristics of Solar module SHARP ND-Q250F7.

Electrical Characteristics	Variables
Maximum Power	250 W
Number of cells	60
Current at (I_{mp})	8.4 A
Rated voltage (V_{mp})	29.8 V
Short circuit Current (I_{SC})	8.9 A
Open circuit Voltage (V_{OC})	38.3 V

2.2. MPPT Algorithms

P&O algorithm has been widely used as a MPPT technique in many aspects of PV applications, it has the benefit of being constructed simply and implemented easily. The basic fundamental of the P&O method is to create repeatable processes between I&V to extract precisely the position of MPP [13]. PI controller is employed in the outer loop of the P&O algorithm to reduce the feedback error caused by the variation step size of the classical P&O. as a result, the extraction of the MPP becomes faster with lower oscillation of the output rated power [14].

Particle Swarm Optimization application to MPPT Control is an excellent candidate because it is an effective and simple meta-heuristic approach that can be used in a multi-variable optimization function which is because of the key merits of having many local optimal points [8].

2.3. Design of Boost Converter

DC Boost converter is commonly utilized between the load and the power supply. It is acting as a conversion step-up voltage stage based on a ratio of the duty cycle given via the MPPT control method. It is worth mentioning that the duty cycle must be calculated to be in a certain amount to keep the output voltage level at the desired value. In this case, it is associated to make an adaption between the suggested load and the rated PV panels to receive a duty cycle signal from a MPPT technique [15]. The basic methodology of the boost converter is to convert low input DC voltage to much higher output desired DC voltage [16,17]. Figure 3 shows the boost converter composed of the inductor (L), the switch (S), the capacitor C2 designed to smooth the output voltage, and lastly, the diode which is used to protect S to avoid current feedback.
where:

F is Frequency, D is Duty cycle and R is the load resistance.

The following mathematical expression is to derive the output voltage [18].

$$V_{out} = V_{in}/(1\text{-}D) \quad (3)$$

Completion of the mathematical design can be derived by the following equations

$$C = (D \times V_{out})/(F \times R \times \Delta V) \quad (4)$$

and

$$V_{in} = (F \times L \times \Delta I)/D \quad (5)$$

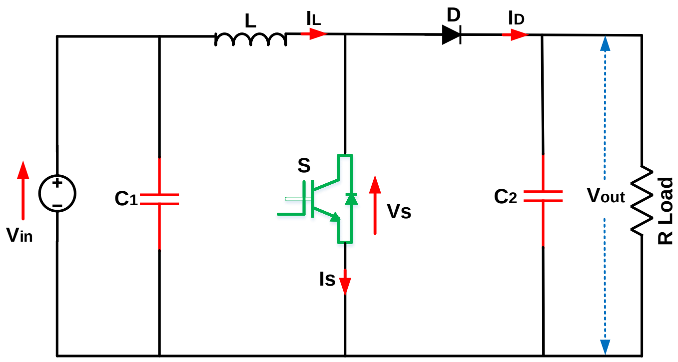

Figure 3. The electrical circuit of a boost converter.

Parameters of DC-DC boost converter are given in Table 2. The duty cycle of the boost converter is calculated according to the power rating demand of the householder.

Table 2. Parameters of the boost converter.

Electrical Variables	Values
input voltage	100–120 Vdc
output voltage	240 Vdc
Output current	30 A
Switching frequency	5 kHz

3. Result and Discussion

This work was implemented in MATLAB (2020a), This proposed PV system was conducted by using three MPPT algorithms which are as follows.

- Conventional perturb and observe (P&O) algorithm.
- PI controller + perturb and observe (P&O) algorithm.
- PSO Algorithm + PI Controller + perturb and observe (P&O) algorithm.

The testbed was considered two states of different irradiances G = 1000 W/m^2 and G = 800 W/m^2 with the constant temperature at T= 25 C^o for the period given.

Figure 4 shows the dynamic performance of the proposed PSO based on MPPT with different algorithms to visualize the effeteness of the suggested control algorithm. The proposed PSO optimization technique has demonstrated a high level of effectiveness and superiority with the much better achievement of power extraction compared to the other controls. whereas, the P&O has large oscillations in the case of the shading conditions for all variables; power, voltage, and current.

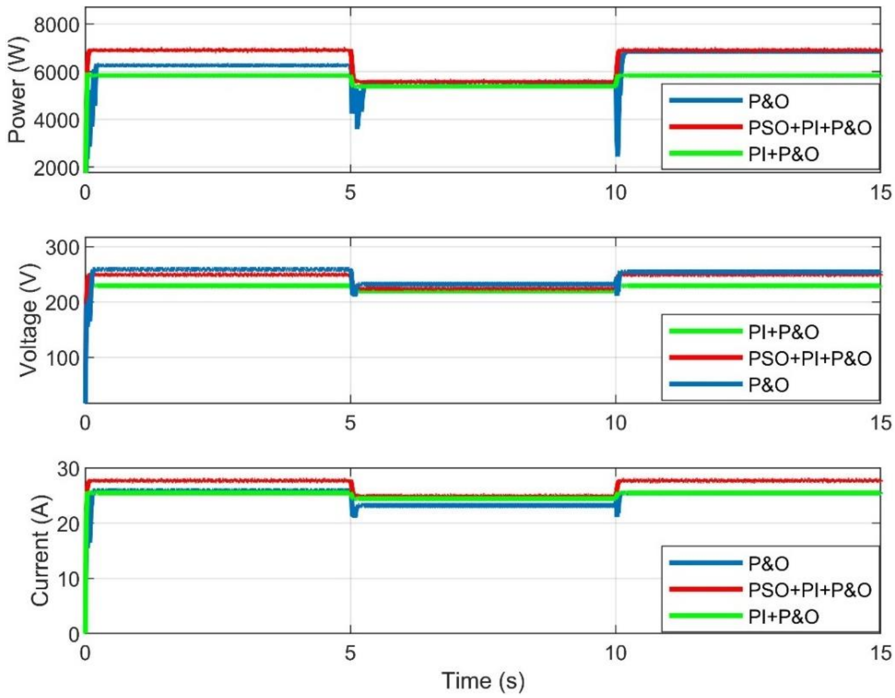

Figure 4. Comparison results of power, voltage, and current using PSO + PI + P&O, PI + P&O and P&O

4. Conclusion

The test was carried out under changed values of irradiance and fixed temperature. The proposed PSO control scheme provides satisfactory performance for many aspects such as achieving the highest extraction point of power and fast dynamic performance of the system regardless of nominal rated power was slightly decreased. This work can be extended in the future by implementing artificial intelligence such as a Genetic Algorithm (GA) to avoid much more fluctuation around the MPP.

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