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A New Sensorless Hybrid MPPT Algorithm Based on Fractional Short-Circuit Current Measurement and P&O MPPT

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Abstract—This paper presents a new maximum power point tracking (MPPT) method for photovoltaic (PV) systems. The proposed method improves the working of the conventional perturb and observe (P&O) method in changing environmental conditions by using the fractional short-circuit current (FSCC) method. It takes the initial operating point of a PV system by using the short-circuit current method and later shifts to the conventional P&O technique. The advantage of having this two-stage algorithm is rapid tracking under changing environmental conditions. In addition, this scheme offers low-power oscillations around MPP and, therefore, more power harvesting compared with the common P&O method. The proposed MPPT decides intelligently about the moment of measuring short-circuit current and is, therefore, an irradiance sensorless scheme. The proposed method is validated with computer software simulation followed by a dSPACE DS1104-based experimental setup. A buck-boost dc–dc converter is used for simulation and experimental confirmation. Furthermore, the reliability of the proposed method is also calculated. The results show that the proposed MPPT technique works satisfactorily under given environmental scenarios.

Index Terms—Efficiency, hybrid MPPT, maximum power point tracking (MPPT), modeling and simulation, photovoltaic (PV).

I. INTRODUCTION

The electricity generation through nonconventional energy sources have seen a boost in second decade of the 21st century because of better efficiency and declined cost. Solar photovoltaic (PV) is among the most anticipated nonconventional energy sources. In a PV system, 70%–80% cost comprises PV module and inverter [1]. In the past 20 years, the decrease in production cost of solar PV systems had a significant impact on cost per unit [2], [3]. When compared with conventional energy sources like thermal and hydal power, the PV systems need less time to produce electricity. According to the European Photovoltaic Industry Association, total installed capacity of PV systems is more than 100 GW [4]. It is a good sign, as PV systems are environment friendly. Estimates suggest that the rate of PV installations in the past 15 years has been around 45% [5], which means that in the near future, PV systems will have the largest share in electricity generation among available renewable energy sources [6].

A solar PV module is a current source, i.e., it produces electric current whose amplitude depends on falling insolation on the surface of PV module. The characteristic curve ($I$–$V$ and $P$–$V$) of PV module is nonlinear and it has only one maximum power point (MPP) under full exposure to sunlight. The MPP varies with the changing insolation and temperature. Therefore, an organized set of rules is required to operate the system at MPP. These sets of rules are commonly referred to as MPPT tracking (MPPT) methods [7]. Because of nonlinear behavior of the PV module, MPPT is essential for an efficient PV system. Various MPPT methods have been proposed and published in relevant scientific literature, which are, in fact, diversified ways to implement the impedance matching [8]. The most discussed methods are as follows [9], [10]:

1) perturb and observe (P&O);
2) incremental conductance (InC);
3) fractional open-circuit voltage (FOCV);
4) fractional short-circuit current (FSCC).

These MPPT algorithms can be subdivided into two broader categories, i.e., online and offline methods. P&O and InC are online MPPT techniques, as they do the tracking without isolating the PV module from the system [11]. Online MPPT methods have an intricate implementation process, but they are not subjected to any power loss as a result of isolating the PV module. However, they do suffer power loss because of power oscillations around MPP. Online MPPT methods can track the true MPP. The convergence speed of the online MPPT techniques listed above depends on the size of the change in operating point (also referred to as step size). A larger step size will track MPP more rapidly, but it will also result in greater power oscillations around the MPP. A smaller step size will reduce power oscillations around MPP, but it will need more time to track the MPP. Generally, the perturbation step size is in the range of 0.05–0.1. On the other hand, offline methods disconnect the PV module from the system to measure the operating parameters [short-circuit current ($I_{sc}$) and open-circuit voltage ($V_{oc}$)] [11]. FOCV and FSCC fall under the offline category. Offline techniques are simple to implement using analog or digital electronics and they have a high
convergence speed. Since, the environmental conditions are not constant, offline MPPT methods need periodic isolation of PV module to measure the operating point. However, during measurement of short-circuit current or open-circuit voltage of PV module, no power is delivered to the system, consequently resulting in power loss. Literature survey of offline MPPT methods reveals that usually the time-based isolation method is adopted. The work presented in [12]–[15] is based on time-based measurement of FOCV. For FSCC MPPT, one method to reduce periodic measurements is to use a sensor that measures the irradiance and decides when to measure the short-circuit current. However, an added sensor increases the cost. Offline methods do not track true MPPT and therefore they are not suitable for high-efficiency applications. Some researchers have proposed changes in the conventional algorithms. The work of [16] is an attempt to detect the partial shading using FOCV and P&O. Authors of [17] and [18] have proposed a variable step size P&O method. A modified FSCC method is presented by [19] where a lookup table is used. The computed value from lookup table is then compared with a calculated value and is fed to the PI controller. However, this paper lacks comparison of the proposed technique with the conventional method. The work of [20] is an improved form of P&O where instead of voltage perturbation they have used current perturbation. In addition, they measure the of voltage perturbation they have used current perturbation. In this paper, a 115-W solar PV module (BP3115) is modeled for simulation and for carrying out experimental work. The characteristics of this module under standard testing conditions of 1000 W/m² at 25 °C are given in Table I [23]. Verification of proposed MPPT algorithm is accomplished through modeling and simulation in MATLAB/Simulink and experiments carried out using dSPACE DS1104-based embedded solution.

### II. Fractional Short-Circuit Current MPPT

Under any given environmental condition, the current at MPP ($I_{mpp}$) has approximately a linear relation with short-circuit current ($I_{sc}$) as expressed in the below equation

$$I_{mpp} \approx kI_{sc}$$  \hspace{1cm} (1)

where $k$ is the constant of proportionality.

Value of $k$ is unique for different PV modules. Typically, it varies from 0.72 to 0.92. Since it is an approximation, it does not track the real MPP. However, the tracking speed is fast with a reasonable efficiency up to 90% [24]. It is cheap and easy to implement because it needs only one current sensor. FSCC requires periodic measurements of $I_{sc}$ to track the approximated MPP, which results in temporary power loss. Fig. 1 shows the block diagram for duty cycle calculations using FSCC.

### III. Perturb and Observe (P&O) MPPT

P&O or the hill climbing method is the widely used technique to track MPP. It perturbs the operating point and observes the difference in power before and after perturbation. The power is calculated using current and voltage sensors. If power difference is positive, the direction of perturbation remains same; otherwise, it is reversed. Therefore, this algorithm always keeps tracking back and forth even after reaching the MPP, which results in power oscillations around MPP. As discussed in Section I, oscillations can be controlled by reducing the step size which will increase the time to track MPP. Fig. 2 shows the basic idea of P&O MPPT. A time delay in perturbation is required to settle transients of the circuit.

### IV. Proposed MPPT Technique

Flowchart of proposed hybrid MPPT technique is shown in Fig. 3. It has three distinct stages as listed below:

1. **Stage 1**: estimation of MPP using $I_{sc}$;
2. **Stage 2**: P&O loop;
3. **Stage 3**: limit subroutine for decision about measurement of $I_{sc}$.

#### TABLE I

**PV Module Parameters [23]**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power ($P_{mpp}$)</td>
<td>115 W</td>
</tr>
<tr>
<td>Voltage at MPP ($V_{mpp}$)</td>
<td>17.1 V</td>
</tr>
<tr>
<td>Current at MPP ($I_{mpp}$)</td>
<td>6.7 A</td>
</tr>
<tr>
<td>Open circuit voltage ($V_o$)</td>
<td>21.8 V</td>
</tr>
<tr>
<td>Short circuit current ($I_{sc}$)</td>
<td>7.5 A</td>
</tr>
<tr>
<td>Temperature coefficient of $I_{sc}$</td>
<td>0.065±0.015%/°C</td>
</tr>
<tr>
<td>Temperature coefficient of power</td>
<td>-(0.5 ±0.05)/°C</td>
</tr>
</tbody>
</table>

![Fig. 1. Block diagram of fractional short-circuit MPPT.](image)
Fig. 2. Basic block diagram of P&O MPPT.

A. Stage 1: Estimation of MPP Using $I_{sc}$

The proposed MPPT method begins with the estimation of MPP using $I_{sc}$. When this loop starts, the PV panel is isolated to measure and store $I_{sc}$. Next, the value of $I_{mpp}$ is calculated using (1). This loop then measures the output current of the PV panel ($I_{pv}$) and calculates the error difference between $I_{mpp}$ and $I_{pv}$. The resultant value is fed to a compensator and the duty cycle is calculated. When compensator makes the error equal to zero, then power and the duty cycle is stored and the system reaches the P&O loop. Afterward, this loop measures $I_{sc}$ only when prompted by the limit subroutine.

B. Stage 2: P&O Loop

P&O loop starts storing the duty cycle (D) as soon as the algorithm reaches the compensator block of the stage 1. After the error becomes zero, P&O loop starts tracking the power. The main advantage of using stage 1 is that a very small step size for P&O is possible. In this paper, a step size of 0.003 is applied in simulation and experimentation. This resulted in small power oscillations around the MPP. After perturbing the operating point, system compares the difference between new and old power values. Before the next perturbation (positive or negative), system calls the limit subroutine. If the limit subroutine is not activated, then next perturbation is applied. The loop halts when the limit subroutine loop instructs the system for new measurement of $I_{sc}$. At this instant, the algorithm goes back to stage 1 and obtains a new value of $I_{sc}$.

C. Stage 3: Limit Subroutine

The intelligent mechanism of this subroutine determines the instants for the measurement of $I_{sc}$ during the working of the proposed MPPT technique. This loop contains the stored value of $I_{sc}$ and continuously updates the instantaneous values of photovoltaic current $I_{pv}$. It then calculates and updates the constant $k_2$ and computes the difference between $k_1$ and $k_2$. This process is repeated until the difference exceeds the limits. This limit defines the sensitivity of the system; lower value means more measurements of $I_{sc}$, whereas higher value means less measurements. It must be noted that power loss occurs during $I_{sc}$ measurement. By a hit-and-trial method, 0.05 has been found as optimized value of this limit for the experimental setup. If the difference between two constants surpasses this limit, the algorithm isolates the PV panel and a fresh value of $I_{sc}$ is measured and stored in the system memory. This loop inspects the difference between $k_1$ and $k_2$ after every perturbation and waits until PV panel exceeds the limit.

V. WORKING OF THE PROPOSED TECHNIQUE

To understand the working of the proposed hybrid MPPT technique, let us consider Fig. 4. It has five PV curves marked with respective MPP at different irradiance levels. Let us assume that, at the beginning, we need to track MPP at 1000 W/m² irradiance. To do that, the algorithm will short circuit the PV panel and using stage 1, it will quickly calculate the approximated MPP. Then, it proceeds to stage 2 P&O loop. It tracks the MPP by perturbing and observing the output power of PV panel. Let us assume that irradiation is decreasing with the passage of time, which means that the $I_{pv}$ also decreases. However, the short-circuit current is measured and stored at a different irradiation level (1000 W/m²). The decision about measuring the short-circuit current for the new irradiation value depends on limit subroutine loop, which monitors the difference between the two constants $k_1$ and $k_2$. If limit is small, system
will undergo more short-circuit current measurements resulting in power loss. A higher value will benefit the system by less short-circuit current measurements. In Fig. 4, it is indicated that the system can take a fresh value of $I_{sc}$ for the PV curve at $800 \text{ W/m}^2$. However, since the fall in irradiance is linear, system can track MPP with the help of P&O without operating in stage 1. It should be noted that the small green circles on PV curves show the range of operation for P&O MPPT. Using limit subroutine loop to fix the value of limit makes the system flexible.

In order to see the functionality of proposed algorithm under partial shading condition, consider Fig. 5 where three different scenarios are considered. It is assumed that the two PV panels are connected in series and there is no mismatching.

One PV module is subjected to three different irradiation values. Here, $G = 1$ refers to $1000 \text{ W/m}^2$ irradiance. The three different values of $G$ are 1, 0.9, and 0.4. This means that while one of the PV module enjoys the full irradiation of $G = 1$, the multiple MPP will appear because of the varying irradiance on other module.

Considering the above-mentioned scenario, the PV curve is plotted in MATLAB/Simulink as shown in Fig. 6. In Fig. 6, the above graph shows the PV curve and lower is IV curve. The black line shows the curves for homogenous lighting conditions. The red line depicts the curves for modest shading condition, such that one PV module receives $G = 1$ and one receives $G = 0.9$. The blue line shows stiff shading condition, i.e., one PV module receives $G = 1$ and other receives $G = 0.4$. Let us assume that the system was operating with uniform irradiation condition and was at $A_{mpp}$ point. Stage 2 was activated and the power was oscillating between points $A_1$ and $A_2$.

Now, let us consider the scenario that the partial shading case 1 happens. In this case, let us assume that the limit subroutine is not activated; therefore, stage 2 will continue its work and slowly track the MPP. After reaching the point $B_{MPP}$, the limit of operation is confined to $B_1$ and $B_2$. Now, let us assume that a strong shading condition has happened. The initial operating point was $A_{mpp}$ before the partial shading. When the shading occurs, the output power will be reduced suddenly because it is well known that change in PV current is proportional to the light falling on PV module. Therefore, the limit subroutine will be activated and a fresh value of $I_{sc}$ will be measured. This will bring the system to reach $C_1$ after which $C_{MPP}$ is hunted using stage 2.

### VI. Simulation Results

In order to validate the proposed hybrid MPPT, simulation is performed under steady and dynamic weather conditions. A nonisolated buck-boost converter is designed with the component values shown in Table II. In simulation setup, switch $S_1$ and a current sensor frame the arrangement for measuring short-circuit current of the PV panel. An additional diode is used to block the input capacitor current during the instant of short-circuit measurement. The decision about applying gate pulse to switch $S_1$ is made through intelligent mechanism governed by stage 1 and limit subroutine.

**TABLE II**

<table>
<thead>
<tr>
<th>Components</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV module</td>
<td>BP-115 detail given in Table I</td>
</tr>
<tr>
<td>Input capacitor ($C_{in}$)</td>
<td>470 $\mu$F</td>
</tr>
<tr>
<td>Output capacitor ($C_{out}$)</td>
<td>47 $\mu$F</td>
</tr>
<tr>
<td>Inductor ($L$)</td>
<td>0.5 mH</td>
</tr>
<tr>
<td>Load</td>
<td>5 Hz</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>35 kHz</td>
</tr>
</tbody>
</table>
Fig. 7. Result of proposed technique under steady weather conditions (1000 W/m² at 25 °C).

Fig. 8. MPP tracking of the proposed algorithm with dynamic weather conditions.

A. Steady Weather Condition

The standard testing condition is considered for simulating steady weather. Values of irradiance and temperature are 1000 W/m² and 25 °C, respectively. At the start of simulation, FSCC loop measures short-circuit current; hence, power is zero. Later on, it attains a satisfactory steady performance. Power oscillations are small as perturbation step size is 0.003. It is pertinent to mention that steady weather conditions require only one measurement of $I_{sc}$ in the beginning. The proposed hybrid MPPT is compared with [25] and conventional P&O as shown in Fig. 7. As figure shows, the conventional P&O needs more time to track MPP, although it does not require measurement of short-circuit current. The hybrid method presented in [25] suffers from periodic power loss as a result of $V_{oc}$ measurements. In this simulation, we kept the same sampling time for the proposed MPPT method by [25] and conventional P&O MPPT method. In order to simulate impact of step size on tracking speed and power oscillations, three different perturbation step sizes 0.01, 0.03, and 0.005 are applied. For simulation of [25], the step size is same as the proposed hybrid MPPT.

B. Dynamic Weather Condition

Dynamic weather conditions start from standard testing conditions (1000 W/m² at 25 °C) after which the irradiation is dropped to 500 W/m² at 25 °C and then increased to
TABLE III

<table>
<thead>
<tr>
<th>Irradiation (W/m²)</th>
<th>Maximum power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>56.73</td>
</tr>
<tr>
<td>550</td>
<td>62.63</td>
</tr>
<tr>
<td>600</td>
<td>68.53</td>
</tr>
<tr>
<td>650</td>
<td>74.4</td>
</tr>
<tr>
<td>700</td>
<td>80.2</td>
</tr>
<tr>
<td>750</td>
<td>86.15</td>
</tr>
<tr>
<td>800</td>
<td>91.9</td>
</tr>
<tr>
<td>850</td>
<td>97.8</td>
</tr>
<tr>
<td>900</td>
<td>103.6</td>
</tr>
<tr>
<td>950</td>
<td>109.3</td>
</tr>
<tr>
<td>1000</td>
<td>115</td>
</tr>
</tbody>
</table>

900 W/m² at 25 °C as shown in Fig. 8. For comparison, ideal MPP values at various irradiance levels are provided in Table III. Fig. 8 shows simulation results under dynamic weather conditions. It can be observed that whenever limit subroutine is activated, short circuit happens. However, under uniform weather conditions where stage 3 is not activated, the algorithm continues to track MPP using P&O loop (stage 2). It is pertinent to mention that for this simulation, we kept the same sampling time for both the proposed [25] and conventional MPP methods.

VII. EXPERIMENTAL SETUP

An experimental setup was designed to evaluate the proposed technique. The hardware was directly connected to Simulink using dSPACE DS1104 embedded card. Fig. 9 shows block diagram of dSPACE and hardware interface, while actual experimental arrangements are shown in Fig. 10. Irradiation sensor shown in Fig. 10 is used for logging irradiation data during experimentation. A buck-boost converter similar to simulation setup was used for practical confirmation. Current sensing was accomplished using Hall Effect sensor. As explained in simulation setup, an extra diode (D1) is connected in series between PV panel and input capacitor. Experimental arrangements include a single BP-3115 solar panel and a resistor-based voltage divider network that acts as a voltage sensor and LTS 25-NP Hall Effect current sensor. Data fed to the Simulink pass through an ADC, low-pass filter, and finally to the control algorithm. Switching frequency noise is eliminated with a suitable low-pass filter. The output of proposed hybrid algorithm is fed to the DS1104 block, which generates the switching PWM signal at desired frequency. PWM signal is then fed to gate driver that gates the power MOSFET.

VIII. EXPERIMENTAL RESULTS

This experimentation was carried out after mid-day, from 1222 to 1246 h Saudi standard time (SST). Conventional P&O with two distinct step sizes along with the proposed method is tested for 8 min each. During the course of experiment, the irradiation data as shown in Fig. 11 stay almost constant.

Fig. 12 shows the experimental results of the proposed MPPT. It has three waveforms, which includes the power extracted using the conventional P&O method using two different step sizes and proposed hybrid MPPT method. It is visible from Fig. 12 that the proposed hybrid MPPT is swift in tracking the MPP and has less power oscillations. Furthermore, the short-circuit current duration is very small which results in very less power loss.
IX. Discussion

This proposed technique is meant to improve the performance of the conventional P&O algorithm under varying environmental conditions with reduced sensor count. Instead of having a fixed initial operating point, this method seeks the approximate MPP through FSCC and then hunts for exact MPP using P&O with small step size. Under normal environmental conditions, it tracks MPP without isolating the PV panel as shown in Fig. 7. As seen in Fig. 12, losses due to $I_{sc}$ measurement are negligible, when compared with power gain. It is because $I_{sc}$ is not measured frequently and was, in fact, done just once during the experiment. Table IV compares proposed and conventional P&O w.r.t component count, implementation complexity, and other features like tracking speed, power oscillations, PV panel dependency, etc.

As given in Table IV, an additional MOSFET is required to implement the proposed technique. This MOSFET is connected as an auxiliary part and works only when PV module is isolated for $I_{sc}$ measurement. That is why switching losses are negligible. It is also evident from simulation results that the tracking speed of the proposed method is fast. Contrarily, the P&O method suffers high power oscillations with higher step size and slow tracking speed for smaller step size. Although additional MOSFET is turned on only to measure $I_{sc}$, it is desired to have an electro-thermal design of dc–dc converter for commercial use [26]. Reliability of semiconductor components used in dc–dc converters depends on various factors including temperature, voltage stress, environment, constant construction, and their application [27], [28]. In order to evaluate the mean time between failures (MTBF) of the proposed system, (2) is used [27].

$$\text{MTBF} = 1/\left(\lambda_{S1} + \lambda_{S2} + \lambda_{D1} + \lambda_{D2} + \lambda_{C1} + \lambda_{C2} + \lambda_{L}\right)$$

(2)

where

- $\lambda_S$ Failure rate of MOSFET where subscript 1 is for switch $S_1$ and 2 for switch $S_2$;
- $\lambda_D$ Failure rate of diode where subscript 1 is for diode $D_1$ and 2 for diode $D_2$;
- $\lambda_C$ Failure rate of capacitor where subscript 1 is for input capacitor $C_1$ and 2 for output capacitor $C_2$;
- $\lambda_L$ Failure rate of inductor.

Using military handbook of reliability prediction [29], it is calculated that MTBF for the proposed system is $0.0341 \times 10^6$ h. Calculated failure rate goes in harmony with harsh and high-temperature environment in Saudi Arabia. However, it is satisfied with lifetime of a typical solar PV system [28].
Along with the reliability, using the simulation results, tracking efficiency is also calculated using (3) [30] and is shown in Table V

$$\eta = \frac{P_{\text{pmppt}}}{P_{\text{pactual}}}$$  \hspace{1cm} (3)

### X. Conclusion

This paper has proposed and experimentally verified an improvement in conventional P&O MPPT technique. The proposed improvement intelligently calculates the right time to isolate PV panel and thus does not need time-based measurement of short-circuit current. In addition, this algorithm does not need any irradiance/temperature sensor. The merger of conventional FSCC and P&O algorithm simplifies both software and hardware control of PV systems. Moreover, the tracking efficiency is enhanced. The proposed algorithm detects dynamic weather conditions automatically and continues to work in stage 2 if conditions are constant. This hybrid MPPT contributes toward improved stability and power harvesting from PV modules.

### REFERENCES


Hadeed Ahmed Sher (S’14) received the B.Sc. degree in electrical engineering from Bahaudinn Zakaria University, Multan, Pakistan, in 2005, and the M.Sc. degree in electrical engineering from the University of Engineering and Technology, Lahore, Pakistan, in 2008. He is currently pursuing the Ph.D. degree at King Saud University, Riyadh, Saudi Arabia.

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Another research field is the design and implementation of non-conventional power stages based on SiC devices for special functions in automotive, industrial, green energy, and space applications.