An Interleaved Isolated Flyback Converter with MPPT using Modified P&O Algorithm for Photovoltaic Generators

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ABSTRACT

Solar energy can be optimally harvested using efficient energy extraction technologies in photovoltaic (PV) systems. The Maximum Power Point Tracking (MPPT) algorithm is one of the most widely used technologies for achieving the Maximum Power Point (MPP) of a PV system. The main drawbacks of MPPT are the large current ripple and high oscillation, which reduce maximum power efficiency. In this study, an MPPT using an Interleaved Isolated Flyback Converter (IIFC) with a modified Perturbation and Observation (P&O) algorithm is proposed. The comparative analysis results between the proposed algorithm and conventional P&O were simulated using the PSIM software. The results showed that the conventional P&O algorithm often suffers from oscillations and slow tracking under rapidly changing irradiance conditions. Meanwhile, the modified P&O algorithm outperformed the conventional P&O method by achieving an average power efficiency improvement of 3.5% and generating a smoother and more stable duty cycle, enabling faster convergence to the MPP, higher PV power efficiency, and minimization of power oscillation. In addition, performance tests under fluctuating solar irradiance demonstrated the algorithm's ability to maintain a high power-tracking efficiency and stable operation. The proposed approach highlights its potential to optimize energy harvesting in PV systems, especially in scenarios with dynamic environmental conditions.

Keywords-photovoltaic; maximum power point tracking; interleave isolated flyback converter; modified P&O

I. INTRODUCTION

Solar energy has long been regarded as a clean and green energy source, offering advantages, such as being environmentally friendly, noise-free, and that of low maintenance [1, 2]. However, the characteristics of a PV system are nonlinear, while it is challenging to operate the system at the MPP [2, 3]. The electrical characteristics of the PV, such as current (I), voltage (V), and power (P), change when solar irradiation and the PV cell temperature fluctuate. Therefore, it is important to track the MPP of PV panels to achieve the maximum PV output power. The maximum output power of the PV module can be extracted using the MPPT technique, and the DC-DC converter is the main circuit for achieving MPPT. Therefore, the MPP can be tracked by adjusting the duty cycle of the DC-DC converter [3, 4]. Currently, many DC-DC converters based on power electronics have been proposed and successfully implemented MPPT techniques.

Conventional flyback converters have been designed for MPPT of PV systems [5, 6]. These converters are capable of controlling PV voltage, but output current ripples still appear above the tolerance limit, reducing the PV output power efficiency. A high-efficiency flyback converter for MPPT PV has been proposed in [7, 8]. This converter is able to improve the output power efficiency by adding active snubber networks, consisting of a capacitor connected in series with a power switch. However, the output-current ripple did not improve. Several other studies have proposed multi-winding flyback converters for solar power plants. The topology of such a converter is identical to that of a conventional flyback converter. However, there is a primary winding on each PV connected in parallel and a single output winding. The performance results of this converter show that the power dissipation of the power converter was reduced. Nevertheless, the ripple current and output voltage of the converter have not been considered [9]. To track the MPP of the PV, the MPPT system on the PV must use an algorithm, either conventional or soft computing. The P&O, incremental conductance, and constant voltage methods [3, 4, 10] are types of conventional algorithms used in MPPT systems. In contrast, soft computing MPPT-PV algorithms include artificial neural network, fuzzy logic control, grey wolf optimization, cuckoo search algorithm, and particle swarm optimization [11-13].

This study proposes an IIFC topology applied to an MPPT system for a PV generator. The proposed converter has double switching that is inversely proportional to each transformer to reduce the ripple current of the converter. Although the conventional P&O algorithm is simple and easy to implement, it has a major weakness: the emergence of small oscillations around the MPP, which cause power loss and reduce efficiency [10]. Therefore, the presented approach proposes the modification of the P&O algorithm by adding variable current measurements that can reduce oscillations and accelerate maximum point tracking when the irradiation changes.

II. METHODOLOGY

The PV array modeling, the role of IIFC, and MPPT control in maximizing the PV output power are discussed in this section. Figure 1 depicts the model system.

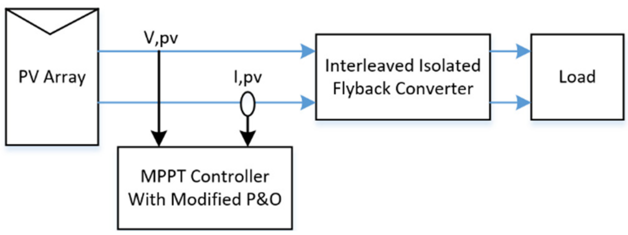

Fig. 1. The modeled PV system.

A. Photovoltaic Characteristics

The PV model characterizes the electrical behavior of a solar cell based on its I-V (current-voltage) and P-V (power-voltage) characteristics. The most widely used model is the single-diode equivalent circuit, which consists of a photocurrent source (I_{ph}), a diode (D), series resistance (R_s), and shunt resistance (R_{sh}). The governing equation for the output current (I) is [14, 19]:

$$I = I_{ph} - I_0 . exp\left(\frac{V+IR_s}{nV_T} - 1\right) - \frac{V+I.R_s}{R_{sh}} \quad (1)$$

where I_0 is the diode's reverse saturation current, V_t is the thermal voltage, and n is the diode ideality factor. The I-V curve is nonlinear and defines key parameters, such as the short-circuit current (I_{sc}), when V = 0, and open-circuit voltage (V_{oc}), when I = 0 [15].

The output characteristics of PV cells are related to the solar irradiance. When solar irradiance changes, the PV array shows nonlinear output characteristics. Therefore, the PV voltage and current are unstable, and the load cannot receive constant power from the PV system. The output current will be constant in most of the working voltage range, although it is close to the open circuit voltage. Figure 2 shows the simulation results for various levels of solar irradiation at a PV temperature of 25 °C. It is observed that the PV output characteristics vary significantly under the influence of solar irradiation. The output power increases, as the solar irradiation also increases [16].

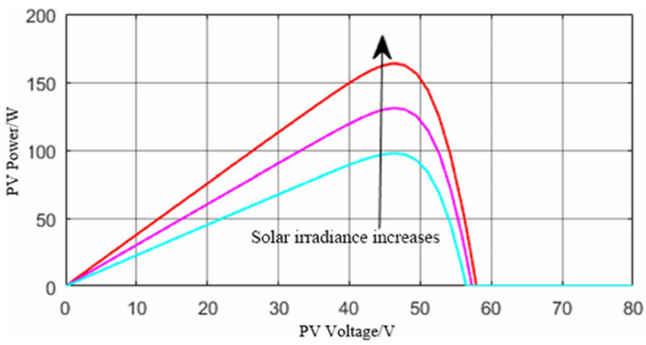

Fig. 2. PV characteristics under various irradiation conditions.

B. Interleaved Isolated Flyback Converter

The proposed IIFC topology converter is identical to the flyback converter. The IIFC consists of two flyback converters connected in parallel and each converter is controlled by two Pulse Width Modulation (PWM) control signals with a phase difference of 180°, as displayed in Figure 3.

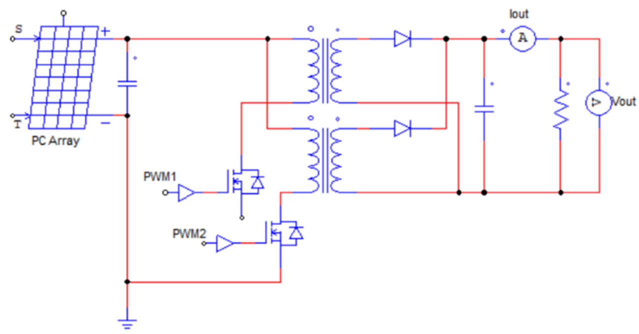

Fig. 3. IIFC.

The IIFC ensures continuous conduction mode operation, minimizing power losses and improving the dynamic response. The interleaved topology effectively doubles the switching frequency, reducing the size of the filter components, and enhancing the output voltage stability. By distributing the power load between the two converters, the heat dissipation and component stress were minimized, leading to higher reliability. This topology also helps mitigate electromagnetic interference and ensures efficient MPPT under varying solar irradiance conditions.

IIFC has several parameters that must be determined. V_0 is the desired output voltage of the converter, defined as:

$$V_O = V_s\left(\frac{D}{1-D}\right)\left(\frac{N_2}{N_1}\right) \quad (2)$$

V_S and D are the converter input voltage and duty cycle, respectively. N_2 and N_1 are the number of turns in the secondary and primary side transformers, respectively.

The IIFC operates in a continuous current operation mode; therefore, the minimum inductor and capacitor values are represented by:

$$L_{min} = \frac{(1-D)^2 R}{2f}\left(\frac{N_1}{N_2}\right)^2 \quad (3)$$

$$C_{min} = \frac{D}{R.f}\frac{V_0}{\Delta V_0} \quad (4)$$

where f represents the switching frequency, and ΔV_0 and R are the voltage current ripple of the converter and resistive load, respectively.

Some of the technical parameters of IIFC are summarized in Table I.

C. Modified Perturbation and Observation Algorithm

The P&O algorithm operates based on the slope ΔP/ΔV of the P-V curve of the solar panel. The P&O method in MPPT was implemented using a reference voltage control, as discussed in various studies [10]. The P&O method was analyzed by measuring the power oscillations and tracking time. When solar radiation fluctuates, this method is unable to reduce power oscillation, and thus, the PV maximum power tracking time becomes longer. This weakness can be minimized through the proposed modified P&O algorithm.

TABLE I. TECHNICAL PARAMETERS OF IIFC

Parameter	Symbol	Value
Input voltage	V_{in}	30 V
Output voltage	V_{out}	375 V
Converter inductance	L	100 µH
Converter capacitance	C	220 µF
Turn ratio primary/secondary	N_1/N_2	8/100
Frequency switching	f	10 kHz

Figure 4 depicts the flowchart of the proposed modified P&O algorithm. This algorithm is able to maximize the output power of the PV system by dynamically adjusting the PWM duty cycle (D) to operate at the MPP. The process begins with initializing the parameters, including the limits for the duty cycle (D_{min}, D_{max}), the initial duty cycle (D), and step sizes for adjusting D (ΔD, ΔD_{avg}, and ΔD_{min}).

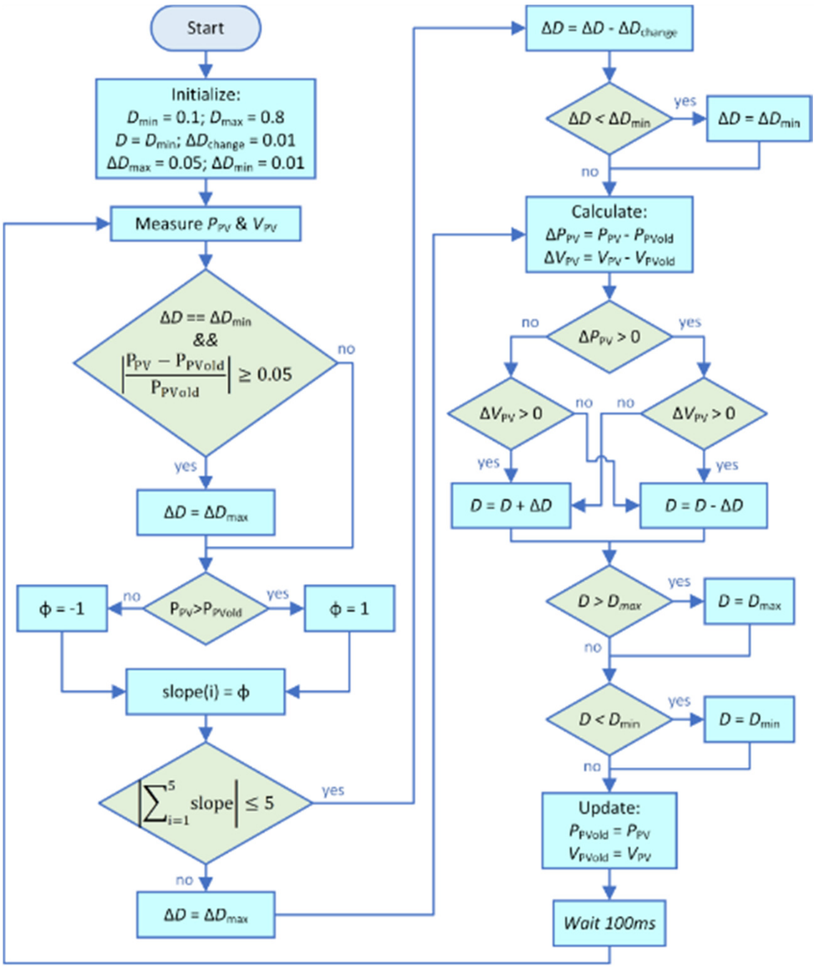

Fig. 4. Flowchart of the proposed modified P&O algorithm.

This algorithm measures the PV system's output power (P_{pv}) and voltage (V_{pv}) at each iteration. The relative change in power (ΔP_{pv}) is calculated from the difference between the current power (P_{pv}) and old power (P_{pvold}). When ΔP_{pv} exceeds a predefined threshold (e.g., 0.05), the step size is increased to accelerate tracking. Additionally, the slope (φ) is computed to determine the direction of the change in power, and the average slope over five iterations is checked. If the slope is small (<5), then the step size is reduced to avoid oscillations around the MPP.

The adjustment of D depends on the relationship between ΔP_{pv} and ΔV_{pv}. When the values of both parameters increase, D increases to approach the MPP. This algorithm ensures that D remains within its predefined limits (D_{min} and D_{max}) to avoid invalid duty cycle values. This dynamic adjustment of D certifies that the system consistently converges toward the MPP under changing environmental conditions.

III. RESULTS AND DISCUSSION

The performance of the IIFC applied to the MPPT of a PV generator was assessed using the PSIM software. The performance testing of the PV system also compared the IIFC using the conventional P&O algorithm with the modified P&O algorithm. The PV module that was used in the simulations had a maximum power of 250 W under nominal conditions (temperature of 25 °C and solar irradiance of 1000 W/m²). Table II lists in more detail the electrical specifications of the solar panel used in the simulations.

TABLE II. ELECTRICAL SPECIFICATIONS OF SOLAR PANEL

Parameter	Value	Symbol
Power maximum	250 W	P_{MPP}
Open circuit voltage	37.8 V	V_{OC}
Maximum power voltage	31.1 V	V_{MP}
Short circuit current	8.28 A	I_{SC}
Maximum power current	8.05 A	I_{MP}

The PV system was also evaluated under fluctuating solar irradiation scenarios. The irradiation varied from 600 W/m^2 to 1000 W/m^2 after 5 s. The irradiation was suddenly changed at t=10 s from 1000 W/m^2 to 800 W/m^2. Figure 5 illustrates the PV curve for this scenario.

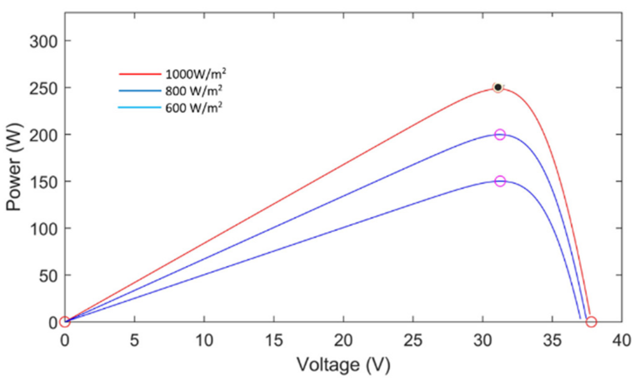

Fig. 5. P-V curve during fluctuating irradiation.

Figure 6 depicts the actual PV output power (P_{PV}) versus the maximum PV power (P_{MPP}) using conventional P&O. During the 0-5 s time, the P_{PV} reached its peak value of 139.5 W. Figure 7 demonstrates that the MPPT with modified P&O can achieve a maximum power of 145.9 W with greater power efficiency and smaller current fluctuations. The results of the PV power tracking tests under fluctuating irradiance are summarized in Table III.

TABLE III. COMPARASION OF PV POWER TRACKING PERFORMANCE UNDER FLUCTUATING IRRADIATION

Time (s)	Irradiation (W/m^2)	P_{MPP} (W)	Conventional P&O		Modified P&O	
			P_{PV} (W)	Efficiency (%)	P_{PV} (W)	Efficiency (%)
0-5	600	150	139.5	93.0	145.9	97.3
5-10	1000	250	241.0	96.4	249.6	99.8
10-15	800	200	191.5	95.8	197.0	98.5

The duty cycle generated by the conventional P&O algorithm exhibited a larger oscillation compared to the modified P&O algorithm, as portrayed in Figures 8 and 9, respectively. In fact, during the irradiation transition phase, the modified P&O produces a smoother and more stable duty cycle in maintaining its maximum power.

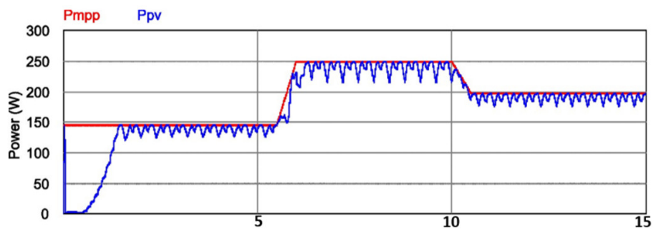

Fig. 6. PV power tracking using conventional P&O under varying irradiance.

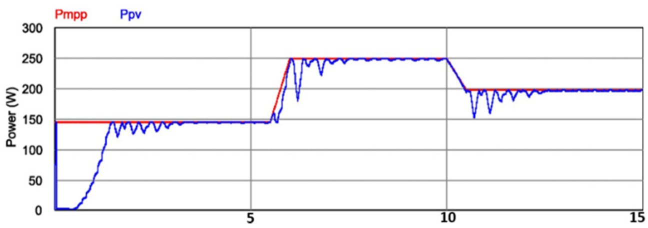

Fig. 7. PV power tracking using modified P&O under varying irradiance.

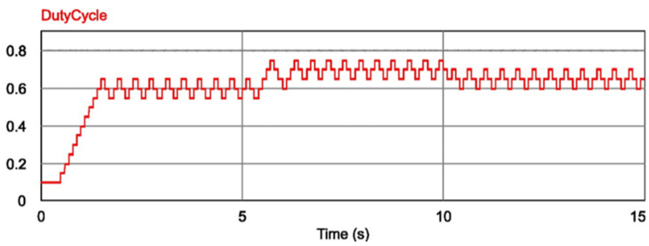

Fig. 8. PWM signal for MPPT control using conventional P&O.

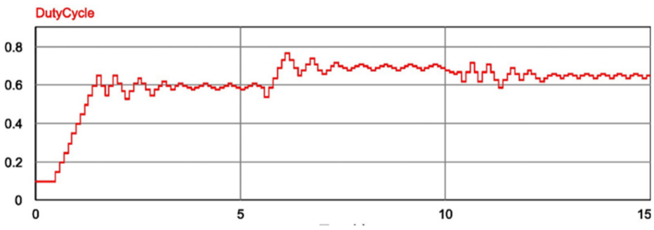

Fig. 9. PWM signal for MPPT control using modified P&O.

The performance of the PV system using MPPT was also tested when a change in the resistive load was applied. At 0-5 s, the resistive load was 800 Ω, then the load was changed to 400 Ω at 5 s, and finally, at 10 s, the load became 600 Ω. Figures 10 and 11 display that the PV output power remained at its maximum, even though the resistive load fluctuated. However, the MPPT system using the modified P&O exhibited smaller oscillations, and the PV output power became more stable when approaching P_{MPP}, as can be seen in Figure 11.

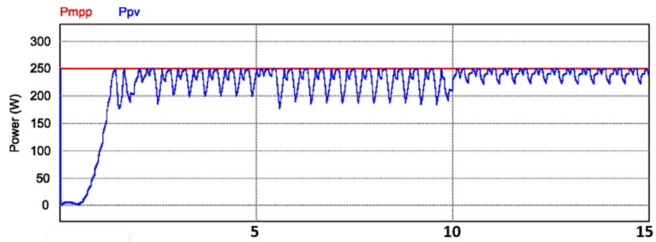

Fig. 10. PV power tracking using conventional P&O under varying load.

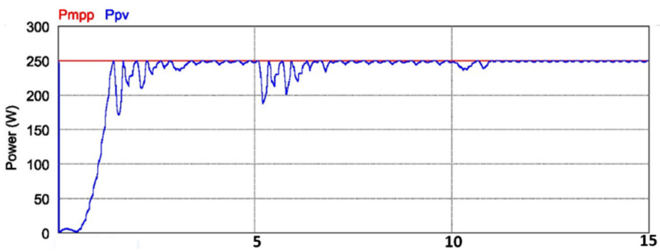

Fig. 11. PV power tracking using modified P&O under varying load.

IV. CONCLUSIONS

This study proposes an Interleaved Isolated Flyback Converter (IIFC) topology for Maximum Power Point Tracking (MPPT) in Photovoltaic (PV) generators, utilizing a modified Perturb and Observe (P&O) algorithm. Unlike conventional flyback converters, the IIFC reduces current ripples through dual inverse switching mechanisms, enhancing power output efficiency. The modified P&O algorithm incorporates dynamic current measurements to mitigate oscillations and accelerate the convergence to the Maximum Power Point (MPP) under fluctuating irradiance conditions. The simulation results demonstrate that the proposed system achieves an average power efficiency improvement of 3.5% compared to the conventional P&O approach. Furthermore, the modified algorithm produces smoother and more stable duty cycles, ensuring reliable performance under varying environmental conditions. Future work will include the combination of modified P&O with machine learning for better adaptability to changing conditions. The combination of PV and fuel cells will create multi-renewable energy systems.

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